Human–Computer Interaction and Innovation in Handheld, Mobile and Wearable Technologies

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Personal mobile devices are increasingly being used as platforms for interactive services. Ease of use is important, but the services should also provide clear value to the user and they should be trustworthy and easy to adopt. These user acceptance factors form the core of the Technology Acceptance Model for Mobile Services introduced in this paper. The model has been set up based on field trials of several mobile services with altogether more than 200 test users. This paper presents the technology acceptance model and describes four case studies of applying the model in practice as a design and evaluation framework.

Heuristic evaluation has proven popular for desktop and web interfaces, both in practical design and as a research topic. Compared to full user studies, heuristic evaluation can be highly cost-effective, allowing a large proportion of usability flaws to be detected ahead of full development with limited resource investment. Mobile computing shares many usability issues with more conventional interfaces. However, it also poses particular problems for usability evaluation related to aspects such as limited screen real estate, intermittent user attention, and contextual factors. This paper describes a modified collec-

testing are discussed, as well as the challenges that are associated with the actual commercialization of the system.

We present a reflection on a series of studies of ubiquitous computing systems in which the process of evaluation evolved over time to account for the increasing difficulties inherent in assessing systems ‘in the wild’. Ubiquitous systems are typically designed to be embedded in users’ everyday lives, however, without knowing the ways in which people will appropriate the systems for use, it is often infeasible to identify a predetermined set of evaluation criteria that will capture the process of integration and appropriation. Based on our experiences, which became successively more distributed in time and space, we suggest that evaluation should become adaptive in order to more effectively study the emergent uses of ubiquitous computing systems over time.

Nowadays, mobile devices features are often linked up to the context of usage. As a consequence, researchers must consider not only the user and the device, but also the surrounding environment when designing effective user study evaluations. Two opposite experimental setups are possible: in-situ and in the laboratory. There is no consensus on their respective benefits, for instance with regard to the number of usability issues detected. In this paper, we isolate independent variables that could contribute to evaluation biases by proposing a taxonomy that splits the in-situ and laboratory experimental setups into two new setups. We describe the concept of the “Uncertainty Principle” to emphasize the dilemma between precise observation and bias minimization and introduce the “Trojan Horse” technique to partially overcome the consequences of the uncertainty principle. As a conclusion, a methodology using the four experimental setups in a complementary way is proposed.

Internet access on cellular phones, after emerging as a new technology in the mid-1990s, is now a thriving activity despite the global economic recession. IDC reported smartphone sales of 1.18 billion units in 2008 (IDC, 2009), compared to the unconnected personal digital assistants approaching merely 1 million units per quarter in the second half of 2003. However, the concept of using handheld devices for wide-area data applications began 25 years prior to the beginning of the end of PDAs.

Today, photo gallery applications on mobile devices tend to be stand-alone and offline. For people who want to share photos with others, many add-on tools have been developed to connect the gallery applications to Internet services to enable photo sharing. We argue that photo-centric social interaction is best supported when the gallery application is fully integrated with an Internet service. In this case, no additional tools are needed and the user's image content is fully synchronized with the service. We designed and implemented Image Exchange, a service-integrated mobile gallery application with a corresponding Internet service. Moreover, we conducted a field study with 10 participants to compare Image Exchange with a state-of-the-art gallery application combined with an add-on photo sharing tool. Image Exchange was preferred by most participants and it was especially appreciated because of the user experience. Above all, the results show that social activity increased amongst the participants while using Image Exchange.

This paper reports user experience findings from two field trials, where Mobile Internet access was supported through Near Field Communication (NFC)-based tag infrastructure, The first field trial was done in public urban environment with the infrastructure of 2650 tags and 248 users, and the other field trial dealt with mobile learning with the infrastructure of 11 tags and 220 users. Our results show that touch-based interaction can provide enhancement to the Mobile Internet user experience. Touch-based access builds a semantic bridge between the physical context of use and the Mobile Internet experience, the user experience converges seamlessly into one where both the physical and digital worlds play a role. We report and analyze the subjective experiences of the end users collected during the field trials. As a result, we summarize recommendations for interface and content design

This paper presents a perspective on what it really means to be mobile - why being mobile is different. It looks at the technological and physical implications, but really considers the broader issues: the social implications, the impact that data on the move can have on people, and the use of mobile devices as sensors that can drive intelligent, contextual systems that provide a much more effective experience for the user than existing systems do.

The large scale deployment of mobile applications inevitably impacts upon our culture as a whole and affects more intimately our daily lives. Not all of these effects are desirable. In a market economy, ethical issues are not the most important drivers in the development of technology. In this paper, we ask whether the mobile human-computer interaction community could take an active role in discussing ethical issues. In so doing we could focus our attention on developing technology for 'human beings' rather than fine tuning our emerging gadgets.

This paper discusses the consequences for the fundamentals of interaction design given the introduction of mobile devices with increased sensing capability. Location-aware systems are discussed as one example of the possibilities. The paper provides eight challenges to the mobile HCI research community, and makes suggestions for how the International Journal of Mobile HCI could contribute to the field.

The Mobile Internet is no longer a new phenomenon; the first mobile devices supporting Web access were introduced over 10 years ago. During the past 10 years many user studies have been conducted that have generated insights into mobile Internet use. The number of mobile Internet users has increased and the focus of the studies has switched from the user interface to user experiences. Mobile phones are regarded as personal devices: the current possibility of gathering more contextual information and linking that to the Internet creates totally new challenges for user experience and design.

In this position paper we argue that it is time for the mobile HCI community to think beyond the traditional screen-keyboard-mouse paradigm and explore the many possibilities that mobility, mobile platforms, and people on the move offer. We present a collection of ideas aiming to encourage HCI researchers to explore how up-and-coming mobile technologies can inspire new interaction models, alternative I/O methods, and data collection methods. The range of possible applications designed to make life easier for specified user populations is limited, we maintain, only by our imagination to understand novel problem spaces, to mix, match and expand on existing methods as well as to invent, test, and validate new methods. We present several case studies in an attempt to demonstrate such possibilities for future mobile HCI.

The mobile phone is one of the most ubiquitous technologies in the developed world. With more than two billion mobile phones worldwide, almost everyone is using this technology. In a market dominated by adults and older teenagers, one group of users that is relatively new to the mobile phone market is children. A discussion of children as users of mobile phones is timely as studies of phone use clearly show that mobile phones are being appropriated by ever younger users. The mobile phone is a complex technology and its use is complicated. Different user groups appropriate the technology in different ways and each group has different needs. When children use mobile phones their needs are sometimes complicated by, or conflict with, the needs of their parents or primary care givers. In an age where the laptop is being redesigned to make it accessible to children on the move, it is interesting and worthwhile to ask the question: 'Do children need a different sort of mobile phone than their parents?' The answer might seem intuitive but the evidence suggests that mobile technology is primarily designed for a single market and the consideration of diverse user needs is only cursorily considered. By considering data about the use and usage of mobile phones, research on the benefits and drawbacks of designing special children's technologies, and research on the needs and expectations of children as mobile phone users, this paper presents the argument that the mobile phone needs a design re-think if it is to meet the needs of this new user group.

A wide range of in-car computing systems are either already in existence or under development which aim to improve the safety, efficiency and the comfort/pleasure of the driving experience. Several unique forces act on the design process for this technology which must be understood by HCI researchers. In particular, this is an area in which safety concerns dominate perspectives. In this position paper, I have used a case study system (vehicle navigation) to illustrate the evolution of some key HCI design issues that have arisen in the last twenty years as this in-car technology has matured. Fundamentally, I argue that, whilst HCI research has had an influence on current designs for vehicle navigation systems, this has not always been in a wholly positive direction. Future research must take a holistic viewpoint and consider the full range of impacts that in-car computing systems can have on the driving task.

Null-hypothesis statistical testing has been seriously criticised in other domains, to the extent of some advocating a complete ban on publishing p-values. This short position paper aims to introduce the argument to the mobile-HCI research community, who make extensive use of the controversial testing methods.

Preface

INTRODUCTION

As mobile devices become increasingly diverse and continue to shrink in size and weight their portability is enhanced but, unfortunately, their usability tends to suffer. Ultimately, the usability of mobile technologies determines their future success in terms of end-user acceptance and, thereafter, adoption and social impact. Widespread acceptance will not, however, be achieved if users' interaction with mobile technology amounts to a negative experience. Mobile user interfaces need to be designed to meet the functional and sensory needs of users. In recognition of this need, a growing research area focusing on mobile human-computer interaction has emerged and will likely continue to grow exponentially in the future.

Successful desktop user interface design does not automatically equate to successful mobile user interface design. This is due to (a) the resource disparity between mobile and desktop technologies themselves, and (b) the extent to which users can allocate their attentional resources to the technologies, given the disparity of contexts in and purposes for which mobile and desktop devices are typically used. Additionally, the form factor of mobile devices typically limits the applicability of standard input and output techniques, making mobile human-computer interaction design ineffective if we insist on adhering to the tried and tested desktop paradigm.

The design and evaluation of mobile human-computer interaction, unlike desktop-based interaction, needs to be cognizant of the implications brought to bear by complex contextual factors affecting both users and technology. Such contextual influences include, but are not limited to, the physical environment in which a mobile device is being used, the impact of multitasking behavior typically exhibited by users of mobile devices (e.g., using a device whilst driving), and the social context in which a device is used. Furthermore, mobile technology can go where desktop technology cannot reach – in particular, it has immense potential in an assistive capacity for special needs users and in disaster management scenarios. With such widespread applicability of mobile technologies, when designing mobile technologies, we must strive to be suitably cognizant of their potential social impact – that is, their potential acceptability as well as the influence they may bring to bear on the society into which they are introduced. All in all, designing the user interface for mobile applications is a very complex undertaking which is made even more challenging by the rapid technological developments in mobile hardware.

Not only is the design of human-computer interaction for mobile technologies difficult, so too is the evaluation of such designs. Evaluation techniques for mobile technology require as much consideration as the design of the user interfaces themselves; for the results of evaluations of mobile applications to be meaningful, the manner in which the evaluations are conducted needs to be, and is, the focus of considerable research in itself.

This Advances book is a compendium of articles from the inaugural volume of the *International Journal of Mobile Human Computer Interaction (IJMHCI)*. The mission of the IJMHCI is to provide an international forum for researchers, educators, and practitioners to advance knowledge and practice in all facets of design and evaluation of human interaction with mobile technologies; to encourage readers to think out of the box to ensure that novel, effective user interface design and evaluation strategies continue to emerge and, in turn, the true potential of mobile technology is realized whilst being sensitive to the societal impact such technologies may have. The IJMHCI brings together a comprehensive collection of research articles from international experts on the design, evaluation, and use of innovative handheld, mobile, and wearable technologies; it also considers issues associated with the social and/or organizational impacts of such technologies. Emerging theories, methods, and interaction designs are included and are complemented with case studies which demonstrate the practical application of these new ideas.

The aim of the journal is to increase exposure to, and heighten awareness of, the complexity of current and future issues concerning mobile human-computer interaction. In its inaugural year, and over the life of the journal, articles have presented (and will undoubtedly continue to present) alternative points of view for some of the field's hotly debated topics. Such variance is not only stimulating but also essential in terms of encouraging readers to think to the future and embrace the challenge of new paradigms both for interaction design and evaluation.

NEW BEGINNINGS

The inaugural volume of the IJMHCI comprised 4 issues which, collectively, highlight the vibrant nature of the field of mobile HCI and showcase some of the interesting and exciting work that is being done.

The first five articles included in this publication appeared in the very first issue of the IJMHCI. The articles were selected for inclusion from the top-ranked, peer-reviewed chapters of the *Handbook of Research on User Interface Design and Evaluation for Mobile Technology* – the IGI Global publication that triggered the establishment of the IJMHCI. Collectively, these articles touch on some of the most important issues and questions related to mobile human-computer interaction. In the first article, entitled "*Instrumented Usability Analysis for Mobile Devices*", Andrew Crossan, Roderick Murray-Smith, Stephen Brewster and Bojan Musizza introduce the concept of using sensors (such as accelerometers) to elicit quantitative, objective information about the "moment to moment" actions of users as they interact with mobile technology. Instrumented usability analysis such as the method proposed by Crossen *et al.* is really important for supporting evaluation of mobile and wearable devices which cannot be realistically tested without artificially constraining users; using their method, Crossen *et al.* are able to explore, for example, the impact of gait on input error when using touchscreen technology in motion. An ability to conduct evaluations such as those enabled by Crossen *et al.* helps us move towards better and effective design for user interfaces intended to be used when truly mobile.

The second article, written by Enrico Bertini, Tiziana Catarci, Alan Dix, Silvia Gabrielli, Stephen Kimani, and Giuseppe Santucci, is entitled "*Appropriating Heuristic Evaluation for Mobile Computing*" and describes a modified collection of usability heuristics that are designed to be appropriate for heuristic evaluation of *mobile* technologies. Heuristic evaluation has proven effective and popular for desktop-based user interfaces over the years. Although mobile computing shares some usability issues with traditional desktop-based user interfaces, there are numerous additional challenges to usability brought about by the form factor and contexts of use of mobile technologies. The modified usability heuristics presented by Bertini *et al.* embrace these additional challenges to allow the recognized advantages of heuristic evaluation to be effectively applied to mobile user interface design.

In the third article, by Mark Dunlop and Michelle Montgomery Masters, entitled "*Pickup Usability Dominates: A Brief History of Mobile Text Entry Research and Adoption*", the authors review mobile text entry techniques based on smaller keyboards and touchscreens and reflect on the nature of the evaluations that have been conducted to assess their validity. The article also reports on an initial assessment of iPhone text entry rates. As noted by Dunlop and Montgomery Masters, text entry on mobile devices has presented, and continues to present, a research challenge for emerging mobile technologies. The authors' reflection on past developments and assessment of technology that is rapidly becoming mainstream is essential for our understanding of this field, both in terms of text input mechanisms and effective means by which to evaluate their efficacy.

The fourth article – "*On-the-Move and in Your Car: An Overview of HCI Issues for In-Car Computing*" – by Gary Burnett outlines a very specific mobile use case – the driving context – and highlights the range of computing systems (and associated user interfaces) being introduced into this context. The article describes the factors that designers of user interfaces to in-car technologies must consider, compares the various facilities available to support the design and evaluation (e.g., simulators, instrumented vehicles) of such systems, and highlights continuing research challenges in this field.

The fifth article was written by Eija Kaasinen et al., and is entitled "*User Acceptance of Mobile Services*". It asserts that usability alone does not determine user acceptance of mobile services and introduces the Technology Acceptance Model for Mobile Services (TAMM) which models the way in which a complex set of user acceptance factors affect users' mobile service acceptance. Given the complexity and variety of contexts in which mobile technologies may be used, it is essential that we appreciate the "bigger picture" affecting the acceptance of these technologies; only in full knowledge and recognition of these factors will we be able to best, and effectively, design mobile systems of the future.

Advancing the Evaluation of Mobile and Ubiquitous Systems

Continuing a recurring theme amongst the articles already outlined, the second issue of the IJMHCI was a special issue on *Advances in Evaluating Mobile and Ubiquitous Systems* guest-edited by Katie Siek, Steve Neely, Graeme Stevenson, Christian Kray, and Ingrid Mulder. Currently, evaluators of mobile and ubiquitous systems lack the generally accepted methods, benchmarks, and guidelines available to evaluators of traditional, desktop-based systems. Furthermore, there is a lively ongoing debate as to the appropriateness of lab- v. field-based evaluation approaches for mobile technologies. The collection of articles – each of which represents the best paper from a series of independent workshops – comprising the special issue go some way towards establishing an agreed upon set of usability methods for in situ evaluation. In their detailed preface to the special issue, the guest editors provide background and motivation for their issue; to situate the ensuing showcase of best papers, they introduce and discuss the collection of workshops relevant to the theme of their special issue and from which the best papers were selected – in itself, this discussion presents a useful roadmap of venues in which cutting edge research on evaluation methods is presented and discussed at an international level; interested readers should refer to IJMHCI Vol. 1, Issue 2 to read the preface itself.

The paper by Jörg Muller, Keith Cheverst, Dan Fitton, Nick Taylor, Oliver Paczkowski, and Antonio Krüger, entitled "*Experiences of Supporting Local and Remote Mobile Phone Interaction in Situated Public Display Deployment*s", notes the increasing ubiquity of public displays and mobile phones and the exciting possibilities offered by the combination of the two technologies. Muller *et al.* also note, however, that "*current usability evaluations* […] *have explored only a small part of this design space, as usage of such systems is deeply embedded in and dependent on social and everyday context*". The authors report on six different field deployments, ranging from exploratory prototypes to technology probes, of systems that combine both mobile phone and public display technologies; they discuss the advantages and disadvantages of different evaluation methods applied in such contexts and reflect on the challenges faced when conducting field studies involving public displays and mobile devices.

In their paper entitled "*Lessons out of Chaos: Lessons Learned from the Noise of Non-Traditional Environments*", Antony Glascock and David Kutzik reflect on seven years' worth of experiences evaluating a behavioral monitoring system in a range of real-world environments, from a living suite in a hospital to home-based deployment within large communities. The authors emphasize the role that what might initially be perceived as "noise" can play in the evaluation of a mobile system.

Scott Sherwood, Stuart Reeves, Julie Maitland, Alistair Morrison, and Matthew Chalmers present a paper entitled "*Large Scale User Trials: Research Challenges and Adaptive Evaluation*". In this, Sherwood *et al.* note that ubiquitous systems are designed to be embedded into the daily lives of users and, as such, must go through a process of integration and appropriation. Reflecting on a series of studies of ubiquitous technologies which saw evolution of their evaluation process to accommodate the inherent difficulties of true field-based assessment, they argue that evaluation methods for such systems need to become more adaptive in order to support the effective study of emergent uses of ubiquitous technologies over time.

In the final paper of the special issue – "*Experimental Setups for User Evaluation of Mobile Devices and Ubiquitous Systems*" by Francis Jambon – lab- and field-based evaluations are compared. Jambon discusses the "uncertainty principle" and introduces a new evaluation technique – the "Trojan Horse" technique – designed to partially overcome the consequences of the uncertainty principle. Jambon proposes a method to make complementary use of both laboratory and in-situ (field) experiments for the evaluation of mobile technologies.

Enhancing the Mobile Internet User Experience

Motivated by two workshops on Mobile Internet User Experience (MIUX), and guest edited by the workshops' organizers (Virpi Roto and Eija Kaasinen), the inaugural volume of the IJMHCI also played host to a special issue on MIUX. With a focus on solutions for improving the user experience when using the internet on mobile devices, the articles associated with this special issue include extended submissions from the workshop attendees as well as articles from other eminent researchers working in this field. In their informative preface to the special issue, Roto and Kaasinen set the scene for MIUX research and provide strong motivation for the work in this area. In drawing together their collection of articles, Roto and Kaasinen illustrate the variety of avenues in which work is currently being done to improve the mobile internet user experience and encourage researchers in the field of mobile HCI to take up the challenge and continue work in MIUX; interested readers should refer to IJMHCI Vol. 1, Issue 4 to access the preface itself.

To headline their special issue, Roto and Kaasinen invited Evan Koblentz, a technology historian with a specialization in the history of portable computers, to author an article entitled "*How it Started: Mobile Internet Devices of the Previous Millennium*". In describing the ancestry of current mobile internet devices, Koblentz eloquently provides a perspective for the subsequent research articles.

A collaborative effort from several of the MIUX workshop participants – namely, Eija Kaasinen, Virpi Roto, Kristin Roloff, Kaisa Väänänen-Vainio-Mattila, Teija Vainio, Wolfgang Maehr, Dhaval Joshi, and Sujan Shrestha – led to the article entitled "*User Experience of Mobile Internet: Analysis and Recommendations*". As the title suggests, this article provides a comprehensive overview of topics of research in the field of MIUX, identifying factors that make internet use on mobile devices an enjoyable experience. Discussing the many ways in which the mobile internet user experience could be improved, this article provides some concrete development recommendations for improving users' experiences and serves as an ideal introduction for readers and practitioners new to the area of MIUX.

In their article entitled "*How People Really Use the Mobile Web: A Framework for Understanding Motivations, Behaviors, and Contexts*", Carol Taylor, Nancy Samuels, and Judith Ramey report on their study which was designed to discover (for US mobile phone users) what motivates users to explore the web on their mobile phones, what people do when browsing the web on their phones, and where they choose to access the web using a mobile device. On the basis of their study, they developed then validated a taxonomy of behaviors, motivations, and contexts associated with mobile web use. This framework helps readers understand the "bigger picture" of mobile web use.

In "*Improving the User Experience of a Mobile Photo Gallery by Supporting Social Interaction*", Elina Vartiainen presents a case study on improving the mobile internet user experience for an internet-integrated photo-sharing application. By reflecting on her experience designing and developing the application, Vartiainen highlights aspects associated with mobile user experience from which other developers can benefit. As noted by Roto and Kaasinen, Vartiainen's article "*provides us with a glimpse of future internet services for mobile devices, where data connection costs do not prohibit good user experiences*".

The final article of the MIUX special issue is entitled "*Touch-Based Access to Mobile Internet: Recommendations for Interface and Content Design*". In this, Minna Isomursu and Mari Ervasti report on user experience findings from two different field trials in which the advantages of touch-based interaction for content and service discovery, mobile internet access, and integrated situated and embodied experience are highlighted. Isomursu and Ervasti argue that touch-based access creates a semantic bridge between the physical context of use and the MIUX, meaning that the user experience manifests as a seamless convergence of the physical and digital worlds.

Research Challenges for Mobile HCI

The IJMHCI would not be possible without the advisory team who work together to lend strength, passion, and inspiration to the journal. The efforts of journal advisors oftentimes pass relatively unnoticed; their association with a journal is listed, but the true extent of their contribution and value often remains hidden. The IJMHCI is honored to boast a dedicated, talented, and truly motivated group of advisors – each committed to helping the IJMHCI realize its potential. The International Advisory Board members include: Anne Kaikkonen, Nokia, Finland; Fabio Paternò, CNR, Italy; Jakob Nielsen, Nielsen Norman Group, USA; Matt Jones, Swansea University, Wales; and Stephen Brewster, University of Glasgow, Scotland. The team of Associate Editors includes: Antti Pirhonen, University of Jyväskylä, Finland;

Gary Burnett, University of Nottingham, England; Gitte Lindgaard, Carleton University, Canada; Janet Read, University of Central Lancashire, England; Jesper Kjeldskov, Aarlborg University, Denmark; Mark Dunlop, University of Strathclyde, Scotland; Roderick Murray-Smith, University of Glasgow, Scotland; and Russell Beale, University of Birmingham, England.

In working towards the inaugural volume of the IJMHCI, I asked the journal's advisors to reflect on what it takes to make a journal great. Unanimously, they agreed that, for a fledgling journal (especially one in a discipline such as Mobile HCI which is, compared to others, in its relative infancy), it is important to essentially posit research challenges to readers such that researchers gain a clear perspective on the goals and directions of the journal and the field in general. Given the range of research expertise represented by the journal's advisors, I felt that to invite the advisors to submit position papers which outlined their personal take on the future of mobile HCI as a discipline, and to suggest where we need to focus in the future (10 years, say) would generate a thought provoking and challenging issue for our readers. Hence, the inaugural volume of the IJMHCI came to include an issue which represents a collection of personal reflections on the future of mobile HCI, the challenges it presents, and the potential opportunities it offers; in essence, an opportunity to step back and reflect on or assess our position, achievements, and our future societal and innovative obligations as mobile HCI researchers. I asked that, where applicable, the advisors be deliberately controversial such that this collection of position papers by eminent mobile HCI researchers evokes thought and debate amongst readers; the goal is that the position papers will collectively act as a catalyst for other researchers to take up the challenges presented – if they have not already – or to contradict/refute the positions presented, and to subsequently engage in high quality, interesting work which will spark further interest and debate, thus continuing the catalytic momentum which was intended by this particular issue of the IJMHCI.

In the first position paper – entitled "*What does Mobile Mean?*" – Russell Beale questions what we really mean by *mobile* human-computer interaction. He argues that, to date, mobility has been defined by the portability of a device and that this has, in turn, defined the way mobile applications have been designed. Russell contends that the real issue is not device mobility but rather user mobility. He notes that when we consider users and their mobility, rather than focus on the technology itself, other interaction opportunities become apparent – a theme that is picked up in later position papers by Roderick Murray-Smith and by Gitte Lindgaard and Sheila Narasimhan. Russell suggests four characterizations of user mobility – the *modern worker*, the *migratory worker*, the *nomadic*, and the *twitterer* – and elaborates on their implications for future mobile HCI design and research. He identifies some of the potential benefits and most effective uses of well designed applications for mobile users, some of which allude to the ethical dichotomy introduced by Antti Pirhonen and Elizabeth Sillence in the second paper, entitled "ICT for Consumers or Human Beings: What's the Difference?".

In their paper, Antti and Elizabeth discuss the impact on our culture of large scale deployment of mobile applications. In this deliberately controversial paper, they ask whether we, as a research community, need to take more of an active role in discussing the ethical issues associated with the technology we research and develop – that is, to consider more fully the ethical problems resulting from the rapid penetration of mobile applications. They argue that many of the research techniques we currently adopt, whilst contributing to the usability of a product, tell us very little about the more complicated ethical issues involved. From "roasting our brains" to being "chained" to our work to the dissolution of family life, Antti and Elizabeth explore the broader societal impact of mobile technologies as they affect our welfare. They suggest that the term "human" – as currently used in "human-computer interaction" – is misleading and that current trends in our discipline could be better reflected with more appropriate wording – e.g., "user" or "consumer" rather than "human". They suggest that we should reserve the term "human" for research motivated by a desire for better understanding of humanity, and thus the construction of a better world; in effect, they soberingly remind us that as the designers and practitioners of today we are "creating all of our tomorrows".

Taking a different perspective to the previous paper, Roderick Murray-Smith (in "*Empowering People Rather Than Connecting Them*") considers the ways in which mobile technologies can empower rather than simply connect users. He argues that the emergence of modern technologies, such as increasingly sophisticated sensors, create the potential for novel interaction paradigms as well as scope for instrumented usability evaluation techniques. He suggests that, with additional sensory perception embedded in mobile technologies, interesting and unpredictable social behaviors will emerge. Your take on the ethical quandaries presented by Antti and Elizabeth will color whether you believe this to be potentially good or bad, but Roderick makes a compelling argument for research that will lead us towards an environment which is controlled by those who inhabit it and which, in turn, empowers rather than enslaves its inhabitants. Envisioning future interaction akin to dancing – "*a sympathetic ebb and flow of control between the user, their mobile device, and the broader environment*" – Roderick examines the future of location-based interaction, and highlights some of the research challenges that need resolution in order to progress.

In "*Mobile Internet: Past, Present, and the Future*", Anne Kaikkonen asks what we learned from the first years of WAP and whether or not it constitutes a valuable step on the path towards effective web access on mobile technologies of the future. She raises the questions of when we need mobile-tailored content as opposed to full web content, as well as how best to design websites that accommodate access on both desktop and mobile computers. She metaphorically maps full web browsing on a mobile device to free diving, browsing mobile-tailored websites on mobile devices to snorkeling with occasional deeper dives, and internet use via mobile applications as snorkeling in a swimming pool. Related to Russell Beale's suggestion that we should be designing for the mobility of users, Anne stresses the importance of developing web content that is tailored to suit mobile use; she suggests that most users access the web on different devices (e.g., desktop PC and mobile device) and so there is a need to support user mobility by making browsing compatible based on, and across, devices and contexts. Anne, like Antti and Elizabeth, reflects on the need for our discipline to consider what people do (in terms of web access) and why, rather than just the usability of devices and user interface designs; she also touches on concerns about the social dichotomy of being 'always connected' versus an individual's need for personal privacy or space. Linking the papers of Roderick and Antti and Elizabeth, Anne discusses the ability for our mobile devices to gather information about our physical environment but leaves us with a cautionary reminder of our obligation to "*think about, and evaluate, the potential side effects on people's lives of the systems we create*" – stressing that it is our responsibility to do our utmost to minimize the negative without compromising on the positive.

Gitte Lindgaard and Sheila Narasimhan – in their paper entitled "*Novel Technologies and Interaction Paradigms in Mobile HCI*" – draw on elements inherent in all of the preceding articles and encourage us to think beyond that to which we are accustomed, and to explore the possibilities offered by mobility, mobile technologies, and people on the move in terms of developing novel interaction paradigms. They suggest that the range of possible applications which could ultimately make our lives easier are limited only by our imaginative understanding of problem spaces and the potential to combine existing, and invent and validate new, methods of interaction. They note that, for mobile user interfaces, user safety must be of concern despite its seemingly direct contradiction of the accepted goal of engagement. They go beyond the use of sensors as discussed by Roderick to explore the future for sensory substitution – e.g., for visually impaired users – in addition to discussing the complexities associated with designing user interfaces for other special needs user groups, such as illiterate adults. Complementary to the evolution of interaction techniques is the need to evolve data collection and usability evaluation methods for mobile systems; arguing that there is a place for both lab and field studies in Mobile HCI, Gitte and Sheila encourage us to consider how best to adapt, substitute, or replace investigative methods that "*maximize our understanding of contextual constraints on users, usability, and usage patterns*". They urge us to be inventive in our approach to interaction design as well as to invent "*novel approaches to understanding users, designing for users, and evaluating the fruits of our collective labor*".

"*Designing Mobile Phones for Children: Is there a Difference?*": Janet Read certainly thinks so as outlined in her position paper which looks closely at the differences between children's and adults' use of mobile phones and the associated implications in the design of these devices. As mobile phones are increasingly appropriated by younger and younger users, Janet argues that the design of mobile phones needs a re-think in order to best meet the needs of this new user group. In her work with children as technology users, Janet is clearly taking up the gauntlet laid down by Gitte and Sheila in terms of better understanding her users, and focusing on how we can better design for them. She acknowledges that the mobile phone is "*simultaneously lauded as a great device and reviled as a destructive irritation*"; in discussing the potential benefits of mobile phones – both from a future technological perspective and from the perspective of parents who are pro such technologies – Janet notes that "*there is a very fine line between being in touch with a child and the child being surveilled*", an issue which clearly links the discussions of Russell, Antti and Elizabeth, and Roderick. As a proponent of the capacity for mobile phones to benefit children, Janet considers that such technologies for children should be designed to meet their needs and, to this end, presents a series of design ideas to address some of the most serious and common problems with their current design.

In his paper entitled "*SatNav or SatNag? A Case Study Analysis of Evolving HCI Issues for In-Car Computing*", Gary Burnett also imbues many of the elements concerning the meaning of being mobile and the ethical issues associated with user interface design (as per the previous articles by Russell and Antti and Elizabeth, respectively) – in this case, specifically those associated with designing in-car systems where safety concerns dominate. Gary introduces the 4 primary tensions inherent in the design of any in-car system, reflecting on their respective impact on the methods, tools, and user interface design practice employed in this domain. Using a case study which focuses on the design of a vehicle navigation system, Gary eloquently illustrates the tension between avoiding driver overload but, at the same time, avoiding underload; the latter has ethical implications in terms of drivers' over reliance (and propensity to blindly follow the guidance of a navigation system irrespective of its accuracy) on the information provided by a navigation system as well as drivers' over reliance on such systems to the extent that they are becoming increasingly less able to form useful cognitive maps – an inability that negatively impacts drivers' navigational ability, their flexibility in navigational behavior, and their social responsibility. Gary suggests that, to date, the styles of user interface (for navigation systems) recommended by the research community have actually "exacerbated" problems of driver safety and traffic efficiency; he therefore strongly encourages us to undertake novel studies in this research space.

The final paper – entitled "*Paper Rejected (p>0.05): An Introduction to the Debate on Appropriateness of Null-Hypothesis Testing*" – by Mark Dunlop and Mark Baillie serves as a timely cautionary and thought-provoking caveat to researchers motivated to make a dent both in the topics already highlighted as well as the myriad other research avenues of mobile HCI as a discipline. Deliberately controversial, this paper introduces the mobile HCI community to the ongoing discussion on the perceived limitations of p-based null-hypothesis statistical testing – a practice which has been seriously criticized in other domains, some going so far as to advocating a ban on the use of such techniques. Mark and Mark introduce the key problems associated with the reliance on such statistical methods, reflecting on the severity of the problem within our own discipline – i.e., the extent to which we are "statistical sinners". They provide some suggested solutions, but principally encourage researchers and reviewers alike to read the deliberately short, and therefore manageable, bibliography presented in the paper.

As I am sure readers will agree, these position papers are, in their treatment of the varied yet related subject matter, thought provoking, stimulating, encouraging, and best of all, demonstrative of the passion and dedication of the journal's advisors. As I said previously, I hope that these articles act as motivating catalysts to encourage you to further explore your existing fields of research with renewed vigor and/or different perspectives, to let your imagination lead you to new and exciting possibilities for interaction with mobile technologies, and to reflect on how you can best consider the ethical ramifications of what we, as a discipline, deliver, and then to act upon these considerations.

The articles presented in the inaugural volume of the *International Journal of Mobile Human Computer Interaction* highlight just some of the diverse aspects of mobile human-computer interaction design, evaluation, and acceptance that challenge us as we look to the future. I sincerely hope that researchers, academics, and practitioners alike will benefit from, and be challenged by, the high quality research and practice reflected in these articles.

Advances, Challenges, and Blue-Sky Thinking

In preparing this introductory chapter, I wanted to reflect on the most significant advances in recent times across the discipline of mobile HCI, to identify the current and future challenges faced by the field, and to reflect on some blue-sky thinking in terms of where the field might go in the coming months or years. Given the broad range of research areas encompassed by the mobile HCI 'label' I thought where better to gather such ideas than from the esteemed experts who make up the advisory team of the IJMHCI. Hence, I asked the team to reflect on the three aspects noted above within their respective areas of expertise and the following discussion reflects their responses.

Opening the discussion with a high level of reflection, Russell Beale, who leads the Advanced Interaction Group at Birmingham University, UK, suggests that "*widespread adoption of highly interactive technologies…*[the fact that] *mobile phones are widespread and offer texting and simple communications facilities to millions, especially in the developing world*" together with the added advantage that "*iPhones/Androids give access to intuitive gestural interactions*" are perhaps the most significant advancements within the field of mobile HCI in recent times. He sees current and future challenges in terms of fully "*understanding how people's fundamental needs are affected and supported by the developments in technologies*" and can imagine a world in which there is "*increased obscuring of the computer in the interaction cycle, increased awareness of distributed cognition artifacts and designing for them, and revised design methodologies to support more general and wider-stakeholder systems*".

When asked his opinion of the most significant advances of recent times, Jesper Kjeldskov, Associate Professor in the Department of Computer Science at Aalborg University, Denmark responded: "*The iPhone. It represents the first mobile device that provides a pleasurable mobile user experience. It's the mobile device we have been envisioning for a decade, and its uptake confirms that we were right about what people would want to do with mobile technology if we could just provide them with a device (and* *application infrastructure) that was good enough*". Jesper notes that the current and future challenges include "*context-centred mobile interaction design – designing mobile applications that are truly useful and that fit the diverse aspects of human life. A major challenge for future research is to "cast the net" wider than traditionally done within user-centred design and focus more specifically on context"*. Finally, in terms of blue-sky thinking, Jesper identifies as pivotal "representational context-awareness – systems that present context information for the user to act on rather than trying to adapt to it – a sort of response to the somewhat failed project of context-awareness. *Using context information and machine intelligence to automatically make interfaces provide the information that users need in any given context has proven extremely difficult. In response, I suggest that context-aware systems are used to represent context information to its users rather than adapting to it automatically: making use of human intelligence instead"*.

Related to the above, and focusing on the topic of interactive migratory user interfaces, Research Director and Head of the Human Interfaces in Information Systems Lab at CNR, Italy, Fabio Paternò comments that "*nowadays people are ever more exposed to ubiquitous environments, which are characterized by the availability of various interactive devices with different interaction resources. Thus, the possibility to opportunistically exploit the resources that such contexts offer (e.g., moving from stationary to mobile devices) is invaluable for providing an effective interaction experience to the user. In this context, interactive migratory user interfaces offer the added value of enabling users to migrate across various types of devices while preserving the task continuity. Various types of migration can be identified depending on the number of source and target devices or whether the entire user interface or only a part of it migrates. In particular, partial migration concerns moving only a portion of the interactive application to another device in order to better support a mobile user*". In terms of blue-sky thinking, Fabio suggests that "*we can expect in the near future to have migration involving types of devices/modalities other than desktop and mobile devices. Another interesting evolution is in the area of end-user development because this approach allows fast prototyping of mobile applications starting from existing desktop applications in a way feasible even for people without programming knowledge*".

Mark Dunlop – Senior Lecturer at Strathclyde University, UK – discusses the advances and challenges faced in the realm of mobile text entry: "*the widespread move to full screen touch interface phones has been liberating in many areas but perhaps most so for text entry which has been seriously constrained by both the physical keyboard layout and text entry patents. While most touchscreen phones use ye-olde QWERTY keyboard transposed to a touchscreen, the widescreen adoption has sparked a wide range of alternatives, both in research labs and as third-party applications. Alternative layouts have been predicted to give higher entry rates, e.g. the unambiguous Fitaly layout for stylus-based PDAs and the ambiguous JustType keyboard layout. As well as redesigning the layout, we could also exploit technologies such as pressure sensitive screens. Currently there is a flurry of developer activity trying to produce alternative keyboards and input methods on touchscreens – the research community has to analyze these alternatives, attempt to find consistent lessons, and understand how people enter text on mobiles – for example, does it differ when walking and sitting while texting or emailing? Out of this should emerge both new alternative technologies and a deeper understanding of how we can best interact with small phones. Certainly an exciting time compared to the constrained recent history of mobile phone keypads*".

Picking up on the topic of her position paper, Janet Read, Director of the Child Computer Interaction (ChiCI) Group at the University of Central Lancashire, UK, notes that "*in the field of design and evaluation of mobile technologies for children, the landscape is continuously changing. Each generation, or even micro generation (5 years) seems to adopt a new technology of choice and as fast as the* *technologies and generations change, so does the usage*". Janet reflects that "*it is often the children that go outside the box and create new ways to interact and use technologies. As we move into the next few years, the generation of children as smart phone users will no doubt challenge many of our adult assumptions about use, about privacy and about ownership of data. It is highly likely that children will find new ways to use their mobile devices to communicate, to express themselves and to locate products and services*". In terms of blue-sky thinking, Janet suggests that "*mobile technology for children will not necessarily be constrained to traditional mobile phone devices. The addition of projection facilities to mobile phones, the cheaper access to internet time, the reduced cost of GPS technologies and the additional services offered by technology providers will all offer new possibilities – children could be receiving and sending their homework on mobile devices while also augmenting their school bags and products with smart mobile products that will do much of their thinking!*" and challenges us to "*imagine a school bag that knows what has been put into it and tells the child to hurry up as he or she dawdles to school!*".

Gary Burnett is an Associate Professor in human factors at Nottingham University, UK, where his research focuses on human aspects of advanced technology within road-based vehicles. Also elaborating on the theme of his position paper, Gary notes that "*vehicle manufacturers are constantly looking to utilize new mobile technologies and drivers (and passengers) increasingly bring a range of technology devices into their vehicles (e.g., mobile phones, mp3 players, etc.). Such trends are having a radical effect on the safety, efficiency and comfort of modern vehicles; hence, the minimization of overload in mobile technology design will continue to be a focus for research"*. Gary reflects that research in this area has led to the refinement of "*specific methods to assist designers in predicting the potential negative effects of alternative interfaces. This development has been largely technology and cost-driven, and there is an urgent need to understand what makes a 'good' simulator, relating to issues of validity, reliability, etc.*". Looking to the future, Gary suggests that research "*will increasingly need to address issues of underload (largely relating to the affects of automation). Primary driving tasks have remained largely the same since vehicles were first developed but forecasts suggest that the future driving experience will be considerably different, as greater numbers of vehicles possess technologies that automate varying aspects of driving. There will be an important need to understand behavioral adaptation affects and the fundamental issues concerning the nature of driving 'skill'*". Gary closes by warning that "*ultimately, research in this area will need to understand the complex relationships between overload and underload conditions. Safety should always be the over-riding consideration in such research!*".

Gitte Lindgaard is Professor of Psychology at Carlton University, Canada where she holds NSERC/Cognos Chair in User-Centred Design in Human Oriented Technology Lab (HOTLab) of which she is director. When asked about the most significant advances in mobile HCI, she notes that "*much is happening in the field of disaster management, especially in the CBRNE (Chemical, Biological, Radiological, Nuclear, Explosives) area. Particular focus is on technologies supporting communication both among first responders representing different agencies, and among responders and the public. Prominent among these are various speech-based technologies including efforts to provide speech-based or EMG-based (Electromyelography) technologies for responders dressed in hazmat suits and wearing gas masks. Web technologies are also being used for instant communication purposes*". In terms of current and future challenges, Gitte reflects that "*there is still so much to be done to support disaster management, be they natural disasters or terrorist attacks. Speech recognition, while advancing rapidly, is still not sufficiently well developed to be relied upon in an emergency. Cellular networks tend to be swamped, leading to consequential breakdowns; geo-spatial technologies are evolving and can be employed in certain situa-*

tions, but positioning accuracy is still insufficient to support, for example, fire fighters finding their way inside burning buildings. EMG technologies, while promising, need further development, and there are probably many other possible solutions to effective and timely disaster management yet to be explored". Finally, in terms of the future, Gitte comments that "*I am sure that we are on the verge of solving many of the known issues in CBRNE management…but there is a long way to go still*".

Antti Pirhonen is a senior researcher in the University of Jyväskylä, Finland. Although he considers the most important advances of mobile HCI in recent times to be "*assistive technologies. Smart phones, which enable text-based communication in mobile settings, have probably added a new dimension in the life of people with hearing impairments. It is a good example of an application which has enhanced quality of life.*", he cautions that "*there are many examples of assistive technologies, though, in which human help has just been replaced with a technical solution"*. Antti goes on to challenge us via his observation that "*human-computer interaction, because of its history, is not a human-centric area of research in a positive sense only. The negative side-effect of the human, or user-centric, approach is what could be called* "*individual centeredness*"*. In our postmodern era, individualistic approaches are resonating with various areas of society, and with economy in particular. In the area of mobile HCI, individualism is perhaps an exceptionally salient phenomenon since applications are extremely personal. However, to be human-centric, the real challenge of the research of mobile HCI is to widen the scope of research to cover more essential issues of human life than just the details of usage of applications. To be a credible branch of science, genuinely critical views about the impact of current trends in our culture, social well-being and health, to name but a few, should be raised in mobile HCI*".

From widespread adoption of mobile technologies to effective context-awareness to migratory interfaces on such technologies, from the specifics of text input on mobile devices to their use in road-based vehicles and by children, and consideration of the use of mobile technologies in disaster management, the above discussion on the advances, challenges and blue-sky future of mobile human-computer interaction gives us much to consider. Interesting and encouraging to note is the thread of discussion permeating much of what has been presented in this introduction and throughout the articles included in this book related to the ethical and societal impact of what we do as mobile HCI researchers. We are repeatedly encouraged to be most mindful of Antti's provocation to carefully consider the impact on our culture, social wellbeing and health of current and future research trends in our field. Readers may agree or disagree with some of the positions stated; either way, my hope is that the discussions prove stimulating and convey the energy and excitement of the past, present, and future of the field of mobile HCI.

CLOSING COMMENTS

The inaugural volume of the *International Journal of Mobile Human Computer Interaction* has delivered exciting research, practical guidance, and stimulating food for thought in terms of research directions and challenges across the spectrum of the mobile HCI discipline. In bringing together not only the various articles included in four issues of the inaugural volume but also reflections on advances, challenges, and blue-sky directions by some of the field's most eminent researchers, I believe this publication serves as an invaluable compendium for researchers, educators, students, and practitioners alike.

I would like to conclude by thanking everyone who has been involved with the evolution and development of the IJMHCI – the invaluable contribution of the journal's advisory boards and board of reviewers and, of course, the essential contribution made by the authors of published articles and guest editors of the special issues – which has not only led to an exciting and vibrant journal, but has culminated in this comprehensive publication. All that remains now is for me to welcome you to this book which draws together all the research achievements and challenges presented in the inaugural volume of the IJHMCI as well as setting out challenges for the future of the field of mobile HCI.

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Chapter 1
Instrumented Usability Analysis for Mobile Devices

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ABSTRACT

Instrumented usability analysis involves the use of sensors during a usability study which provide observations from which the evaluator can infer details of the context of use, specific activities or disturbances. This is particularly useful for the evaluation of mobile and wearable devices, which are currently difficult to test realistically without constraining users in unnatural ways. To illustrate the benefits of such an approach, we present a study of touch-screen selection of on-screen targets, whilst walking and sitting, using a PocketPC instrumented with an accelerometer. From the accelerometer data the user's gait behaviour is inferred, allowing us to link performance to gait phase angle, showing there were phase regions with significantly lower error and variability. The article provides examples of how information acquired via sensors gives us quantitatively measurable information about the detailed interactions taking place when mobile, allowing designers to test and revise design decisions, based on realistic user activity.

INTRODUCTION

Mobile and wearable devices are becoming increasingly important in our daily lives, and there is a correspondingly large activity in the design of interaction for these devices. It is obviously very important to be able to evaluate their usability, but by their very nature, these devices are intended for use in mobile settings, not for use by someone seated in a usability lab.

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As described by (Kjeldskov & Stage, 2004), there is a wealth of guidelines for running laboratory-based usability studies, but these studies will lack realism for mobile devices. To test mobile devices in mobile settings, however, we are required to use field-based evaluations, which are far from straightforward to implement. Kjeldskov and Stage's review of the literature points out three difficulties: 1. It is difficult to define a study that captures the use-scenario, 2. It is hard to use many established evaluation techniques, and 3. Field evaluations complicate data collection, and limit experimental control. Examples of papers where researchers have proposed additional techniques such as distance walked and percentage preferred walking speed to assess usability include (Brewster, 2002), (Petrie, Furner, & Strothotte, 1998), and (Pirhonen, Brewster, & Holguin, 2002), using a mix of qualitative questions and manual recording of walking pace. (Mizobuchi, Chignell, & Newton, 2005) examine the effect of key size on handheld devices while walking.

(Barnard, Yi, Jacko, & Sears, 2005) review the differences between desktop and mobile computing, and they observe for researchers aiming to isolate the effects of motion from other contaminants, the idea of such uncontrolled studies can be daunting. Control is critical for empirical data collection methods employing the scientific method.

Roto et al. (2004) discuss the use of Quasi-experimentation based on best possible control over nuisance variables, coupled with recordings of the user, interaction with the device and environment. The innovation in their recordings was the use of multiple cameras worn around the body of the user, and attached above the screen of the mobile device. This does make the recording process obtrusive and might change both user behaviour and that of people in the environment around them. It is also time-consuming to analyse after the experiment. This recording arrangement has been used successfully in (Oulasvirta, Tamminen, Roto, & Kuorelahti, 2005) to investigate the fragmentation of attention in mobile interaction.

INSTRUMENTED USABILITY ANALYSIS

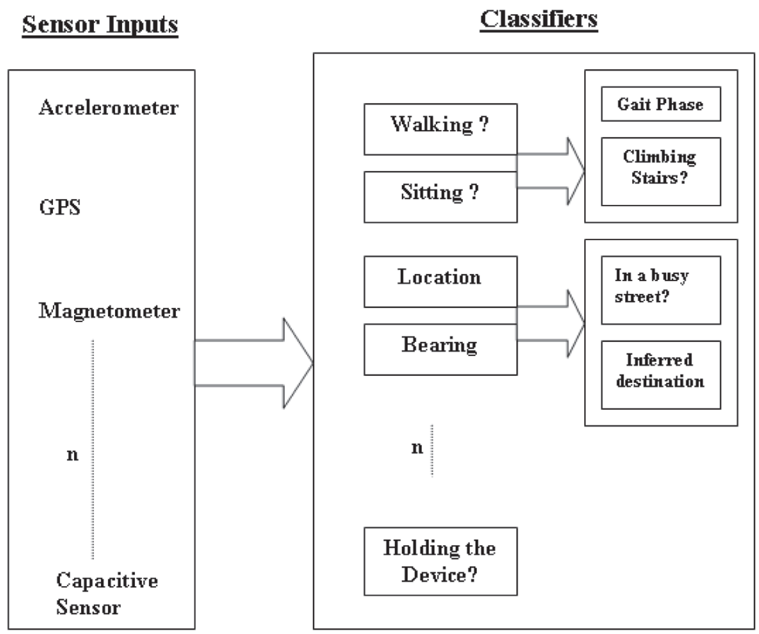
Here, we define *'Instrumented usability analysis'* as the use of sensors during a usability study which provide observations from which the evaluator can infer details of the context of use, or specific activities or disturbances.

Sensors such as accelerometers, magnetometers and GPS systems have been added to mobile devices, and are now in mass-production in mobile phones. These have been included for informing the user (about location, number of steps taken), or giving the user novel input mechanisms, such as gesture recognition or input for game playing.

There are many examples of both prototype and commercially available sensors and sensor packs for motion or context sensing. (Fishkin, Jiang, Philipose, & Roy, 2004) describe a system for detecting interactions with RFID technology and suggest it can be used to infer user movement by examining signal strengths from a sensor network. (Gemmell, Williams, Wood, Lueder, & Bell, 2004) describe the SenseCam system used to capture life experiences without having to operate complex recording equipment. SenseCam combines a camera with a group of sensors including an accelerometer, infrared, light and temperature sensors and a clock to automatically detect, photograph and map out changes in context or events during a persons day. (Kern & Schiele, 2003) describe a hardware platform combining multiple wearable accelerometers in order to infer the user's context and actions. They demonstrate how these acceleration signals can be used to classify user activity into actions such as sitting, standing, walking, shaking hands and typing.

More recently, the general purpose Bluetooth SHAKE (Sensing Hardware Accessory for Kinesthetic Expression) inertial sensor pack, described

Figure 1. An example of how sensors and classifiers could be combined to infer user actions during a usability study, and store these as an annotated log file, allowing developers to correlate different states with user interaction behaviour. Raw readings are interpreted in a hierarchical fashion by a range of plug-in classification or signal transformations. These can be arranged hierarchically, so e.g. only if the person is classified as "walking" do we infer gait phase angle, and whether they are climbing the stairs or not.



in (Williamson, Murray-Smith, & Hughes, 2007), which is available for general use by the research community, from SAMH Engineering Services. It features a tri-axis accelerometer, tri-axis magnetometer, dual channel analogue inputs, dual channel capacitive sensing and an internal vibrating motor. Communications are over a Bluetooth serial port profile. SHAKE includes a powerful DSP engine, allowing real time linear phase sample rate conversion. These capabilities allow rapid prototyping of inertial-sensing-based interfaces with real-world hardware. But the small size, and the onboard processor and memory mean that the device can be used completely separately from the implementation on a mobile device, and can be used to log movement at multiple points around a user in a wide variety of situations. It can be attached to the back of their device, or could be attached to their belt, or elsewhere on the body, to detect activity without wires to restrict a person's movements.

In this article we suggest that such sensors and sensors packs can be used in an indirect fashion, to better understand what was happening to the device and user at any point in time during a usability experiment. Figure 1 demonstrates how such a system would work. There could potentially be multiple sensors placed on the user or mobile device. Outputs from the sensor would be run through one or many classifier algorithms that could infer the user's actions or context at any one time

Of course, as the algorithms for automatically inferring context of use from sensors develop to a level of robustness which allows them to be used online, they can be used in everyday mobile situations to subtly adjust the nature of the interaction—the "background interaction... using naturally occurring user activity as an input that allows the device to infer or anticipate user needs" described in (Hinckley, Pierce, Horvitz, & Sinclair, 2005). For example, if tapping is less accurate when a user is walking, the display could adjust to a mode which had fewer, but larger, buttons. In this article, however, we will concentrate on the use of such information to analyse user behaviour in greater temporal detail than is typical in mobile usability trials. Rather than performing a trial, and then asking subjective questions, or analyzing video footage, we will classify activity from sensors on the device or user, and relate these to any log of explicit interaction activity during the evaluation. If a user has an unusually high error rate, can we better determine exactly what was happening at that point in time in each case?

This approach is obviously related to research in context-dependent interaction which used information from sensors to infer context of use (walking, running, in car, inside, outside), to allow more appropriate behaviour from the device. (Yi, Choi, Jacko, & Sears, 2005) used an accelerometer in evaluation, but used mean activity over the whole period in different conditions, rather than detailed results during the evaluation.

These techniques can be combined with a system such as Replayer described by (Morrison, Tennent, & Chalmers, 2006). This is a system designed to aid usability evaluation and provides tools that allow evaluators from different backgrounds to easily view, annotate, and analyse multiple streams of heterogeneous data logged during a usability study. These data streams could potentially be obtained from multiple sensors attached to a mobile device. A first prototype of this, using the MESH device used in this article, is described in (Morrison, Tennent, Williamson, & Chalmers, 2007).

Example: Mobile Text Entry

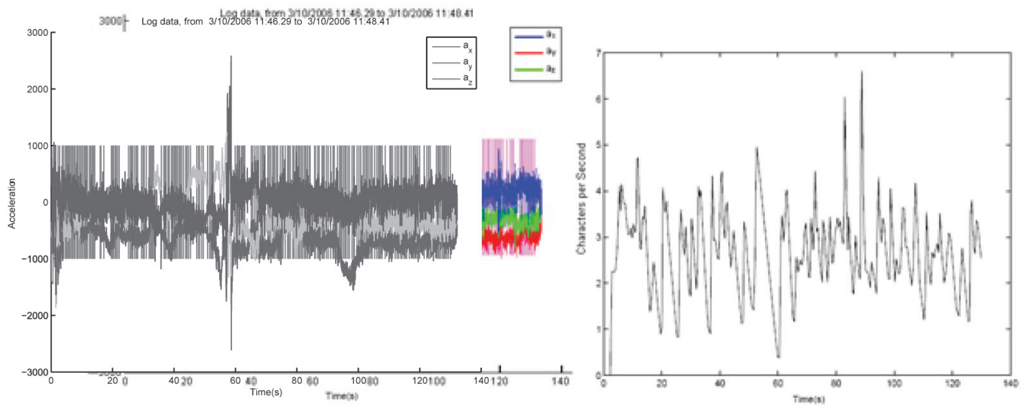
An illustration of how the method could be used is that of mobile text entry. The questions we might want to answer for a given method could be: do people use it on the go, as well as when stationary? How much slower are they when they use it while walking? Do they enter text continuously, but slowly, or do they stop every few metres to enter more text? How is their error rate related to their walking speed? Do they link the entry of a new character with a new step? What is the effect on walking speed, when entering text? If the user enters text in a car, or bus, how are they affected by movement of the vehicle? Do they wait until the bus stops then enter text?

Figure 2 below shows a time-series of accelerometer readings while a user enters text, while seated as a passenger in a car in urban rush hour traffic with frequent stop-start activity.

Figure 3 shows the example of a user entering text in various contexts. The user started to enter text while sitting, stood up, walked around some narrow corridors avoiding objects, down stairs, along a straight corridor, up stairs, then returned to seated position, and entered more text while resting his hand on a table. The plots show the overall activity of the user, along with the throughput of characters entered at each point. In the walking case, we can see text entry pause, as the user takes a seat just after 140s, and we see faster entry rates while seated in the car, compared to walking. The text entry rates while walking are nevertheless fairly constant. This illustration acts as an example of how the accelerometers can give us extra information from which we can infer more about what was happening at each point in the interaction.

In this article, which expands on our earlier work in (Crossan, Murray-Smith, Brewster, Kelly, & Musizza, 2005), we work towards a quantitative understanding of the detailed interactions taking place, via additional sensors on the mobile device and user, so that we can better

Figure 2. Text entry while seated in a car. The number of characters entered per second is plotted to the right of the acceleration time series (the vertical lines in the left plot are individual key-press events).



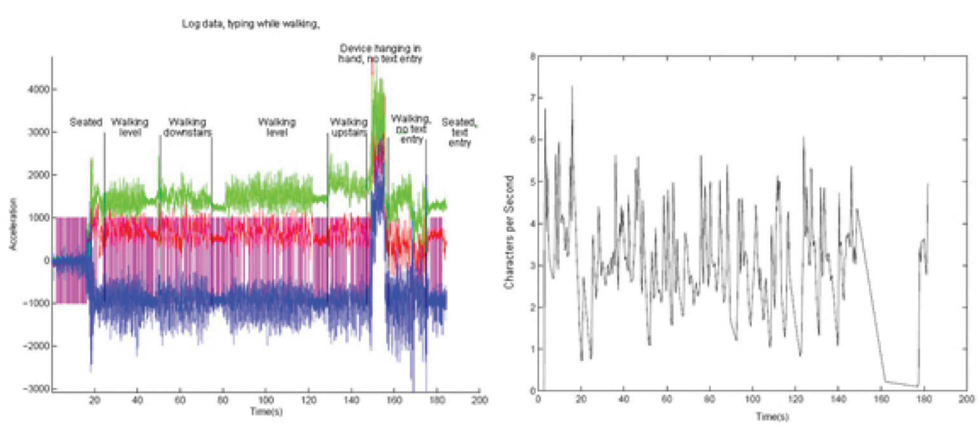
understand how users interact with the devices, and so further improve the designs.

DETAILED CASE STUDY OF WALKING AND TAPPING

Here, we present a detailed example of an instrumented usability study to demonstrate the benefits of this approach. Standard usability time and error metrics are gathered, while the instrumentation allows us to gain a greater insight into the users actions and disturbances during the study. Although this example specifically examines users walking patterns sensed through an accelerometer, the techniques discussed can be applied to a wide range of contexts.

Given the importance of devices being used while the user is walking, and the difficulty researchers have had about getting detailed insight into user behaviour, down to the level of each step taken, we now concentrate on the example

Figure 3. Text entry in a range of conditions. The number of characters entered per second is plotted to the right of the acceleration time series (the purple vertical lines in the left plot are individual key-press events, and the black ones delineate the different walking conditions).



of tapping buttons or other widgets on a touch screen. This is a common form of input, and is effective when seated, but difficult when walking. (Brewster, 2002) showed a more than 30% reduction in performance tapping buttons on the display of a PDA when walking, compared to sitting. If we can gain more detailed insight into how and when users tap during walking, we might be able to adjust the design of the interface to improve robustness.

Here we show how sensors, like accelerometers, can be used in ways other than for explicit interaction. In this case we use the acceleration data to infer the user's gait, and we investigate whether the rhythm of walking affects the tap timing and error rate of a user selecting targets on screen, while walking and sitting.

EXPERIMENT

Introduction

This study examines in detail the behaviour or users tapping on the screen of a mobile device. It analyses behaviour in two different situations that a user might perform this task: while sitting and while walking. The sitting condition will be used to provide a performance baseline for the walking condition. Disturbances to the device and the users stylus due to the user's walking will affect how and how well the user performs the task. By instrumenting the device with a sensor (in this case an accelerometer), we will be able to gain a deeper understanding of how these disturbances affect performance.

Equipment

This system was developed using an HP 5550 PDA with the Xsens P3C 3 degree of freedom linear accelerometer attached to the serial port, as shown in Figure 4. Its effect on the balance of the device is negligible (its weight is 10.35g). The accelerometer was used to detect movement of the device, sampling at a rate of approximately 90Hz.

Task

The interface used for the study is displayed in Figure 4. Participants were asked to tap on a series of cross-hair targets (drawn 30 pixels high and wide) that were displayed on the screen. There were 15 possible target positions spaced equally around a 3 wide by 5 high grid of positions on the screen. Every second target presented to the participants was the target in the centre of the screen. This ensured that the user must return the stylus to the centre of the screen such that when a target other than the central target was tapped, the path to that target was always from the centre. The other 14 targets were displayed to the user in a random order four times each. The accuracy and speed of tapping were both emphasised as equally important. The position of the tap was recorded as the initial stylus down position on the screen. Once one target had been selected, the next target was displayed a random time interval from 0.5

Figure 4. PDA with the Xsens P3C accelerometer attached to the serial port

to 1.5 seconds after the previous selection. This was to prevent rhythm effects affecting the tapping phase information in the mobile condition. There were no restrictions on the accuracy that was required by the user. A tap anywhere on the screen regardless of the position of the target counted as a selection.

There were two experimental conditions: tapping while sitting and tapping while walking and 20 users performed both conditions in a counterbalanced order, with 18 participants being right handed and 2 participants being left handed. All participants tapped with their dominant hand while holding the device in their non-dominant hand. For the walking condition, the participants navigated a quiet triangle of paths on the university campus (of total length approximately 200 metres).

Calibration of the screen becomes an issue when looking at accuracy of tapping in a pen based interface, as an error in the calibration can lead to a consistent and unwanted bias in the results. The screen was calibrated once at the start of the experiment, and the same device was used throughout the experiment. Three participants tested the screen calibration. The device was placed on the desk and users performed a similar task to the tapping study for four separate sessions. In this case accuracy was heavily emphasised as the most important aspect of the study. This was borne out by the much closer concentration of points than in the final results, with mean standard deviation of the error for each participant for all targets being less than a pixel. After each session, the device was rotated by 90 degrees (additive for each section) to negate any systematic tapping bias. Mean values were recorded for each screen target position and were subtracted from the final results. This method provides a closer match between the position the user actually tapped in and the recorded tap position.

Metrics

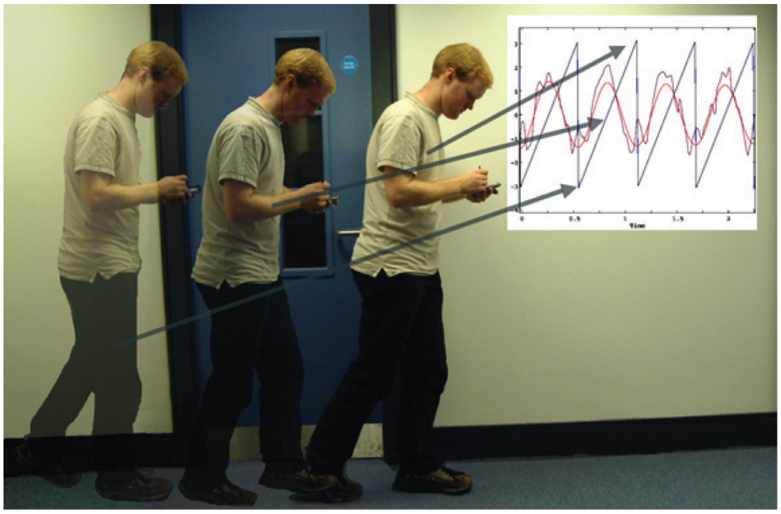
Standard usability metrics were used for assessing user performance in the task. Comparisons were made between time to tap and accuracy of tap for each of the groups. Time to tap was taken from the time that the target was displayed on the screen to the time of the stylus down event. The hypotheses were that users would be more accurate and faster in the seated condition. The effect of screen position of the target on accuracy of the tap was also examined.

The instrumented usability approach also allows us to gain further insights into the users actions during the study. The interactions of participants' tapping and step patterns were examined.

Gait Detection

As a mobile user walks while holding a mobile device, his or her arm will oscillate as a result of the user's gait. If we examine only the vertical axis of this oscillation, there will be one oscillation per step. Figure 5 shows a time series for the vertical acceleration axis. A Fast Fourier Transform is used to determine the frequency at which the peak amplitude occurs, between 1 and 3Hz in the spectrum. For the controlled conditions in this study, this corresponds to the walking step rate. In practice, this is the frequency of maximum power in the spectrum as the users are looking at the screen and therefore trying to hold the device relatively still with respect to their body as they walk. The vertical axis acceleration signal is then zero phase shift filtered using a narrow bandpass Butterworth filter centred around this frequency. Figure 5 demonstrates the filtered signal. As the user walks with the device held steady in one hand, an approximately regular oscillation is formed in the vertical axis. One oscillation corresponds to one step.

Figure 5. A user walking with the device and corresponding acceleration trace. The unfiltered vertical acceleration signal (rough sinusoid), the filtered signal (smooth sinusoid) and the phase estimate (in radians) for the signal (saw-tooth).



The algorithms used in this article were developed in research on synchronisation effects in nature. The oscillations involved in many natural systems are often irregular, ruling out simple strategies. In some cases, such as respiratory examples, or electrocardiogram data, there are clear marked events with pronounced peaks in the time-series which can be manually annotated, or automatically detected. One practical advantage of the use of synchronization theory is that often we have a quite complex nonlinear oscillation, which might be sensed via a large number of sensors. The phase angle of that oscillation is however a simple scalar value, so if we are investigating the synchronization effects in two complex systems, the analysis can sometimes be a single value, the relative phase angle $\varphi_1 - \varphi_2$.

The Hilbert Transform

How do we find the phase angle from the data? A common approach is to use the Hilbert transform introduced by Gabor in 1946, which gives the instantaneous phase and amplitude of a signal s(t) (Pikovsky, Rosenblum, & Kurths, 2001). The Hilbert transform signal $s_H(t)$ allows you to construct the complex signal

$$\varsigma(t) = s(t) + is_H(t) = A(t)e^{i\phi(t)}$$

where $\varphi(t)$ is the phase at time t, and A(t) is the amplitude of the signal at time t. The Hilbert transform signal of s(t) is

$$s_H(t) = \frac{1}{\pi} \lim_{T \to \infty} \int_{-T}^{T} \frac{s(\tau)}{t - \tau} d\tau$$

Although A(t) and $\varphi(t)$ can be computed for an arbitrary s(t) they are only physically meaningful if s(t) is a narrow-band signal. For the gait analysis, we therefore filter the data to create a signal with a single main peak in the frequency spectrum around the typical walking pace (between 1 and 3Hz).

This phase plot signal is again shown as the saw-tooth waveform in Figure 5 and Figure 6 and can be seen to reset at the lowest point in the signal. This corresponds to the lowest point of the hand in the oscillation.

Details of the Hilbert transform and filtering are included here for completeness, however, this functionality is easily accessible in many standard data analysis programs such as Matlab through simple function calls and understanding these equations is not essential for understanding the remainder of this article.

Standard Usability Results

Time to Tap

The mean time to tap was lower in the sitting case than the walking case as would be expected. The mean time to tap a target in the walking condition was 0.79s (std dev = 0.18) compared to 0.70s (std dev = 0.22) in the seated case. This can be further broken down into tapping the centre target and outer targets. The mean time to tap the centre target was 0.75s (std dev = 0.23) when walking and 0.65s (std dev = 0.19) while sitting. This compared to 0.82s (std dev = 0.22) while walking and 0.75s (std dev = 0.20) while sitting to tap the outer targets. This difference between centre and outer targets is indicative of users predicting the appearance of the centre target since it consistently appeared every second target.

Tap Accuracy

A graph of tapping accuracy is shown in Figure 7. The graph demonstrates that as expected, users were more accurate tapping in the seated condition with 78% of taps being within 5 pixels in the seated case compared to 56.5% in the walking case. Participants remained more accurate in the seated case and reached 98% of taps within 15 pixels in the seated condition compared to 25 pixels in the walking condition. Separating these into x and y pixel error showed little difference between accuracy in vertical or horizontal error.

Above the range of 30 pixels, structure can be seen in the errors where tap position corresponds to the position of the previous target (shown in Figure 8). This indicates a tap when the user did not mean to tap. This is most likely the result of a user accidentally double tapping in position of the previous target. These taps were viewed as outliers and discounted from the final analysis.

Observation in the walking condition showed that when tapping, all participants immediately adopted the strategy of grounding the side of their hand holding the stylus on the hand holding the device to reduce independent movement of the hands and thereby improve accuracy. Targeting therefore involve pivoting the hand about the grounded position.

Figure 6. Generating the phase angle $\varphi(t)$ from observed acceleration data a(t) from a user walking

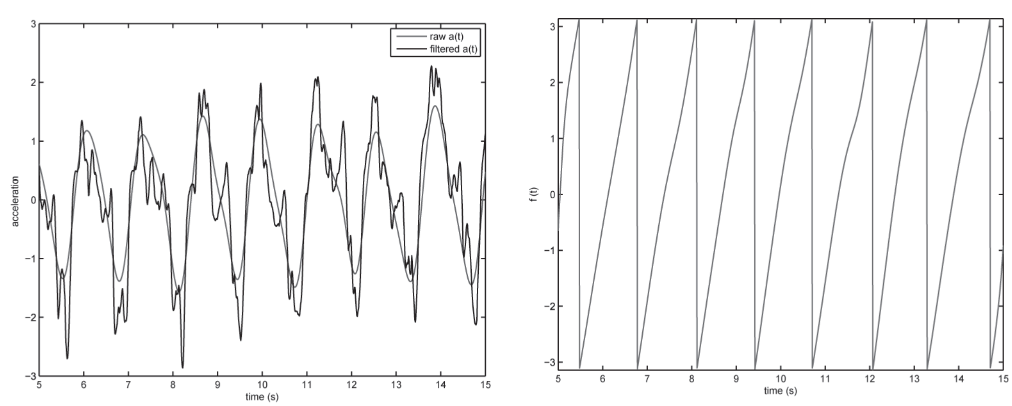


Figure 7. Percentage of taps with the given pixel radius for sitting and walking users

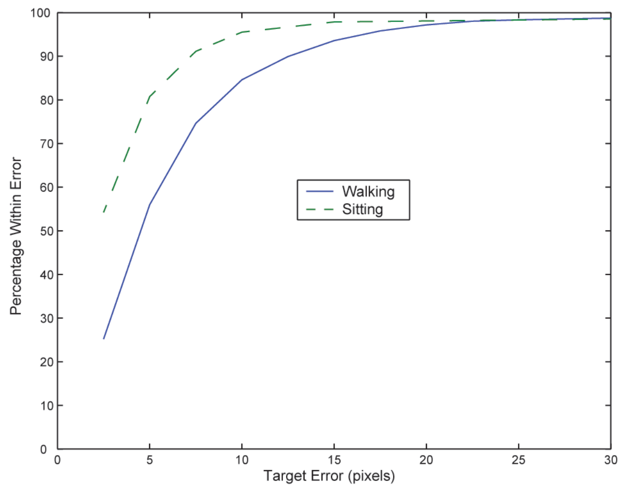


Figure 8. The x- y pixel errors for all users for all targets. The structure of the 3 by 5 grid of targets can be seen indicating users mistakenly double tapping.

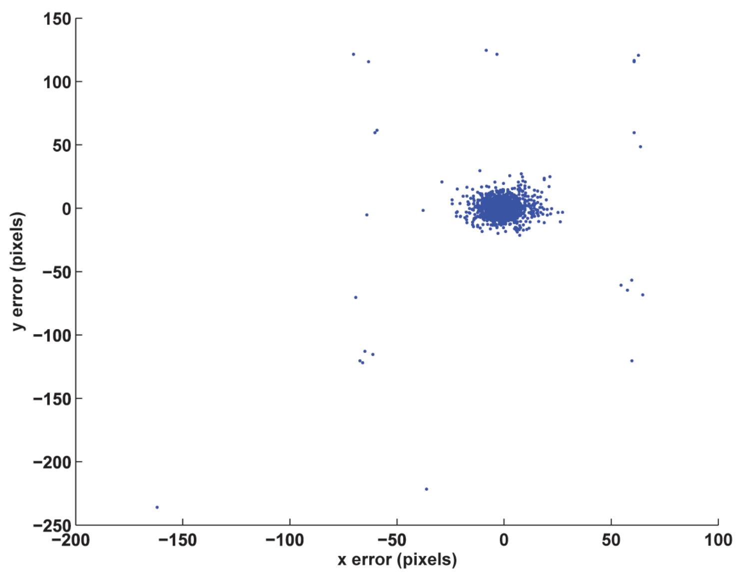
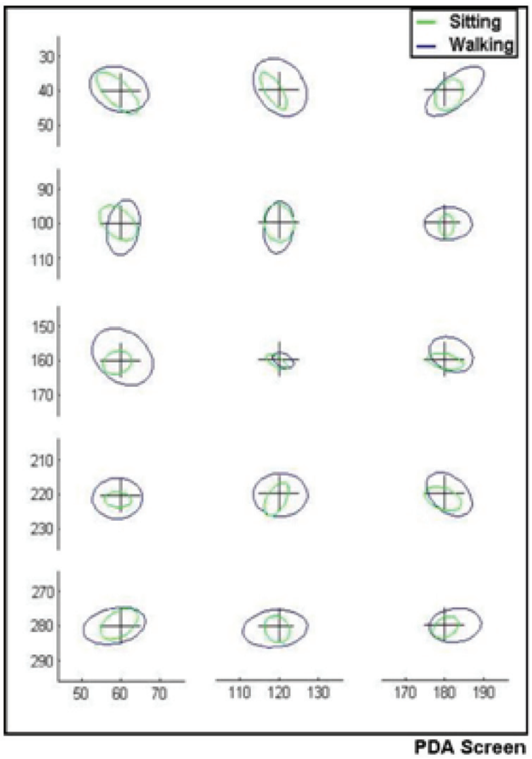


Figure 9 shows the mean variability and covariance of the x and y target errors for all users for each of the 15 targets. In almost all cases, the variability in tapping is smaller in the seated condition than in the walking condition. Due to the controlled conditions of this study, the movements to the outer targets were always from centre target. The variability in tap position for the centre targets is less than that of the outer targets. This is due to the fact that the stylus over the centre target position was the default position for most users. Covariance of the x and y tap positions can be seen to be along the direction of movement for most of the targets. This is particularly true for the corner targets.

Figure 9. Ellipses show 2 standard deviations of a Gaussian fit to the spread of mean tap positions (from 4 points per participant) from all 20 participants, for each target. In each case the smaller ellipse shows the results for the seated condition and the larger ellipse shows the results for the walking condition. The crosses represent the target positions.



Instrumented Usability Analysis Results

Tap Phase

The method for obtaining the phase of step that the tap occurred at is described above. Figure 10 splits one step into 10 equal sections and plots the median of the number of taps in each section for each participant. The reset phase position corresponds to the lowest point of the vertical accelerometer trace. Bins 1 to 5 correspond to the arm as it moves upwards to its peak, and bins 6 to 10 correspond to the arm moving downwards.

A bias in clearly shown towards tapping in the second half of the oscillation. This bias is not present when analysing the phase at which the targets are displayed and must therefore have been introduced by the user. The phases when most taps occur correspond to when the device is moving downwards with the arm. As soon as the device begins to move upwards in the hand again towards the stylus, the number of taps on the screen decreases. When questioned after the experiment, none of the participants was aware that a bias existed.

Figure 11 shows the median of the mean magnitude tap error for each participant, for each of the step phase bins above. This figure shows that users were more accurate when tapping in the second half of the phase - the time when most taps occurred. The mean error is 7.1 pixels in the first section (just when the arm starts to rise again), compared to a mean of 5.6 pixels in the fourth section when the hand is moving downwards.

Further to this, if we consider just the three most probable tap phase bins (P_{HP}) and the three least tap probable tap phase bins (P_{LP}) a clearer indication of this is given. Figure 12 shows a box plot of the tap error in P_{HP} and P_{LP}. P_{HP} has median tap error of 4.6 pixels compared to 5.7 pixels for P_{LP}. A Mann Whitney test showed that this difference was highly significant ($p < 0.002$). If we consider the timing data for the same phase regions, it can be seen that users take significantly longer to tap in the high probability regions. Users took a median of 0.69 seconds to tap in P_{LP} compared to 0.73 seconds for P_{HP}. This difference was again tested using a Mann Whitney test and was shown to be significant ($p = 0.05$). Figure 13 shows the corresponding skew plot for high and low tap probability regions.

When combined with the results shown in Figure 10 above, these data suggest that users were able to subconsciously alter their behaviour in the task in order to improve their accuracy by

Figure 10. Box plot visualising the distribution of tapping times. Median phase in which the user taps (split into 10 sections) with the reset position for the phase corresponds to the lowest point of the arm which occurs just after a step.

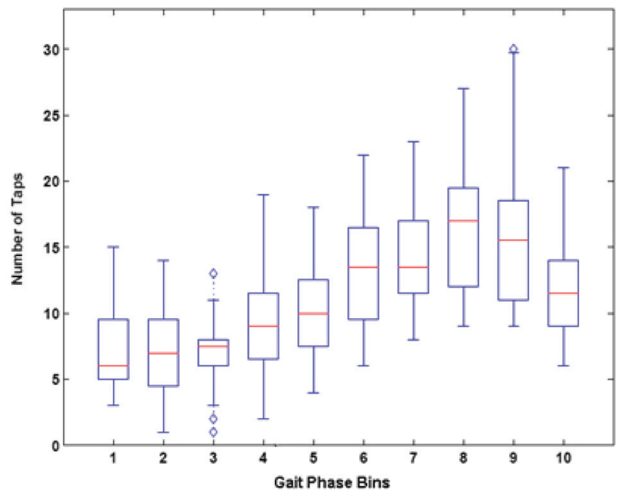
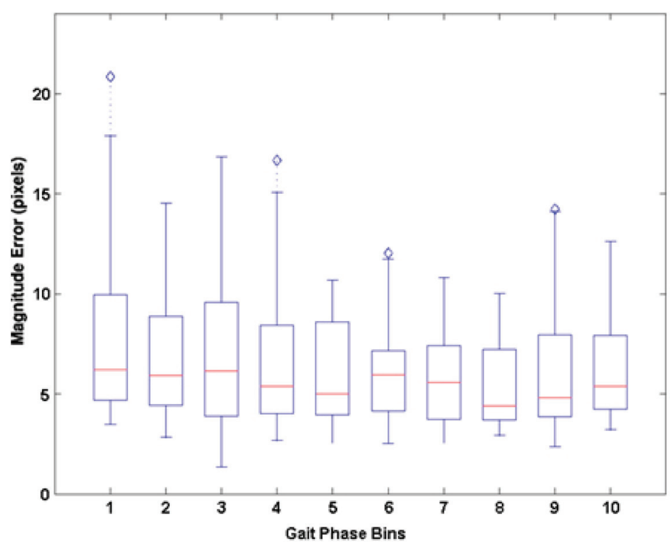


Figure 11. Median target tap error in pixels for each phase of the motion (split into 10 segments) with the reset position for the phase corresponding to the lowest point of the arm which occurs just after a step.



tapping at a time in their step when it was easier to tap more accurately. The longer time to tap in the high probability region indicates that users tended to subconsciously wait for that particular phase region to tap in.

Left–Right Step Analysis

For the previous set of results, each step has been treated as one cycle. However, we could also choose to separate out the left foot steps from the right foot steps. As the user walks, the verti-

Figure 12. Target tap error in pixels for the high probability tap phase region and the low probability tap phase region

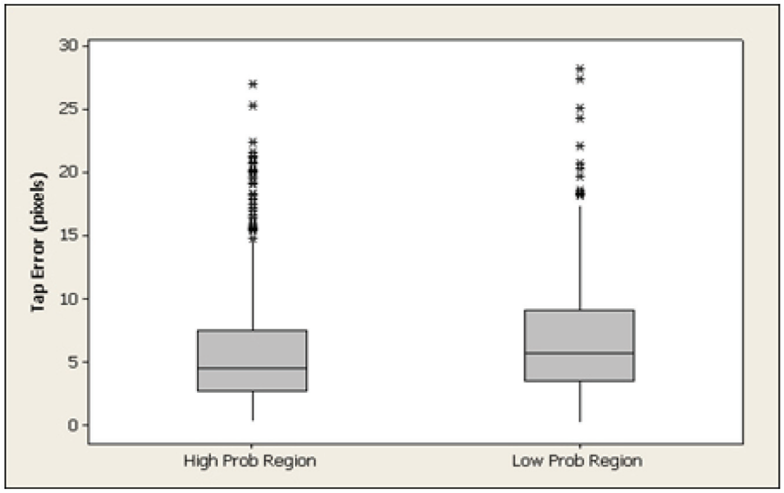
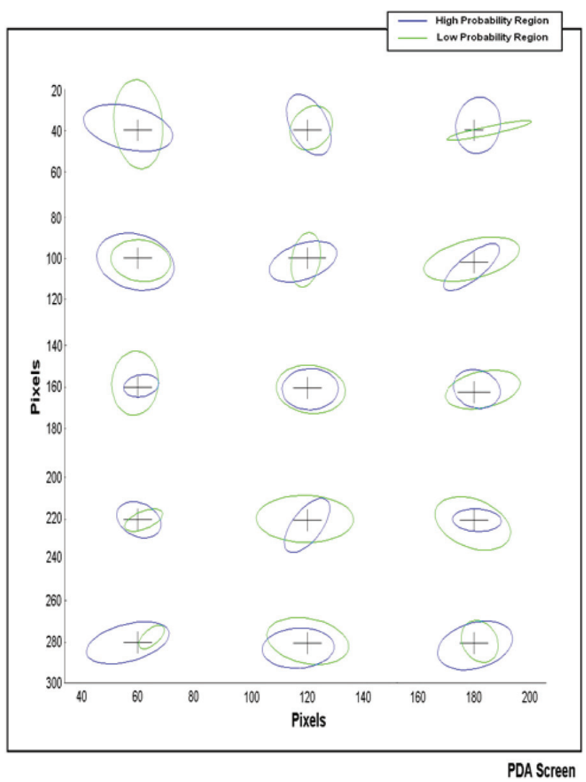


Figure 13. Target tap error in pixels for the high probability tap phase region and the low probability tap phase region.



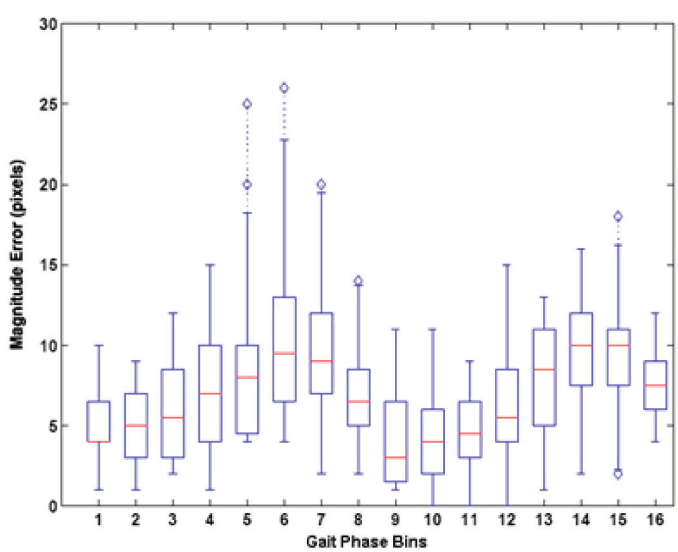
cal acceleration sensed through the device will complete one phase cycle at every step the user takes. The lateral acceleration can also be seen to be oscillatory. However, one oscillation in the lateral direction will now correspond to a combination of one left foot step and one right foot step. The dominant frequency of the lateral oscillation is therefore half that of the vertical oscillation. The device will therefore undergo consistently different disturbances depending on whether the user is stepping with the left or right foot.

The data gathered from the accelerometer was analysed to separate left and right foot steps. The vertical acceleration was used to delineate the steps with the lateral acceleration used to determine right and left foot steps. Using this method ensures that valid comparisons can be made between the one step-one cycle data and the one step-two cycle data. Figure 14 shows the distribution of tapping through the phase of the left and right foot steps. The first eight bins correspond to a left foot step, and the second eight bins to the right foot step. It can be seen from this figure that the tapping pattern for the two step per phase cycle data follows the one step per phase cycle data. There are distinct interactions visible between the tapping and the stepping in each step. The pattern for each step is consistent, with the peak tapping phase values occurring at around the foot down phase of the step for both left and right foot. There were no significant differences detected between the tap errors for left foot steps and right foot steps. The median magnitude of error for taps occurring during the left foot phase was 2.9 pixels compared to 2.8 pixels for taps during the right foot phase section. There were no significant differences with either the separated *x* error or the *y* error for taps during the left or right steps.

Walking Speed Analysis

Analysis of the participants'walking speed throughout the experiment showed that the step rate during the study was relatively consistent for all users. Figure 15 shows the estimated step rate for five typical participants over the duration of the study. The task chosen for the study was consistent throughout the task (tapping on a

Figure 14. Box plot visualising the distribution of tapping times. Median phase in which the user taps (split into 16 sections). Unlike Figure 10, one phase cycle includes both a left and a right step.



screen). The path that the participants traversed during the experiment was relatively quiet. There was therefore little reason for the participants to speed up or slow down their step rate. In other experiments where the path is more complex or the user must perform different tasks, we would expect the step rate to be more variable, but in this study, mean step rate might actually have been sufficient when analysing the effects of walking rate.

Other Analysis

The results presented so far have involved analysing the acceleration trace to extract information about the users' steps. Now we examine all disturbances affecting the device. If the device is moving around more, we would expect the user to be tapping less accurately. By looking at the magnitude of the of the acceleration trace in *x*, *y*, and *z* we gain an insight into the mean magnitude of disturbance that the device was going through. Figure 16 shows a scatter plot of the magnitude of the tap error plotted against the mean magnitude of the disturbance of the device for the one second previous to the tap. As the figure shows, in this instance there is no simple correlation between tap error and device acceleration.

Discussion

Using standard usability metrics, we were able to show that tapping accuracy was, unsurprisingly, typically greater when sitting still, rather than walking. However, the above results demonstrate the extra insights into user behaviour that were made possible by taking an instrumented usability approach.

Specific experimental observations of this instrumented usability approach are:

- Users' tapping time is significantly correlated with gait phase angle. Users were approximately 3 times more likely to tap at the most favoured tap phase than the least favoured tap phase.
- Users' tapping position accuracy is significantly higher (lower mean error and lower variability) at these preferred phase angles. Analysis of the timing data for the different phase regions showed that users subconsciously delayed their target selection in order to tap in one particular phase

Figure 15. The step rate of five typical participants for duration of the walking condition

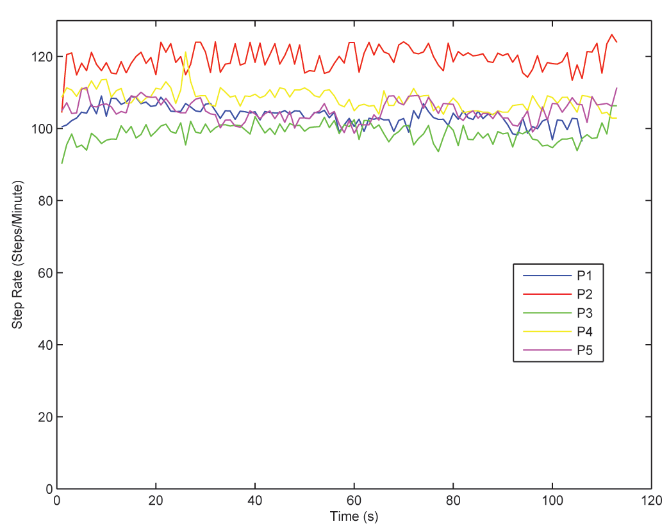
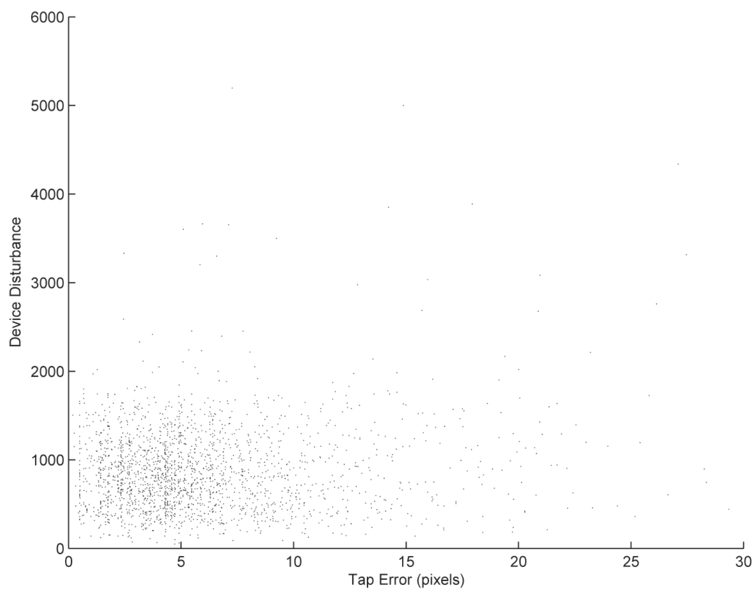


Figure 16. A scatter plot of the magnitude of the device disturbance plotted against the tap error in pixels



area rather than any other. There is further structure in the left step-right step tap density, error biases and variability, but even when averaged over all steps, the results are significant.

- The distribution of tapping errors varies both with phase of step, and between walking and sitting and across different screen positions.

It is interesting to note that although there is no simple correlation between tap error and device acceleration, the inferred phase angle, which is based solely on the acceleration observations, does show a strong link between acceleration and tapping accuracy, emphasizing the need for appropriate models in data analysis. One potential reason for this is that the walking route chosen for the study did not require the user to make irregular adjustments to their movements. The path was quiet so that the user only infrequently had to avoid objects. This limited the disturbance of the device to lower than might be expected in a more crowded environment, or in e.g. a moving vehicle. The participants grounded their tapping hand on the device while tapping, which minimised the effect of the external disturbance in this instance, so the main disturbance came from the gait cycle of walking itself.

CONCLUSION AND FUTURE WORK

This work has demonstrated that by making fine-grained observations from sensors during a usability study, that we can learn increased detail about the timing and error rates for users. Until now, linking the analysis of, for example walking behaviour, in a realistic setting would typically have required the use of hand scoring videotapes of users' actions—a time-consuming, and potentially subjective and error-prone approach which is also not open to online experimental control. Recent rapid developments in mobile device capacity, and compact sensors, coupled with the use of the analytic tools from synchronization theory, have opened up a new way of investigating gait effects in interaction. The inertial sensors monitor walking patterns throughout the experiment, and can potentially be used together with machine learning classification algorithms, during the experiment to control for experimental stimuli, and adapt the experimental situation online, providing a more stringent method of exploring mobile interaction.

The work opens new directions in both design and usability areas for future work. The specific results gained through the use of the accelerometer data for gait analysis allow us to explore new areas to inform mobile design. For example, one question raised from this study is—does designing an interface such that users tend to tap in preferred phase ranges lead to quantitatively better performance and qualitatively more pleasant user experience? Might it be better to delay user prompts until a particular phase region, in order to sustain rhythmic interaction? (See (Lantz & Murray-Smith, 2004) for a discussion of rhythmic interaction). This suggests experiments deliberately timing the presentation of prompts, or by using rhythmic vibrotactile or audio feedback in such a way that the user is pushed towards tapping in the specific phase regions. This sensor-conditional feedback can be generalised, such that specific interventions can be generated in usability experiments, with a frequency which is proportional to the probability of different contexts, allowing users to 'interact in the wild' while retaining an increased level of experimental control.

The effects of bias and correlation in tapping errors can be systematically compensated for in real time, improving the tapping accuracy. This information can also be used to automatically adapt screen layout to walking speed, simplifying and spreading out the targets as the speed increases.

Further to that, we have the opportunity to couple the more objective methods of measuring walking speed used in this article with the existing literature relating usability to the subjective use of Percentage Preferred Walking Speeds in, e.g. (Pirhonen, Brewster, & Holguin, 2002). For experimental environments that are more difficult for a user to navigate (such as crowded streets), these techniques could potentially provide more information about user disturbances and behaviour. The online recognition of context or situations could be used to have more targeted experiments in realistic environments, where a particular stimulus could be presented when the sensors recognise data compatible with a pre-specified situation.

The experiment described here specifically examines user performance when walking. However, the general approach is applicable to mobile usability studies in general as a method of gaining more information about the moment to moment actions of the user. Specifically, it allows us to gain greater insight into user actions in an uncontrolled environment allowing mobile usability tests to more easily take place in more realistic, less laboratory based circumstances. This work has relevance for tasks such as text entry or menu navigation in mobile settings. While this work was tap-based, similar features might be found in button-pressing, graffiti gestures or tilt-based interaction.

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REFERENCES

Barnard, L., Yi, J. S., Jacko, J. A., & Sears, A. (2005). An empirical comparison of use-in-motion evaluation scenarios for mobile computing devices. *International Journal of Human-Computer Studies*, *62*, 487–520. doi:10.1016/j.ijhcs.2004.12.002

Brewster, S. A. (2002). Overcoming the lack of screen space on mobile computers. *Personal and Ubiquitous Computing*, *6*(3), 188–205. doi:10.1007/s007790200019

Crossan, A., Murray-Smith, R., Brewster, S., Kelly, J., & Musizza, B. (2005). Gait phase effects in mobile interaction. In *Proceedings of ACM SIG CHI 2005* (pp. 1312-1315). Portland, OR.

Fishkin, K. P., Jiang, B., Philipose, M., & Roy, S. (2004). I sense a disturbance in the force: Unobtrusive detection of interactions with rfid-tagged objects. In *Proceeding of UBICOMP 2004* (pp. 268-282).

Gemmell, J., Williams, L., Wood, K., Lueder, R., & Bell, G. (2004). Passive capture and ensuing issues for a personal lifetime store. In *Proceeding of ACM CARPE 2004* (pp. 48-55).

Hinckley, K., Pierce, J., Horvitz, E., & Sinclair, M. (2005). Foreground and background interaction with sensor-enhanced mobile devices. *ACM Transactions on Computer-Human Interaction*, *12*(1), 31–52. doi:10.1145/1057237.1057240

Kern, N., & Schiele, B. (2003). Multi-sensor activity context detection for wearable computing. In *Proceedings of the European Symposium on Ambient Intelligence*, Eindhoven, The Netherlands.

Kjeldskov, J., & Stage, J. (2004). New techniques for usability evaluation of mobile systems. *International Journal of Human-Computer Studies*, *60*, 599–620. doi:10.1016/j.ijhcs.2003.11.001

Lantz, V., & Murray-Smith, R. (2004). Rhythmic interaction with a mobile device. In [Tampere, Finland: ACM.]. *Proceedings of NordiCHI*, *04*, 97–100. doi:10.1145/1028014.1028029

Mizobuchi, S., Chignell, M., & Newton, D. (2005). Mobile text entry: Relationship between walking speed and text input task difficulty. In *Proceedings of ACM MobileHCI'05* (pp. 122-128), ACM.

Morrison, A., Tennent, P., & Chalmers, M. (2006). Coordinated visualisation of video and system log data. In *Proceedings of the 4th International Conference on Coordinated and Multiple Views in Exploratory Visualization*, London (UK).

Morrison, A., Tennent, P., Williamson, J., & Chalmers, M. (2007). Using Location, Bearing and Motion Data to Filter Video and System Logs. In *Proceedings of the 5th International Conference on Pervasive Computing* (pp. 109-126), Toronto.

Oulasvirta, A., Tamminen, S., Roto, V., & Kuorelahti, J. (2005). Interaction in 4-second bursts: the fragmented nature of attentional resources in mobile HCI. In *Proceedings of ACM CHI 2005* (pp. 919-928), Portland, OR, ACM.

Petrie, H., Furner, S., & Strothotte, T. (1998). Design lifecycles and wearable computers for users with disabilities. In *Proceedings of the First workshop on human-computer interaction with mobile devices*, Glasgow, UK.

Pikovsky, A., Rosenblum, M., & Kurths, J. (2001). *Synchronization: A universal concept in nonlinear sciences*. Cambridge University Press. doi:10.1017/CBO9780511755743

Pirhonen, A., Brewster, S. A., & Holguin, C. (2002). Gestural and Audio Metaphors as a Means of Control for Mobile Devices. In *Proceedings of ACM CHI 2002* (pp. 291-298), Minneapolis, MN: ACM Press Addison Wesley.

Roto, V., Oulasvirta, A., Haikarainene, T., Kuorelahti, J., Lehmuskallio, H., & Nyyssönen, T. (2004). *Examining mobile phone use in the wild with Quasi-experimentation* (Tech. Rep. 2004-1). Helsinki Institute for Information Technology, Finland.

Williamson, J., Murray-Smith, R., & Hughes, S. (2007). Shoogle: Multimodal Excitatory Interaction on Mobile Devices. In *Proceedings of ACM CHI 2007*, San Jose.

Yi, J. S., Choi, Y. S., Jacko, J. A., & Sears, A. (2005). Context awareness via a single device-attached accelerometer during mobile computing. In *Proceedings of ACM Mobile HCI 2005* (pp. 303-306).

Chapter 2
Appropriating Heuristic Evaluation for Mobile Computing

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ABSTRACT

Heuristic evaluation has proven popular for desktop and web interfaces, both in practical design and as a research topic. Compared to full user studies, heuristic evaluation can be highly cost-effective, allowing a large proportion of usability flaws to be detected ahead of full development with limited resource investment. Mobile computing shares many usability issues with more conventional interfaces. However, it also poses particular problems for usability evaluation related to aspects such as limited screen real estate, intermittent user attention, and contextual factors. This article describes a modified collection of usability heuristics that are designed to be appropriate for evaluation in mobile computing. They have been systematically derived from extensive literature and empirically validated. They therefore offer a sound basis for heuristic-based evaluation in mobile computing. Besides introducing the reader to the practical use of heuristic evaluation, the article also closes with a description of potential future research in the area.

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INTRODUCTION

Expert-based evaluation techniques, such as heuristic inspection (Nielsen et al., 1990) and cognitive walkthrough (Wharton et al., 1994) typically benefit from providing evaluators with guidance (for instance, a set of heuristics or a checklist) for identifying a prioritized list of usability flaws (Kjeldskov et al., 2005). Expert-based evaluation techniques are also well-known methods that can realize a relatively quick and easy evaluation.

According to Po (2003), mobile computing devices are typically 'smart products' or 'information appliances', and are generally consumer products. Their users are thus a 'heterogeneous group' (Sade et al., 2002) and so it may be more difficult to find suitable surrogate users for user-based testing in mobile computing (Po, 2003). Po further observes that even if appropriate surrogate users were found, the realistic re-creation of the user context in laboratories would be challenging because of user mobility, which makes observation and video recording difficult (Vetere et al., 2003). "Given the problems associated with user-based evaluations of mobile devices, expert-based usability techniques are considered to be more appropriate" (Po, 2003). However, it is worth noting that expert-based techniques have in the past been criticized for finding proportionately fewer problems in total, and disproportionately more cosmetic problems (Karat et al., 1992). In mobile computing the capacity of expert-based techniques to adequately capture the multiple contextual factors that affect user–system interactions in real settings has been questioned (for instance: Kjeldskov et al., 2003; Johnson, 1998).

We believe that heuristic evaluation can be enriched and adapted toward capturing contextual factors. This article describes how standard heuristic evaluation can be made more appropriate/relevant for mobile computing. In particular, the article describes a modified collection of usability heuristics that are designed to be appropriate for this area. The heuristics have been systematically derived from extensive literature and empirically validated, and so offer a sound basis for heuristic-based evaluation of mobile computing. As well as introducing the reader to the practical use of heuristic evaluation, the article also describes potential future research in the area.

This work has been carried out in the context of MAIS[1], a project whose research goal is to provide a flexible environment to adapt the interaction, and the information and services provided, according to ever changing requirements, execution contexts, and user needs.

The rest of the article is organized as follows: Section 2 highlights some of the challenges posed by mobile devices, applications and context; Section 3 discusses the standard heuristic evaluation method; Section 4 describes the methodology we adopted to appropriate heuristic evaluation for mobile computing and the results that we obtained; Section 5 contains reflections regarding this research activity; and Section 6 concludes the article and highlights some future work.

Our focus in this article is on usability problems in mobile devices and a discussion of their sources. However, this should be set against a broader view of the fantastic world of new opportunities, advantages, and benefits that mobile devices and contexts bring. While we will not touch explicitly on this again, the article should be read in the light that the problems and limitations are ones worth tackling because of the opportunities offered by the technology.

Mobile Devices, Applications, and their Context

In order to better understand how usability in mobile computing can be evaluated and improved, it is useful to outline specific limitations inherent in mobile devices, applications and their context. These fall into two broad categories: limitations due to the nature of the devices themselves, and limitations due to context of use and style of interaction.

Limits Posed by the Device

- **Small-screen:** In order to be portable, mobiles must necessarily be small, and tend to have small screens, therefore problems due to the screen real estate are intrinsic and can be addressed only by figuring out new techniques to organize information visually.
- **Limited input:** Because of device format, input mechanisms are inherently limited. Currently the most common means of interaction are: numeric keypads, which are used in almost all cell phones; and styluses, which are the primary input means in PDAs and smart phones.
- **Limited bandwidth and cost:** Mobile Internet connections are still slow. This is in fact still one of the main factors limiting mobile Internet access. To this we must also add the problem of the cost model. Most companies offer their Internet access in a pay per KByte policy that obviously limits the size of pages and the number of requests.
- **Limited connectivity:** Perhaps more than bandwidth, the latency of the connection affects its usability. The limited coverage of different networks and the consequent intermittent connection makes the latency extremely variable, as well as giving rise to problems of how to portray these hidden network properties to the user. There is also the problem of seamlessly switching between different types of network, e.g. WiFi to GPRS.
- **Limited computational resources:** This means the capabilities of applications are limited. However, this should be overcome in the near future as new processors and memories specifically designed for mobile devices increase their quality and speed.
- **Limited power (batteries):** This is often an underestimated issue, but the batteries are still a big problem for every kind of mobile system (laptops included). This has a big impact on end users: limited autonomy means limited availability, which in turn means limited reliability.
- **Wide heterogeneity (of OSs and physical properties):** Users of mobile systems must always adapt to new forms of interaction as they switch to different mobiles. Changing the physical device and operating system usually translates into the need to re-learn functions, operations, messages, etc., with an enormous waste of resources.

Limits Posed by Context and Interaction

- **Variable context:** Since mobile devices, by definition, are mobile, the context in which they are used is continually changing. This poses challenging new issues because, though context has always been considered a fundamental aspect to analyse in usability studies, only now must we address such frequent and complex context variations within the same device, application, or single user.
- **Kind of interaction:** The nature of interaction also changes in mobile settings. In general, users tend to interact in small and focused chunks of activities, more so than in fixed settings. A high proportion of tasks in a mobile environment consist of a few fast steps that the user should be able to execute without cognitive effort. In addition, mobile tasks may happen in conditions where users' attention is necessarily reduced, or may be part of more complex activities with which they should not interfere.
- **Interruptions:** Mobile devices/applications are always "with us". If this, on one hand, means that computation and data are always available, it is also true that notifica-

tions and requests for attention can happen at inappropriate moments and that some tasks may be interrupted. This raises two kinds of problem: appropriateness of notifications and recovery from interruptions.

- **Privacy and security:** Privacy issues become more prominent. While staying mobile, users find themselves in a variety of spaces (private and public), in a variety of situations (formal and informal), and in a variety of infrastructures (wireless and cable connection). Moving through these settings means having different needs for privacy and security.
- **Intimacy and availability:** Because mobile devices are mobile, they are personally available in a way that fixed devices are not. Moreover, they seem to engender a sense of being "personal" in a deeper sense than desktop PCs (e.g., not just my PC but *my* PDA and definitely *my* phone).

HEURISTIC EVALUATION

Introduction to Heuristic Evaluation

Heuristic evaluation (Nielsen et al., 1990; Nielsen, 1994b) is an inspection usability evaluation method. In heuristic evaluation, experts scrutinize the interface and its elements against established design rules. The experts should have some background knowledge or experience in HCI design and usability evaluation. Three to five experts are considered to be sufficient to detect most of the usability problems. The enlisted experts individually evaluate the system/prototype under consideration. They assess the user interface as a whole and also the individual user interface elements. The assessment is performed with reference to some usability heuristics. When all the experts are through with the assessment, they come together and compare and appropriately aggregate their findings. In Molich et al. (1990) and Nielsen et al. (1990) Rolf Molich and Jakob Nielsen initially proposed a set of usability heuristics for the design of user interfaces. Aiming to maximize the explanatory power of the heuristics, Nielsen later refined them (Nielsen, 1994b), thereby deriving the following set:

1. **Visibility of system status:** The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
2. **Match between system and the real world:** The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
3. **User control and freedom:** Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.
4. **Consistency and standards:** Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.
5. **Error prevention:** Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
6. **Recognition rather than recall:** Make objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.
7. **Flexibility and efficiency of use:** Accelerators—unseen by the novice user—

may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.

8. **Aesthetic and minimalist design:** Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.
9. **Help users recognize, diagnose, and recover from errors**: Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
10. **Help and documentation:** Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

Strengths of Heuristic Evaluation

Here are some strengths of heuristic evaluation:

- Its ease of implementation and high efficiency (Law et al., 2002; Nielsen, 1994b). It is considered to have a good success rate in that typically only 3–5 usability experts are needed to detect most (75–80%) of the usability flaws a system presents (Nielsen, 1994b).
- Its early applicability in the development lifecycle and low cost: it requires neither a working prototype nor the real users (Nielsen, 1994b).
- It is becoming part of the standard HCI curriculum and therefore known to many HCI practitioners (Greenberg et al., 1999.). The heuristics are well documented and therefore easy to learn and put to use, so it may be argued that heuristic evaluation can also be effectively conducted by non-usability experts (Nielsen, 1994b).

On the whole, heuristic evaluation is considered to be a cost-effective evaluation method. Its main strengths lie in providing discovery and analysis resources (Cockton et al., 2003), such as domain and system knowledge, where it generally outperforms other popular inspection techniques like guideline-based methods or cognitive walkthrough (Wharton et al., 1994).

Limitations of Heuristic Evaluation

Here are some specific limitations of heuristic evaluation:

- Heuristic evaluation is highly dependent on the skills and experience of the specific usability expert(s) involved. At a high level of generality, the heuristics are "motherhood statements that serve only to guide the inspection rather than prescribe it" (Greenberg et al., 1999).
- Participants are not the real users. Regardless of the experts' skills and experience, they are still "surrogate users" (i.e. experts who emulate real users) (Kantner et al., 1997), therefore the resulting data are not really representative of the real users.
- Heuristic evaluation does not fully capture or take into account the context of use of the system under evaluation but rather evaluates it "as a relatively self-contained object" (Muller et al., 1995).
- It has been said that the majority of usability flaws detected by heuristic evaluation are 'minor' usability problems (for instance, by Nielsen (1994a)), or false positives, problems that do not negatively impact user performance or users' perception of system quality (Simeral and Russell, 1997).

When compared to other expert techniques, such as guideline-based methods and cognitive walkthrough, heuristic evaluation is strong in terms of thoroughness (percentage of problems found), but weak in terms of efficiency (number of true positives vs. false positives) and, like other inspection methods, is vulnerable to expert biases (Cockton et al., 2003).

APPROPRIATING USABILITY HEURISTICS

Analyses of heuristic evaluation (HE) have shown that it is more likely for this method to miss relevant usability problems when the system to be evaluated is highly domain-dependent, and when evaluators have little domain expertise[2]. To overcome these limitations of the method when applied to mobile systems and settings, we have conducted an in-depth investigation of usability issues affecting mobile applications. The work leading to the set of specialized heuristics for mobile computing presented in the section entitled *Methodology for Realizing Mobile Heuristics* is based on this empirical evidence. The goal of the mobile heuristics described in that section is to better support and contribute to the domain expertise of evaluators applying HE to mobile computing.

Methodology for Realizing Mobile Issues

To develop usability heuristics for mobile computing, three authors of this article worked as usability researchers at the following activities:

1. Each of the three was assigned a unique set of papers to analyze independently. The papers originated from the list used in Kjeldskov et al. (2003); a recent meta-analysis of HCI research methods in mobile HCI[3]. We updated the list with papers published in the period 2004–2005 and selected only those with elements of evaluation. The analysis entailed documenting, for each of the papers, appropriate values for the following dimensions:
   - **Evaluation goal:** is the evaluation mainly intended to demonstrate whether one technique is better than another, that is, a comparative study; or is it mainly exploratory, that is, understanding what kind of usability problems may rise with a given design.
   - **Evaluation method:** is the evaluation method expert-based (made by experts through inspection), user-based (observing users performing tasks), or model-based (computing usability metrics through formal models).
   - **Evaluation setting:** is the evaluation conducted in a laboratory (or any other controlled setting) or in the field.
   - **Real device/emulator:** is the application under inspection tested with a real device or in a emulated environment.
   - **Location matters:** does the application take location into account or not. Moreover, each of the usability researchers individually documented mobile usability issues that were indicated by (or evident from) each of the papers. At the end of this process, three different lists of usability issues were produced, containing the analysis of all the papers collected in the first phase.
2. In the next step, the usability researchers came together and consolidated their individual realizations. Individual findings had to be cross-checked and merged into a single consolidated list. This was done in the form of a spreadsheet.
3. Each researcher was then given the same realized list of mobile usability issues and

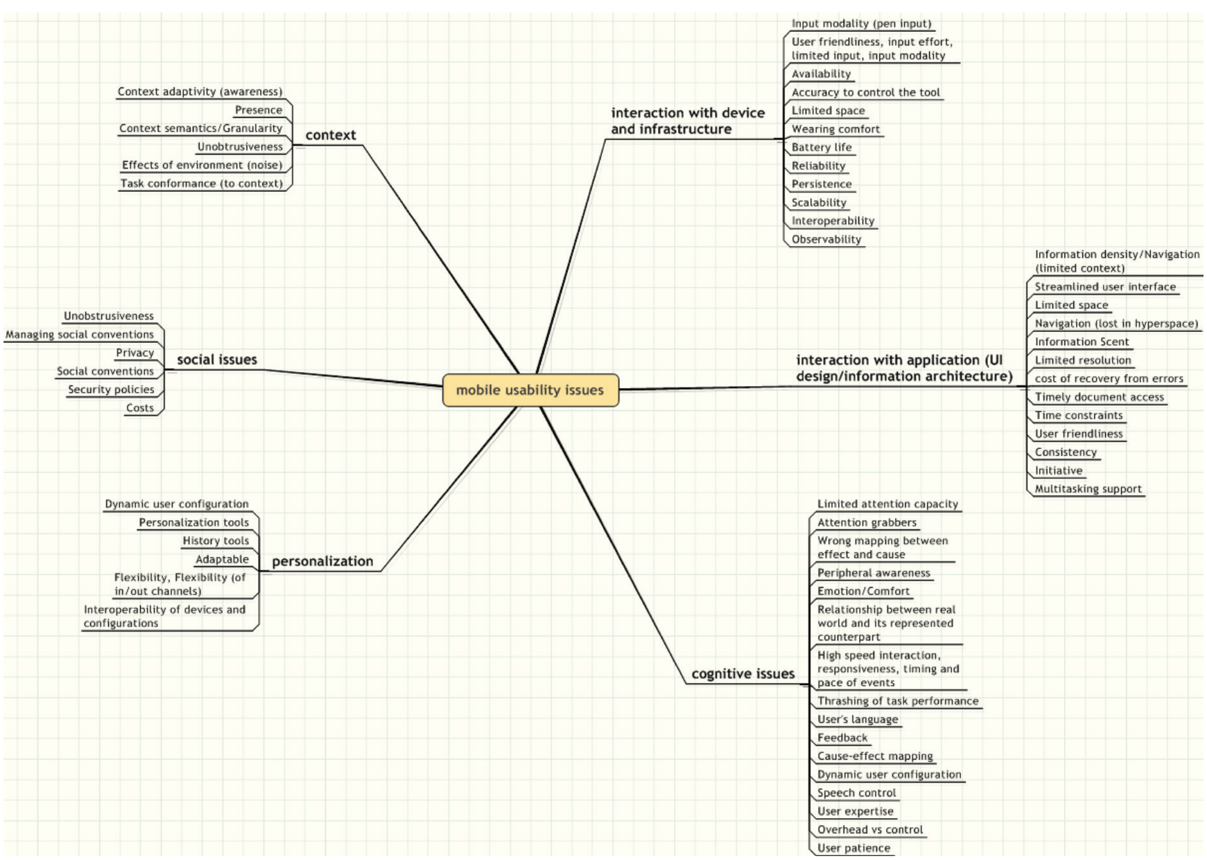
asked to independently categorize (group or cluster) the issues. The idea was to find a way to summarize all the encountered issues and present them at a higher level of abstraction. On reflection, this was useful to check whether traditional heuristics covered each class of usability problems, or not. The researchers then presented and shared their individual categorization results with each other. Each researcher was requested to individually work further on his/her categorization with reference to the other categorizations, by eliminating redundant usability issues, clarifying the mobile usability issues, and grouping the obtained issues to an abstraction level that would be appropriate for developing/generating heuristics. Finally, they came together again to brainstorm and consolidate their work, and to harmonize the terminology used to describe the issues. Figure 1 shows an image of the set of issues produced. Here we present the top-level classes of problems with examples of subclasses to make their meaning clear.

Mobile Usability Issues

Below we describe the usability issues collected and grouped in high-level classes as described in the previous section.

- **Interaction with device and infrastructure:** many of the problems we have found in our research have a strong connection with the limits of the device and/or the infrastructure it is connected to.

Figure 1. Mobile usability issues



- **Interaction with application:** this collects classes of problems connected to traditional screen design and information architecture.
- **Cognitive issues:** here we characterize usability problems stemming from an overload of cognitive resources or a mismatch between a cognitive model and reality. While this aspect has always been taken into account in traditional studies, in mobile settings it becomes more evident and presents new challenges.
- **Personalization:** standard heuristics tend to overlook problems connected to personalization or adaptation. While in standard settings this issue can be considered minor with respect to others, with mobile devices this aspect can really be critical.
- **Social issues:** mobile devices and applications are used in a wide spectrum of environments and social conditions: private or public, alone or in groups, etc. This means that the social impact of adopted design solutions cannot be underestimated. Issues like privacy, security, user image, and social conventions thus become of great importance.
- **Context:** similarly to social issues, it is necessary to take into account how the environment can affect interaction. Not only do social conventions and relationships with people matter, but also how potential physical environment features affect the design of an interface.

Methodology for Realizing Mobile Heuristics

This section discusses our research toward developing a set of mobile usability heuristics and also our efforts toward assessing the proposed mobile usability heuristics.

Toward a Set of Heuristics

The brainstorming activity described in the previous section was continued and further articulated in a series of new individual or collaborative tasks aimed at developing a set of heuristics for mobile computing evaluations. By capitalizing on the outcome of our previous analysis of mobile usability issues, we decided to rely on the following developmental process to come up with a new set of heuristics, better suited to be applied to mobile evaluation settings.

Phase 1

Each of the 3 usability researchers was provided with a table reporting Nielsen's traditional heuristics (Nielsen, 1994b) together with their corresponding definitions. Each researcher worked individually at assessing: which of Nielsen's heuristics were considered irrelevant for mobile settings; which of Nielsen's heuristics were relevant, but needed some revision or modification; and which additional heuristics needed to be included in the original set to cover relevant aspects of mobile applications. To better steer our individual relevance judgment of the heuristics, we thought it useful to define a guiding principle to be adopted and shared during the assessment work: this was a concise answer to the question: "What are the primary goals of mobile applications?", which we expressed as follows: "To enable a user-friendly navigation of relevant information or features in mobile conditions of use". The assessment and brainstorming activity performed in this phase was also informed by the consolidated version of the mobile usability issues that had been previously realized (see section entitled *Methodology for Realizing Mobile Issues*).

Phase 2

Each of the usability researchers compared her/his own table of proposed heuristics with that of another researcher, to produce a new consolidated table. This activity was meant to be carried out individually, but based on comparing the work done by two researchers. The aim was to speed up the improvement of the set of heuristics proposed, in terms of their clarity and relevance to the mobile application field.

Phase 3

A new refinement process was started on the set of heuristics included in the three consolidated tables produced in phase 2. It involved: first, a discussion meeting among the usability researchers to arrive at a shared table consolidated from the three developed in phase 2; then, submitting this set of heuristics (with their definitions) to a number of targeted HCI researchers and professionals in the mobile computing and usability community, to elicit feedback on the adequacy of the heuristics proposed. We contacted 19 experts, in person, by email or by phone, and we received feedback from 8 of them. The 3 researchers then met to discuss and compare the experts' comments with the researchers' consolidated table, and arrived at the final set of mobile usability heuristics summarized in Table 1 and described below:

- **Heuristic 1:** Visibility of system status and losability/findability of the mobile device: Through the mobile device, the system should always keep users informed about what is going on. Moreover, the system should prioritize messages regarding critical and contextual information such as battery status, network status, environmental conditions, etc. Since mobile devices often get lost, adequate measures such as encryption of data should be taken to minimize loss. If the device is misplaced, the device, system or application should make it easy to recover it.
- **Heuristic 2:** Match between system and the real world: Enable the mobile user to interpret the information provided correctly, by making it appear in a natural and logical order; whenever possible, the system should have the capability to sense its environment and adapt the presentation of information accordingly.
- **Heuristic 3:** Consistency and mapping: The user's conceptual model of the possible function/interaction with the mobile device or system should be consistent with the context. It is especially crucial that there be a consistent mapping between user actions/interactions (on the device buttons and controls) and the corresponding real tasks (e.g. navigation in the real world).
- **Heuristic 4:** Good ergonomics and minimalist design: Mobile devices should be easy and comfortable to hold/carry along as well as robust to damage (from environmental agents). Also, since screen real estate is a scarce resource, use it with parsimony. Dialogues should not contain information that is irrelevant or rarely needed.
- **Heuristic 5:** Ease of input, screen readability and glancability: Mobile systems should provide easy ways to input data, possibly reducing or avoiding the need for the user to use both hands. Screen content should be easy to read and navigate through notwithstanding different light conditions. Ideally, the mobile user should be able to quickly get the crucial information from the system by glancing at it.

Table 1. Number of usability problems identified

	Appl. 1	Appl. 2	Total	Mean (SD)
NHE	22	28	**50**	**12.5 (10.40)**
MHE	26	38	**64**	**16 (3.74)**

- **Heuristic 6:** Flexibility, efficiency of use and personalization: Allow mobile users to tailor/personalize frequent actions, as well as to dynamically configure the system according to contextual needs. Whenever possible, the system should support and suggest system-based customization if such would be crucial or beneficial.
- **Heuristic 7:** Aesthetic, privacy and social conventions: Take aesthetic and emotional aspects of the mobile device and system use into account. Make sure that users' data is kept private and safe. Mobile interaction with the system should be comfortable and respectful of social conventions.
- **Heuristic 8:** Realistic error management: Shield mobile users from errors. When an error occurs, help users to recognize, to diagnose, if possible to recover from the error. Mobile computing error messages should be plain and precise. Constructively suggest a solution (which could also include hints, appropriate FAQs, etc). If there is no solution to the error or if the error would have negligible effect, enable the user to gracefully cope with the error.

Assessing Heuristics Performance

To investigate the potential benefits of applying our set of heuristics for the evaluation of mobile applications, we devised and conducted an experimental study aimed at comparing the support provided by our new set of mobile heuristics vs. standard usability heuristics (here Nielsen's heuristics) to experts performing heuristic evaluation of mobile applications.

Experimental Design

Here we describe various parameters pertaining to the set-up or design of the experimental study.

Participants and Materials

The study enlisted 8 usability experts[4], as participants, to perform a HE of two mobile applications for which we had already identified a number of usability flaws. The two criteria we used to select the applications to test were: being a typical application whose problems are known and evident; application whose tasks are simple and/or self-evident. After searching for applications fulfilling the foregoing conditions, we chose the following two applications: Appl.1) a mobile device application in which location matters or that primarily relies on mobility: we considered a PDA-based supermarket application; Appl.2) a mobile device application in which interface navigation is key: we considered a web-based freeware email application for PDAs[5]. We also prepared the following materials for the evaluators: consent form, demographics questionnaire, post-evaluation form for participant's comments (to be filled out by the study moderator), a set of Nielsen's 10 usability heuristics, our proposed set of mobile usability heuristics (Figure 2), and Nielsen's five-point Severity Ranking Scale (SRS) (Nielsen, 1994b) (which is described in Figure 3).

Experimental Conditions

The experiment had the following two experimental conditions:

- **Condition 1:** N. 4 experts individually performed the HE by applying Nielsen's standard set of heuristics and Nielsen's SRS to both applications.
- **Condition 2:** N. 4 experts individually performed the HE by applying our set of mobile heuristics and Nielsen's SRS to both applications.

Figure 2. Mobile usability heuristics

Mobile Heuristic	Description
Heuristic 1	Visibility of system status and losability/findability of the mobile device
Heuristic 2	Match between system and the real world
Heuristic 3	Consistency and mapping
Heuristic 4	Good ergonomics and minimalist design
Heuristic 5	Ease of input, screen readability and glancability
Heuristic 6	Flexibility, efficiency of use and personalization
Heuristic 7	Aesthetic, privacy and social conventions
Heuristic 8	Realistic error management

Figure 3. Severity ranking scale (SRS)

Rating	*Description*
0	I don't agree that this is a usability problem at all
1	Cosmetic problem only. Need not be fixed unless extra time is available on project
2	Minor usability problem. Fixing this should be given low priority
3	Major usability problem. Important to fix, so should be given high Priority
4	Usability catastrophes. Imperative to fix this before product can be released

Procedure

The 8 usability experts were randomly split into two groups, each assigned to one of the foregoing two experimental conditions (that is a between-subjects design). They all had previous expertise in the HCI evaluation field and were familiar with both the application of traditional HE methods and the use of mobile applications. Nevertheless, they were all given some brief instruction on the technique before starting the evaluation. The following protocol was used for both experimental conditions:

- **Pre-evaluation session:** This entailed first welcoming and greeting each evaluator. After that the goals of the study, the testing procedures, and the confidentiality issues were explained in detail. Scripts were prepared in advance and used for each usability evaluator to ensure consistency across experts and conditions. In a demographics questionnaire experts were asked about their level of education/academic status, relevant experience in both HCI and mobile computing, experience in using both a PDA and Nielsen's heuristic evaluation method; the collected demographic data can be seen in Figure 4. Most of the participants have a high level of education and an average knowledge of HCI and mobile devices. Six participants consider themselves almost knowledgeable about heuristic evaluation, while two give themselves an average rating. A training session was conducted with each evaluator to ensure that they fully understood the usability heuristics, and especially the mobile heuristics, which the participants were not familiar with; this involved the facilitator stepping through each usability heuristic and inviting the evaluators to ask questions in order to clarify the meaning of each heuristic and their understanding of the overall process.
- **Evaluation session:** The usability evaluators performed the usability evaluation on

Table 2. Actual number of flaws and severity

	NHE			MHE		
	Appl. 1	**Appl. 2**	**Mean % for both appl.s**	**Appl. 1**	**Appl. 2**	**Mean % for both appl.s**
Cosmetic	5	7	6	5	5.75	5.375
Minor	5.5	6.5	6	11	13.25	12.125
Major	6.5	6.5	6.5	9	10.25	9.625
Catastrophe	5	8	6.5	1	8.75	4.875
Total of flaws	**22**	**28**		**26**	**38**	

the mobile device by identifying usability problems and prioritizing them according to Nielsen's SRS (Table 2). Presentation of the two applications to be evaluated was counterbalanced to avoid any order effect. While evaluating the mobile device, each usability evaluator was asked to 'think aloud' to explain what s/he was trying to do and to describe why s/he was taking the action. Their comments were recorded by one of the evaluation moderators.

- **Debriefing session:** This focused on the evaluators' experiences of the process, and providing an opportunity to probe where behavior was implicit or puzzling to the researchers.

Data Analysis

The data collected were analyzed both qualitatively and quantitatively. Comparison of HE effectiveness in the 2 experimental conditions was assessed.

Number of Flaws and Variation among Experts

From Table 1, it appears that the use of the mobile heuristics has increased the number of flaws identified in the analysis of both applications, and has reduced variation among experts' analyses. In comparing the type of flaws detected by using the two different sets of heuristics, we did not find evidence of problems identified only by using Nielsen's heuristics. The additional flaws found by applying mobile heuristics were usually different from the ones identified by using Nielsen's heuristics; also, the problems identified by each expert in the mobile heuristics condition were a small number from a larger set of usability difficulties presented by the two applications, although we could find some overlaps (problems pointed out by more than one expert), which supports the idea of inter-expert consistency when applying mobile heuristics.

Severity of Flaws and Distribution

As depicted by Table 2 and Figure 5, Nielsen's heuristics have produced a more equally distributed severity ranking of problems detected for both applications. On the other hand, the mobile heuristics have produced a more positive evaluation of Appl.1 (61% of problems are considered minor or cosmetic) while for Appl.2 the ranking seems to be equally distributed among the four severity levels. Considering the mean values in Figure 5, it does appear that Nielsen's heuristics identify fewer Minor and Major flaws compared to the mobile heuristics. It also seems that Nielsen's heuristics have a relatively even distribution of severity ranking for the problems identified. Nielsen's heuristics could therefore do a moderate job of identifying flaws at any design level. The mobile heuristics do seem to be especially good at identifying Minor and Major flaws rather than those at the extremes.

Figure 4. Participants' demographics. Each value is ranked on a scale between 1 (min) and 4 (max)

Part.	Edu	HCI	PDAs	HE
p1	1	2	3	3
p2	4	2	2	3
p3	4	3	3	3
p4	1	2	2	3
p5	3	3	3	3
p6	2	2	1	2
p7	3	3	2	3
p8	1	1	1	2

Figure 5. Actual number of flaws, severity and distribution

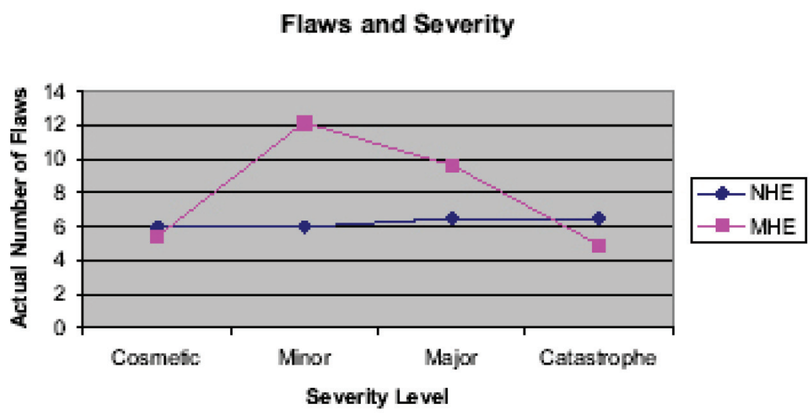


Figure 6 can be used for further analysis of how the specific heuristics from both sets fare with regard to average severity and average number of flaws. Figure 6 indicates that mobile heuristics are more effective in supporting the detection of flaws, while Nielsen's heuristics seem better suited to cover the case in which high severity flaws are present; also, mobile heuristics seem to support a more detailed evaluation of the mobile application (without considering the flaws classified as catastrophic). It is worth noting that some of the foregoing observations from Figure 6 are similar to those from Figure 5.

So far it might be observed that the mobile heuristics produce a more accurate evaluation in terms of number of problems detected (more flaws are identified), reduced variation among experts' analyses, and problems' severity ranking (this is actually also supported by the qualitative data collected during the evaluation, where most experts said that Appl.1 was much better designed for a mobile use when compared to Appl.2). Thus the mobile heuristics tend to focus the evaluation on the mobile issues instead of directing experts' attention at a more general level (although the kind of setting we used in this study promoted an evaluation of applications that was more functionalities-based than contextual). Moreover, the mobile heuristics could be applied when/where the extreme flaws have been addressed or are not an issue in the design. If such flaws have to be identified before proceeding, mobile heuristics

Figure 6. Comparison of the sets of heuristics: flaws and severity

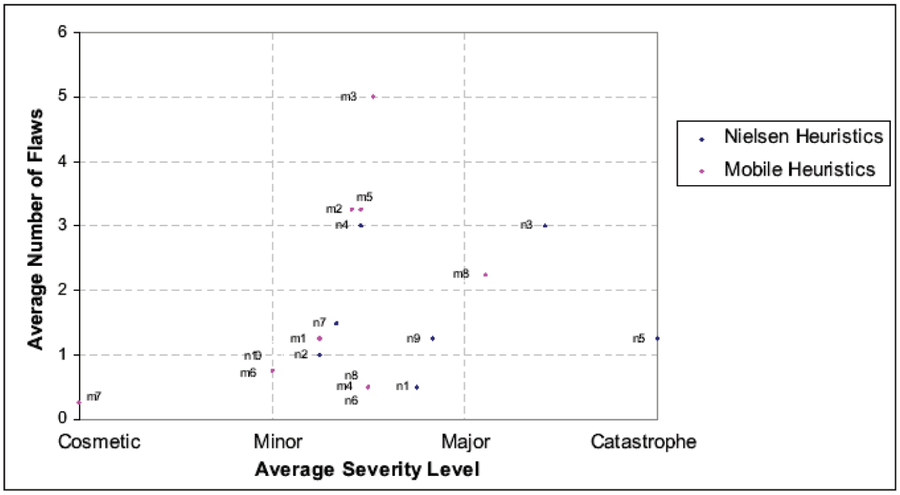


Table 3. Nielsen's heuristics and corresponding usability problems

Nielsen's Heuristics 1-10	Number of Usability Problems	Description of Heuristic
4	12	Consistency and standards
3	12	User control and freedom
7	6	Flexibility and efficiency of use
9	5	Help users recognize, diagnose, and recover from errors
5	5	Error prevention
2	4	Match between system and the real world
10	3	Help and documentation
1	2	Visibility of system status
6	2	Recognition rather than recall
8	2	Aesthetic and minimalist design

could be applied after Nielsen's heuristics. It is worth recalling that there are some problems that Nielsen's heuristics failed to identify (based on Table 1). Some might now be identified by mobile heuristics and might lie between Minor and Major severity levels (Table 2 and Figure 4).

Usability Flaws and Heuristics

As seen in Table 3 and Table 4, the most frequently used/highlighted heuristics in the mobile applications are as follows[6]:

- Nielsen's heuristics: Nielsen's heuristic 4 (12 times), Nielsen's heuristic 3 (12 times). The foregoing are [each] less than any of the following mobile heuristics.
- Mobile heuristics: mobile heuristic 3 (20 times), mobile heuristic 5 (13 times), mobile heuristic 2 (13 times).

It is interesting to observe that these highlighted Nielsen's heuristics (4 [Consistency and standards], 3 [User control and freedom]) are related to the highlighted mobile heuristics (3

Table 4. Mobile heuristics and corresponding usability problems

Mobile Heuristics 1-8	Number of Usability Problems	Description of Heuristic
3	20	Consistency and mapping
5	13	Ease of input, screen readability and glancability
2	13	Match between system and the real world
8	9	Realistic error management
1	5	Visibility of system status and losability/findability of the mobile device
6	3	Flexibility, efficiency of use and personalization
4	2	Good ergonomics and minimalist design
7	1	Aesthetic, privacy and social conventions

[Consistency and mapping], 5 [Ease of input, screen readability and glancability], 2 [Match between system and the real world]). We could consider the highlighted Nielsen's and mobile heuristics as being those most violated or most noticed, although their recurrence could be due to the particular type of evaluation/application(s) that were provided to experts.

The mobile heuristics probably scored such high figures (i.e. were able to identify more flaws under these related heuristics) because of the way the mobile heuristics have been revised and/or extended to capture mobile computing aspects.

It is interesting to note that the mobile heuristics "bring to the top" heuristics that are related to context. For instance: Nielsen's heuristic 2 has a score of 4; the related revised heuristic for mobile computing (mobile heuristic 2) scores 13. It may therefore be observed that the mobile heuristics make issues and flaws that have to do with context more apparent during the evaluation. Also, from our qualitative analysis of experts' reports it was found that when the evaluator identified a flaw that could not be straightforwardly mapped to a specific mobile heuristic, s/he chose to assign it to mobile heuristic 2 or 3. Moreover, an evaluator stressed the need to make more explicit the word 'context' in the description of mobile heuristic 3. The description of the heuristic is found in the section entitled *Methodology for Realizing Mobile Heuristics*.

As seen in Table 3, the participants reported some usability problems regarding 'Help and documentation' (Nielsen's heuristic 10). This observation may be an indication that people using mobile applications still expect such applications to provide help. Though they might prefer that the help be 'interactive', non-distractive, not be a separate task, etc., the designer could consider the use of audio or some 'light-weight' approach (e.g. FAQs).

Time Taken to Evaluate

It seems that the application of the mobile heuristics was more time demanding during the whole evaluation, as seen in Table 5. This may be due to the experts' relative unfamiliarity with these heuristics compared to Nielsen's heuristics. We tried to reduce this familiarity issue (it cannot be eliminated simply in an evaluation session) by giving the experts who were using the mobile heuristics some extra time at the beginning of the evaluation to study the mobile heuristics, in order to familiarize themselves with them and to ask questions. Although the application of the mobile heuristics was more time demanding, we should, however, also observe that variation among experts was relatively high, confirming

Table 5. Time taken in minutes

	Appl. 1	Appl. 2	Total	Mean (SD)
NHE	106	92	**198**	**49.5 (27.196)**
MHE	155	136	**291**	**72.75 (44.776)**

that heuristic evaluation is an evaluation technique strongly dependent on experts' previous knowledge and expertise with the heuristics, the application domain, etc.

As a general observation, it is worth mentioning that because our study adopted a between-subjects design, with the inherent risk that individual differences between participants can bias results, the fact that the application of mobile heuristics results in reduced variation among the participants' analyses is therefore notable.

Reflections toward Deeper Principles

Many of the heuristics in 'traditional' Heuristic Evaluation appear to be phrased in a way that is general over all systems, and this is true also of many of the other forms of design guidelines or principles used in interaction design. This raises a number of questions:

1. Why do we need specific heuristics for mobile devices - why not use standard ones?

If (as this article assumes) we do need them, then this raises further questions.

2. How do we know the heuristics we have presented are correct?
3. How do we know they are sufficient or complete?
4. How do we know they work in real design?
5. Can we assess their scope—do our heuristics simply reflect current mobile technology and applications?

The answer to (i) is that we do need specific heuristics because the traditional heuristics implicitly embody assumptions about static desktop location and use. The differences between standard heuristics and the mobile usability heuristics presented in the section entitled *Toward a Set of Heuristics* are precisely due to the differences between mobile and fixed use.

Our confidence on the correctness (ii) and sufficiency (iii) is based on the rigorous methodology used to derive the heuristics, distilling the knowledge and expertise in published work (section entitled *Methodology for Realizing Mobile Issues*), more analytic refinement of established heuristics (*Toward a Set of Heuristics*, phase 1) and review by experts (*Toward a Set of Heuristics*, phase 3). The feedback from experts gives some confidence in utility (iv), and this was confirmed by the empirical study (section entitled *Assessing Heuristic Performance*), which also bolstered confidence in the correctness and sufficiency.

No set of heuristics or guidelines will be complete, but it can be sufficient to cover the more common or serious pitfalls. However, while the process of distillation from expert opinion and empirical testing suggests that the heuristics are sufficient for current mobile applications, on their own they do not tell us about applicability in the future (v). Mobile technology is changing rapidly and new applications are emerging. While it would be foolish to believe that we can foresee all the ramifications of these, we can try to ensure that we understand the scope of the new mobile heuristics. In particular if we attempt to make explicit the different assumptions that underlie the new heuristics, we will be able to tell when these change and be in a better position to add to or modify this set in the future.

We will examine the differing assumptions that underlie desktop and mobile use under four headings: the nature of mobile devices, the environment of mobile infrastructure, the context of mobile use and the purpose of mobile tasks. For each we will examine the extent to which they are reflected in the heuristics and, where appropriate, how they may develop in the medium term.

The Nature of Mobile Devices

One of the most obvious differences between mobile devices and fixed ones is size.

It has been pointed out that desktop screen design is often lazy design—putting everything on screen and letting the user worry about what is important (Dix, 1999). In contrast, for the small screen of a mobile device it is crucial that just the right information and input options are available at the right time—mobile device designers have to think far more carefully about the user's task than desktop designers. This is emphasized in Heuristic 4 "since screen real estate is a scarce resource, use it with parsimony. Dialogues should not contain information that is irrelevant or rarely needed."; on a desktop application we would (lazily) just show everything. This is also reflected in Heuristic 2: "Enable the mobile user to interpret the information provided correctly, by making it appear in a natural and logical order", and in Heuristic 6: "Allow mobile users to tailor/personalize frequent actions…". While these are both good advice for any interface it is particularly important on a small screen to help deliver the right information at the right time.

Several heuristics pick out issues of system adaptation. The system should (Heuristic 1) "prioritize messages", (Heuristic 2) "… sense its environment and adapt the presentation of information accordingly", (Heuristic 6) "suggest system-based customization" and Heuristic 8 "Constructively suggest a solution" for errors. In desktop systems 'intelligent' system features can often get in the way and it is often better to have simple consistent interfaces. Of course this consistency is itself also more important when descriptions of actions are by their nature more parsimonious and Heuristic 3 focuses on this "consistent mapping between user actions/interactions". The balance between consistency and intelligence changes as the input/output bandwidth diminishes and the potential annoyance of wrong adaptations may be less problematic than the cost of doing everything by hand. Note too that Heuristic 3 is as much about *external* consistency with the environment as *internal* consistency over time.

The overall small physical size is also central to Heuristic 1's focus on losability/findability. A small device can easily get lost both in public places and in the home. However, its size means that it is often kept close at hand, both allowing it to be used as a proxy for the user in location services and also meaning that it becomes a very personal device, often used for private purposes. The importance of privacy is picked up in Heuristic 1: "Since mobile devices often get lost, adequate measures such as encryption of data should be taken to minimize loss" and Heuristic 7: "Make sure that users' data is kept private and safe". The personal nature is also picked up in Heuristic 7: "Take aesthetic and emotional aspects of the mobile device and system use into account". One of the unexpected lessons that mobile phone manufacturers had to learn quickly was that mobile phones are fashion items as well as functional devices. In addition, the content of mobile communications is often very rich and personal.

THE ENVIRONMENT OF MOBILE

Infrastructure

A key difference between driving across Africa and driving across Europe is the different transport infrastructure. The road system, signage, garages for repairs, and petrol filling stations are as much a part of the driving experience as the car dashboard. Similarly, for the mobile user the infrastructure in terms of wireless connectivity, charging, and data synchronization is as much a part of the mobile experience as the usability of the device itself.

The heuristics presented here are focused primarily on the use of the device itself and only marginally refer to this mobile infrastructure. Given that the heuristics reflect the current literature, clearly there is need for research in this area, which then may lead to further heuristics or guidelines for mobile infrastructure.

The influence of infrastructure can be thought of as different kinds of connectivity: connectivity to networks, connectivity to power, connectivity to data and connectivity to location services.

Network connectivity is always of concern to mobile phone users and it is still not uncommon to see people hanging out of windows, or waving phones in the air looking for signal. Heuristic 1 notes the importance of giving information on "network status", and phone users become proficient at reading the signal bars on their phones. In related technologies this is less well managed and owners of digital radio sets often become confused as digital stations seem to appear and disappear without warning; whereas analog broadcasts degrade slowly with distance, digital broadcasts can either be interpreted perfectly from weak signal, or not at all. Similarly WiFi networks are seen as something akin to magic even by expert computer users, both in terms of how displayed signal levels correspond to actual access and in terms of the means to obtain connections through multiple levels of system property settings and authentication dialogues. Clearly we are still a long way from achieving even this simple goal of Heuristic 1.

The variability of network connectivity has been made a deliberate design feature in the notion of *seamful design* (Chalmers et al., 2004). Observations of network-based mobile games showed that players rapidly became aware that they could use patches of good or poor network connectivity in order to give them advantage during game play. This then led to games specifically designed using this notion.

Heuristic 8 on error management, while being partly general advice and partly about minimizing dialogue, is also indirectly related to connectivity. It is needed precisely because the user is far away from documentation, user guides, and expert help, and cannot rely on online help because of small screen size.

Heuristic 1 also notes the importance of "battery status". While battery technology has progressed remarkably, it is still one of the limiting factors for mobile devices, so much so that in some UK motorway service stations there are small racks of mobile phone lockers near the entrance where you can leave your phone to charge while you eat. The larger issues surrounding this are not mentioned in the heuristics, as a designer has little influence over them, but certainly standardization of power supply would seem an important step in reducing the plethora of power adaptors so many of us carry while traveling, as well as making public power-charging facilities easier to manage.

Interestingly, power is not unrelated to network connectivity, as mobile phones consume more power if they have to connect to more distant radio masts. However, few users are aware of these interactions and an application of Heuristic 1 would be to give users a better feel for these things.

Heuristic 1 also notes the importance of minimizing data loss. This is related both to privacy (not losing data to others) and to data recovery. Data synchronization has a long history, back to early systems such as the CODA file system (Kistler et al., 1992; Braam, 1998), but still seems to be only poorly managed in practice. While there are ways to synchronize data between mobile devices and desktop systems, the fact that devices are connected through mobile networks could be used more widely to seamlessly backup crucial information such as phone address books. As mobile devices increase in data capacity, devices such as USB sticks and MP3 players are increasingly becoming the vectors for synchronization, so that perhaps new classes of application and hence a need for new heuristics will arise in this area.

Much of the early research on mobile platforms was based around more substantial mobile computers and (often collaborative) remote applications. Issues of data synchronization over networks were crucial and in particular the problems due to network delays (Davies et al., 1996; Dix, 1995). This is still a major problem; for example, few users are aware that SMS is an unreliable messaging medium and can have substantial delays, especially for international texts. Strangely this does not seem to be prominent in the current literature and hence is not reflected in the heuristics. Perhaps this reflects the belief (as has been the case for 20 years) that 'soon' everything will be quick enough, or perhaps simply that empirical work is usually carried out in areas of high connectivity.

For location-based services, it is important that users understand the accuracy and other features of the location estimates. Where information or other services are based on discretized regions confusion can arise at boundaries, rather like the digital radio example. Heuristic 1 applies again here, making not just location but data about uncertainty available. However, how this can be achieved in practice is still a matter for research, so more detailed general guidelines are not yet possible.

The Context of Mobile Use

Mobile devices are used while walking, (with care) in vehicles, outside in the rain, on the beach in the sand; they are often held while trying to do other things: open doors, carry shopping, pay for the bus, and in environments with other people. This rich set of physical and social contexts is reflected in several of the heuristics.

Heuristic 4 in particular notes the importance of "Good ergonomics" so that devices are "easy and comfortable to hold/carry along" and also that they are "robust to damage" when they inevitably get banged or dropped. Heuristic 1's focus on losability/findability reflects the dynamic context where mobile devices may be put down while carrying out other tasks.

The social context is also noted in Heuristic 7, "Mobile interaction with the system should be comfortable and respectful of social conventions", and this interacts with the ability to (Heuristic 6) "dynamically configure the system according to contextual needs".

Avoiding embarrassing symphonic ring tones and similar context-sensitive adaptations has been the focus of much research and a mobile device may potentially have access to just the environmental information to make this possible. While still very much a matter of ongoing research, this is reflected in several heuristics: (Heuristic 1) "messages regarding … environmental conditions", (Heuristic 2) "the system should have the capability to sense its environment", (Heuristic 3) "user's conceptual model … consistent with the context".

Mobile devices are often used in far from optimal lighting conditions and while moving, making small fonts hard to read and so further reducing effective screen size. Both of these exacerbate the input/output problems of a small device discussed in the section entitled *The Nature of Mobile Devices*. In addition, the user is often performing another task at the same time as using the mobile device, sometimes related to the mobile device's function (following a GPS map, or talking about a task on the phone) and sometimes unrelated (walking round the supermarket while talking to your mother on your mobile, or texting under the desk in a lecture). Heuristic 5 particularly picks up on these issues. When doing another task it is essential that the user can "get the crucial information from the system by glancing at (*the device*)" and avoid "the need for the user to use both hands".

The Purpose of Mobile Tasks

Mobile applications can be split into two broad categories:

1. Those where location matters
2. Those where it does not

Many of the heuristics apply to both categories of application, but some apply more to one.

The first category includes location-aware applications such as navigation, tourist information, targeted advertising, and even augmented reality. Heuristic 2 talks about the "Match between system and the real world" and says the system should "sense its environment and adapt the presentation of information accordingly". Heuristic 3 mentions the importance of consistency between users' actions and "the corresponding real tasks (e.g. navigation in the real world)". The ability of applications to achieve these aims is often dependent on hardware and environment, so additional strategies are used, for example the provision of several different landmarks to choose from, given an imprecise GPS location (e.g., Cheverst et al., 2000). Few location-aware systems include electronic compasses or gyroscopes, so directional consistency is particularly hard to maintain.

The second category is not simply the negation of the first, but the opposite: those applications that you specifically want to be able to do anywhere, such as being able to phone, access email, read electronic documents, write in a word processor. In these applications the aim is to unshackle the user from the need to be physically in a particular place. Some of these are where the user wants access to remote resources from anywhere, and in this case issues of data and network connectivity may be important. For other applications in this category the data is local, but issues of screen size, portability and dangers of data loss become more significant.

CONCLUSION AND FUTURE WORK

In this article, we have pointed out the benefit of expert-based evaluation methods and their need to capture contextual requirements in mobile computing. We have, in the process, described how we have analyzed mobile usability issues, and discussed our efforts toward realizing a set of usability heuristics that is relevant to mobile computing. Our study confirms previous observations that mobile heuristics detect fewer cosmetic problems and that, in any case, they should not be considered as alternative to user studies, but synergic. In particular, as often noted when speaking of inspection methods, we believe these are useful techniques to use when we are in early phases of design/prototyping, or when the low-cost issue is particularly relevant to the evaluation. As far as the false positives problem is concerned, the inter-expert consistency found when applying mobile heuristics may indicate that the flaws detected were not false alarms, although empirical evaluations with end users are the methods to uncover and solve this issue. As part of our future work, we intend to perform further literature analysis to the work reported in the section entitled *Methodology for Realizing Mobile Issues* and possibly consider more dimensions and at different levels of abstraction.

REFERENCES

Braam, P. J. (1998). The Coda Distributed File System. *Linux Journal, 50*.

Chalmers, M., & Galani, M. (2004). Seamful Interweaving: Heterogenity in the Theory and Design of Interac-tive Systems. In *Proceedings of the ACM Designing Interactive Systems – DIS'04 Conference*.

Cheverst, K., Davies, N., Mitchell, K., & Friday, A. (2000). Experiences of Developing and Deploying a Context-Aware Tourist Guide: The GUIDE Project. In [ACM Press.]. *Proceedings of MOBICOM*, *2000*, 20–31. doi:10.1145/345910.345916

Cockton, G., Lavery, D., & Woolrych, A. (2003). Inspection-based Evaluations. In Jacko, J. A., & Sears, A. (Eds.), *The HCI Handbook, Lawrence Erl. Assoc., 2003* (pp. 1118–1138).

Davies, N., G. S. Blair, K. Cheverst and A. Friday (1996). Supporting Collaborative Applications in a Heterogeneous Mobile Environment, Special Issue of Computer Communications on Mobile Computing, 1996.

Dix, A. J. (1995). Cooperation without (reliable) Communication: Interfaces for Mobile Applications. *Distributed Systems Engineering*, *2*(3), 171–181. doi:10.1088/0967-1846/2/3/005

Dix, A. J. (1999, 15th December). Hazy, Crazy, Lazy Days are Over - Time for Designers to Think. (keynote) *Designing Information for Mobile and Broadband Network Users*, London. Available at http://www.hiraeth.com/alan/papers/mobile-and-b-99/crazy-lazy-ohps.html.

Greenberg, S., Fitzpatrick, G., Gutwin, C., & Kaplan, S. (1999). Adapting the Locales Framework for Heuristic Evaluation of Groupware. In *Proceedings of the Conference of the Computer-Human Interaction Special Interest Group of the Human Factors and Ergonomics Society of Australia - OZCHI'99*.

Johnson, P. (1998). Usability and Mobility: Interaction on the Move. In *Proceedings of the First Workshop on Human-Computer Interaction with Mobile Devices*.

Kantner, L., & Rosenbaum, S. (1997). Usability studies of www sites: Heuristic evaluation vs. laboratory testing. In *Proceedings of the International Conference on Computer Documentation - SIGDOC '97* (pp. 153-160). ACM Press.

Karat, C.-M., Campbell, R., & Fiegel, T. (1992). Comparison of Empirical Testing and Walkthrough Methods in User Interface Evaluation. In *Proceedings of the Conference on Human Factors in Computing Systems - CHI'92* (pp. 397-404). ACM Press.

Kistler, J. & Satyanarayanan, M. (1992). Disconnected Operation in the Coda File System. *ACM Transactions on Computer Systems*.

Kjeldskov, J., & Graham, C. (2003). A Review of Mobile HCI Research Methods. In L. Chittaro (Ed.), *International Symposium on Human Computer Interaction with Mobile Devices and Services - Mobile HCI'03* (pp. 317-335). Springer-Verlag.

Kjeldskov, J., Graham, C., Pedell, S., Vetere, F., Howard, S., Balbo, S., & Davies, J. (2005). Evaluating the usability of a mobile guide: The influence of location, participants and resources. *Behaviour & Information Technology*, *24*(1), 51–65. doi:10.1080/01449290512331319030

Law, L. C., & Hvannberg, E. T. (2002). Complementarity and convergence of heuristic evaluation and usability test: A case study of universal brokerage platform. In *Proceedings of the Nordic Conference on Human-Computer Interaction - NordiCHI '02* (pp. 71-80). ACM Press.

Molich, R., & Nielsen, J. (1990). Improving a human-computer dialogue. *Communications of the ACM*, *33*(3), 338–348. doi:10.1145/77481.77486

Muller, M. J., & McClard, A. (1995). Validating an extension to participatory heuristic evaluation: Quality of work and quality of work life. In *Proceedings of the Conference on Human Factors in Computing Systems - CHI'95* (pp. 115-116). ACM Press.

Nielsen, J. (1994a). Enhancing the explanatory power of usability heuristics. In *Proceedings of the Conference on Human Factors in Computing Systems - CHI'94* (pp. 152-158). ACM Press.

Nielsen, J. (1994b). *Usability Engineering*. Morgan Kaufmann Publishers.

Nielsen, J., & Molich, R. (1990). Heuristic evaluation of user interfaces. In *Proceedings of the Conference on Human Factors in Computing Systems - CHI'90* (pp. 249-256). ACM Press.

Po, S. (2003). *Mobile usability testing and evaluation*. Master's thesis, University of Melbourne, Australia.

Sade, S., & Finland, O. N. (2002). Mobile ease-of-use and desirability through user-centered design. In *Proceedings of the SSGRR-2002 Summer Conference on Infrastructure for e-Business, e-Education, e-Science, and e-Medicine*.

Simeral, E.J., & Branaghan, R.J. (1997). A Comparative Analysis of Heuristic and Usability Evaluation Methods. *STC Proceedings (1997)*.

Vetere, F., Howard, S., Pedell, S., & Balbo, S. (2003). Walking through mobile use: Novel heuristics and their application. In *Proceedings of the Conference of the Computer-Human Interaction Special Interest Group of the Human Factors and Ergonomics Society of Australia OZCHI2003*.

Wharton, C., Rieman, J., Lewis, C., & Polson, P. (1994). The cognitive walkthrough method: A practitioner's guide. In Nielsen, J., & Mack, R. L. (Eds.), *Usability Inspection methods* (pp. 105–140). New York: John Wiley & Sons.

ENDNOTES

1. http://www.mais-project.it
2. See also http://www.useit.com/papers/heuristic/usability_problems.html
3. The papers were selected from top-level conferences and journals like CHI, AVI, UIST, TOCHI, etc. For details see J. Kjeldskov and C. Graham. A Review of Mobile HCI Research Methods. In L. Chittaro, editor, *International Symposium on Human Computer Interaction with Mobile Devices and Services - Mobile HCI'03*, pages 317–335. Springer-Verlag, 2003.
4. All the experts were new to the novel set of heuristics and none of the experts involved in the generation of heuristics discussed above were involved in the experimental study.
5. We used hp iPAQ Pocket PC series h5500 PDAs with integrated wireless LAN (802.11b), 48 MB ROM, 128 MB RAM, and Intel processor 400 MHz. The PDAs were running Windows CE.
6. It should be noted that some of the participants indicated that some of the flaws were individually related to more than one type of heuristic (and thus the number of counts for the heuristics shown in Table 6 (and also Table 7) is greater than the number of flaws as shown in Table 4).

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Chapter 3
Pickup Usability Dominates:
A Brief History of Mobile Text Entry Research and Adoption

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ABSTRACT

Text entry on mobile devices (e.g. phones and PDAs) has been a research challenge since devices shrank below laptop size: mobile devices are simply too small to have a traditional full-size keyboard. There has been a profusion of research into text entry techniques for smaller keyboards and touch screens: some of which have become mainstream, while others have not lived up to early expectations. As the mobile phone industry moves to mainstream touch screen interaction we will review the range of input techniques for mobiles, together with evaluations that have taken place to assess their validity: from theoretical modelling through to formal usability experiments. We also report initial results on iPhone text entry speed.

INTRODUCTION

Many mobile services such as text/instant messaging, email, web searching and diary operations require users to be able to enter text on a phone. Text messaging has even overtaken voice calling as the dominant use of mobile phones for many users with mobile email rapidly spreading. Handheld screen technologies are also making it increasingly convenient to read complex messages or documents on handhelds, and cellular data network speeds are now often in excess of traditional wired modems and considerably higher in wi-fi hotspots. These technological developments are leading to increased pressure from users to be able to author complex messages and small documents

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on their handhelds. Researchers in academia and industry have been working since the emergence of handheld technologies for new text entry methods that are small and fast but easy-to-use, particularly for novice users. This article will look at different approaches to keyboards, different approaches to stylus-based entry, and how these approaches have been evaluated to establish which techniques are actually faster or less error-prone. The focus of the article is both to give a perspective on the breadth of research in text entry and also to look at how researchers have evaluated their work. Finally, we will look at perceived future directions attempting to learn from the successes and failures of text entry research. Throughout this article we will cite words-per-minute (wpm) as a fairly standard measure of typing speed, for reference highly skilled office QWERTY touch typists achieve speeds of around 135wpm while hand-writing with pen and article achieves only about 15wpm.

KEYBOARDS

The simplest and most common form of text entry on small devices, as with large devices, is a keyboard. Several small keyboard layouts have been researched that try to balance small size against usability and text entry speed. Keyboards can be categorized as unambiguous, where one key-press unambiguously relates to one character, or ambiguous, where each key is related to many letters (e.g. the standard 12-key phone pad layout where, say, *2* is mapped to *ABC*). Ambiguous keyboards rely on a disambiguation method, which can be manually driven by the user or semi-automatic with software support and user correction. This section looks first at unambiguous mobile keyboard designs, then at ambiguous designs and, finally, discusses approaches to disambiguation for ambiguous keyboards.

Unambiguous Keyboards

Small physical keyboards have been used in mobile devices from their very early days on devices such as the Psion Organiser in 1984 and the Sharp Wizard in 1989 and have seen a recent resurgence in devices targeting email users, such as most of RIM's Blackberry range. While early devices tended to have an alphabetic layout, the standard desktop QWERTY family of layouts, e.g. QWERTY, AZERTY, QWERTZ and QZERTY, was soon adopted as there is strong evidence that alphabetic layouts give no benefits even for novice users (Norman, 2002; Norman & Fisher, 1982). When well-designed, small QWERTY keyboards can make text entry fast by giving the users good physical targets and feedback with speeds measured in excess of 60wpm (Clarkson et al 2005). However, there is a strong design trade-off between keys being large enough for fast, easy typing and overall device size with large-fingered users often finding the keys simply too small to tap individually at speed. Physical keyboards also interact poorly with touch-screens, where one hand often needs to hold a stylus, and they reduce the space available on the device for the screen.

The QWERTY keyboard layout was designed as a compromise between speed and physical characteristics of traditional manual typewriters: the layout separates commonly occurring pairs of letters to avoid head clashes on manual typewriters and is imbalanced between left and right hands. Faster touch-typing office keyboards such as the Dvorak keyboard (Figure 1) are significantly faster but have not been widely adopted—primarily because of the learning time and invested skill-set in QWERTY keyboards. This investment has been shown to carry over into smaller devices, where the sub-optimality issue is even stronger as users tend to type with one or two thumbs—not nine fingers envisaged of touch-typists. While optimal mobile layouts could be designed around two-thumb entry, these are likely to be so different from users' experiences that initial use would

Figure 1. Dvorak keyboard

be very slow and, as with the Dvorak, rejected by end users (and would still be sub-optimal for one-thumb use!).

The half-QWERTY mobile keyboard (Matias, MacKenzie, & Buxton, 1996) (fig 2-left) builds on QWERTY skills and the imbalance between left and right hands by halving the keyboard in the centre. The keyboard has a standard left half of a QWERTY keyboard, while the user holds the space bar to *flip* the keyboard to give the right side letters. Targeting smaller size and fast one-handed entry, experiments have shown that users of the half-QWERTY keyboard quickly achieved consistent speeds of 30 words per minute or higher (when using a keyboard with desktop-sized keys). The FrogPad™ is a variant using an optimised keyboard, so that use of the "right side" of the keyboard is minimised (Figure 2). (Matias et al., 1996) predicted an optimised pad would lead to a speed increase of around 18% over the half-qwerty design. FrogPad™ Inc now manufacture an optimised keyboard along these lines and claim 40+ words per minute typing speeds.

Neither half-keyboards have yet to be integrated into mobiles, while the FastTap™ keyboard, however, has been targeted at mobile devices from initial conception. This patented technology takes a different approach to miniaturisation by including an alphabetic keyboard as raised keys between the standard numeric keys of a phone pad—giving direct non-ambiguous text entry on a very small platform while preserving the standard 12-key keypad currently used by over 90% of mobile users globally (see figure 3). Experiments (Cockburn & Siresena, 2003) have shown that FastTap™ is considerably faster and easier to use for novice users than more standard predictive text approaches and the two approaches perform similarly for expert users (once practiced, FastTap users in their trial achieved 9.3wpm with T9™ users achieving 10.8wpm—somewhat slower than in other trials, see below for discussion of predictive text and T9).

Figure 2. Simplified Half-QWERTY and FrogPad™

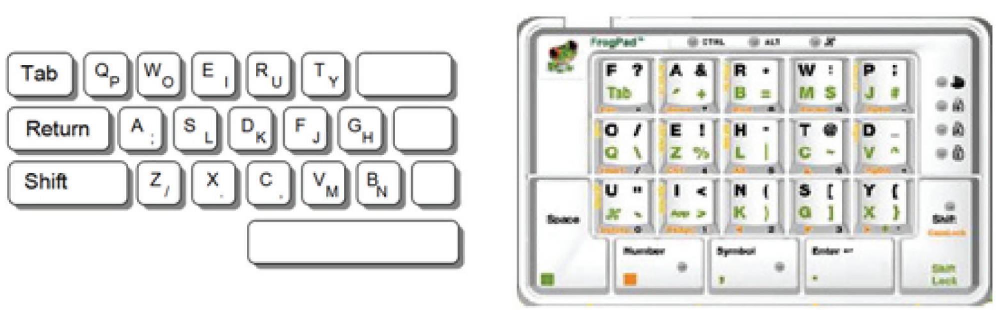


Figure 3. FastTap™ phone keyboard

A drastically different unambiguous keyboard approach is to use chords—multiple simultaneous key-presses mapping to a single character, either using one or both hands. Chord keyboards can give extremely fast entry rates, with court stenographers reaching around 225wpm using a two-handed chord keyboards. One-handed chord keyboards are by definition palm-sized and were originally envisaged as the ideal partner to the mouse (Engelbart & English, 1968), allowing users to enter text and point at the same time. Single-handed chord keyboards have been used in mobile devices (Figure 4 shows the AgendA organiser including an alphabetic keyboard surrounded by a chord keyboard). However, the learning time is prohibitive with few users willing to learn the chords required to use these keyboards. Furthermore, the keyboards are not usable without training—users cannot guess how to use them when first picking up a device. Thus, despite size and speed advantages, chord keyboards are generally considered too alien for main-stream devices and rarely appear on consumer products.

Ambiguous Keyboards

The most common ambiguous keyboard, and the dominant keyboard for mobile phones, is still the telephony ISO/IEC standard 12-key phone keypad (e.g. Figure 5). Originally envisaged for name-based dialling of telephone area codes, this keyboard is labelled with groups of three or four letters on each of the physical keys *2*

Figure 4. Sample chord keyboards (Douglas Engelbart and Microwriter AgendA)

Figure 5. 12-key phone pad (Nokia N73) and stretched phone pad (Blackberry™ 7100)

through *9* plus numeric digits (with the *1, *, #* and *0* keys typically acting as space, shift and other control keys depending on handset). These can, however, represent many characters once accented characters are included (e.g. 2 maps to ABC2ÄÆÅÀÁÂÃÇ). The method of disambiguating the multiple letters per key is discussed later. Recently some phones have been released with a slightly stretched mobile phone pad, typically with two extra columns, reducing the number of characters per key and considerably improving disambiguation accuracy (Figure 5).

While the 12-key mobile phone pad is the smallest commonly found keyboard layout, there has been some work on very small keyboards/devices with as few as three keys. Text entry on these usually involves cursor movement through the alphabet using the 3-key *date-stamp* method widely used in video games (left and right scroll through an alphabetic strip of letters with fire entering the current letter) and 5-key variant using a joystick with a 2D keyboard display. Experiments have shown users of 3-key date-stamp entry can achieve around 9wpm while with a 5-key QWERTY layout users can reach around 10-15wpm (Bellman & MacKenzie, 1998; MacKenzie, 2002b). These experiments also tried dynamically adjusting the layout based on probabilities of next letter but these didn't have the expected speed-up, probably due to the extra attention load of users cancelling out the reduced time to select a letter. An alternative approach for non-ambiguous very small keyboard entry is to use short-codes representing the letters, for example short sequences of cursor keys. (Evreinova, Evreino, & Raisamo, 2004) showed that users could achieve good entry speeds with 3-key combinations of cursor keys, e.g. left-up-left for *A*, and that, despite high initial error rates, users could learn the codes quickly.

Disambiguation

The traditional approach to disambiguating text entry on a mobile phone keypad is the manual *multi-tap* approach: users press keys repeatedly to achieve the letter they want, e.g. on a standard phone keypad *2* translates to *A* with *22* translating to *B* etc. This approach has also been adopted in many other domestic devices such as video remote controls. Multi-tap leads to more key-strokes than an unambiguous keyboard, as users have to repeatedly click for most letters, and to a problem with disambiguating a sequence of letters on the same key, e.g. *CAB* is *222222*. Users typically manually disambiguate this by either waiting for a timeout between subsequent letters on the same key or hitting a *time-out kill* button (e.g. right cursor key)—clearly an error-prone process and one that slows users down. (Wigdor & Balakrishnan, 2004) refer to multitap as an example of *consecutive* disambiguation—the user effectively enters a key then disambiguates it. An alternative manual disambiguation approach is *concurrent* disambiguation; here users use an alternative input method, e.g. tilting the phone (Wigdor & Balakrishnan, 2003) or a small chord-keyboard on the rear of the phone (Wigdor & Balakrishnan, 2004), to disambiguate the letter as it is entered. While clearly potentially much faster than multi-tap and relatively easy to use, this approach has not yet been picked up by device manufacturers.

Aimed at overcoming the problems of multi-tap, predictive text entry approaches use language modelling to map from ambiguous codes to words so that users need only press each key once, for example mapping the key sequence *4663* directly to *good*. While there are clearly cases where there are more than one match to the numeric key sequence (e.g. *4663* also maps to *home* and *gone* amongst others), these are surprisingly rare for common words. The problem of multiple matches can be alleviated to a large extent by giving the most likely word as the first suggestion then allowing users to scroll through alternatives for less likely words. Based on a dictionary of words and their frequency of use in the language, users get the right word suggested first around 95% of the time (Gong & Tarasewich, 2005). AOL-Tegic's T9 (Grover, King, & Kushler, 1998; Kushler, 1998) industry-standard entry method is based around this approach and is now deployed on over 2 billion handsets. Controlled experiments have shown this form of text entry considerably out-performs multi-tap (Dunlop & Crossan, 2000; James & Reischel, 2001), with text entry rising from around 8wpm for multitap to around 20 for T9. While predictive text entry is very high quality, it is not perfect and can lead to superficially unrelated predictions that are undetected as users tend to type without monitoring the screen (e.g. a classic T9 error is sending the message *call me when you are good* rather than *are home*). The main problem, however, with any word prediction system is handling out-of-vocabulary words—words that are not known to the dictionary cannot be entered using this form of text entry. The usual solution is to force users into an "add word" dialogue where the new word is entered in a special window using multi-tap—clearly at a considerable loss of flow to their interaction and reduction in entry speed. As most people do not frequently enter new words or place/people names, this is not a major long-term problem. However, it does considerably impact on initial use and can put users off predictive text messaging as they constantly have to teach new words to the dictionary in the early days of using a new device. This in turn impacts on consumer adoption with many people not using predictive text despite it clearly being faster for experienced users.

An alternative approach to dictionary and word-level disambiguation is to use letter-by-letter disambiguation where letters are suggested based on their likelihood given letters already entered in the given word or likely letters at the start of a word (e.g. in the clearest case in English, a *q* is most likely to be followed by a *u*). This gives the user freedom to enter words that are not in the dictionary and considerably reduces the memory load of the text entry system (no longer an issue with phones but still an issue on some devices). Experiments using this approach (MacKenzie, Kober, Smith, Jones, & Skepner, 2001) showed key-strokes halved and speed increased by around 36% compared with multi-tap. They also claim that this speed is inline with T9 entry and that their approach out-performs T9 by around 30% when as few as 15% of the least common words are missing from the predictive dictionary. Predicting letters based on previous letters is actually a specific implementation of Shannon's approach to prediction based on n-grams of letters (Shannon, 1951). Some work has been carried out to extend this to the word-level and shows good promise: for example bi-gram word prediction in Swedish with word completion reduced keystrokes by between 7 and 13% when compared with T9 (Hasselgren, Montnemery, Nugues, & Svensson, 2003).

In work on watch-top text entry we (Dunlop, 2004) found that moving to a 5-key pad reduced accuracy from around 96% to around 81% with approximately 40% reduction in text entry speed—however, still considerably faster than 2D date-stamp approaches for very small devices. An interesting alternative input method for small devices is to use a touch-wheel interfaces, such as those on iPods™. (Proschowsky, Schultz, & Jacobsen, 2006) developed a method where users are presented with the alphabet in a circle with a predictive algorithm increasing the target area for letters based on the probability of them being selected next, so that users are more likely to hit the correct target when tapping on the touch-wheel. User trials showed around 6-7 words per minute entry rates for novices, about 30% faster than the same users using a 1D date-stamp approach on a touch-wheel.

The letters on an ambiguous phone keypad do not, of course, need to be laid out alphabetically. Here the disambiguation method introduces an additional aspect to designing an optimal layout: the letters can be rearranged to minimise the level of ambiguity for a given language in addition to looking at minimising finger movement. However, experiments predict that a fully-optimised phone layout would improve text entry rates by only around 3% for English (Gong & Tarasewich, 2005). We found a larger but still small improvement of around 8% in keystrokes for a pseudo-optimised 4-key letter layout (Dunlop, 2004). Gong & Tarasewich do, however, show that stretching the standard phone pad from eight to twelve keys for text entry (see Figure 5) is likely to reduce prediction errors by around 65% for optimised keyboard layouts (Gong & Tarasewich, 2005).

TOUCH-SCREEN TEXT ENTRY

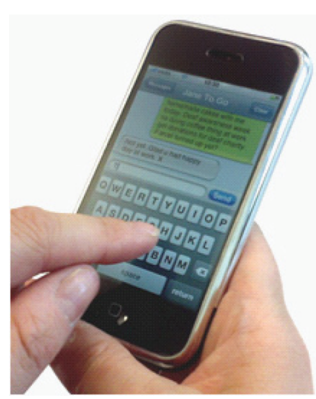
Compared to mobile phones, personal organisers (PDAs) have made more use of touch screens and stylus interaction as the basis of interaction and this is now emerging on high-end phones such as Apple's iPhone. This frees up most of the device for the screen and leads to natural mouse-like interaction with applications. Lack of a physical keyboard has led to many different approaches for text entry on touch-sensitive screens that will be discussed in this section: on-screen (or soft) keyboards, hand-writing recognition and more dynamic gesture-based approaches.

On-Screen Keyboards

A simple solution to text entry on touch-screens is to present the user with an on-screen keyboard that the user can tap on with a stylus, or on larger touch-screens with their fingers. The most common implementation is to copy the QWERTY layout onto a small touch sensitive area at the bottom of the screen (Figure 6). Following a similar experimental protocol to (James & Reischel, 2001) we conducted an initial experiment on three expert iPhone users. James & Reischel measured expert performance on chat style messages at 26wpm; using the same phrases our initial study showed iPhone entry around 50wpm (mean 51.6, stdev 1.5 with similar error rates, though the iPhone spell checker corrected about half of these). Although a very small independent sample study, this does indicate that practiced iPhone users may be up to twice as fast as T9 users.

As with physical keyboards and keypads, there has been research into better arrangements of the

Figure 6. iPhone™ on-screen QWERTY keyboard



keys for touch-screens. Mackenzie and his team have conducted a series of experiments on alternative layouts that are optimised for entry using a stylus (single touch entry). They investigated both unambiguous keyboards and an optimised 12-key ambiguous keypad, inspired by the success of T9 and the fundamental rule of interaction that large targets are faster to tap than small ones (Fitts, 1954). Their results estimate that an expert user could achieve 40+ wpm on a soft QWERTY keyboard with novice soft-keyboard users achieving around 20 wpm (MacKenzie, Zhang, & Soukoreff, 1999). The alternative layouts were predicted to give higher entry rates for expert use: the unambiguous Fitaly layout was predicted to reach up to 56wpm and ambiguous JustType 44wpm (Figure 7). However, novice users achieved only around 8wpm using these alternative keyboard layouts—highlighting the carry-over effect of desktop QWERTY layout.

While simple and fast, the on-screen keyboard approach can be tiring for users as they are required to repeatedly hit very small areas of the screen. The patented technology underlying the XT9™ Mobile Interface from Tegic Communications attempts to address this problem by including a level of disambiguation in an otherwise unambiguous keyboard (Robinson & Longe, 2000). For example, if the user taps letters adjacent to the letters in the intended word, then the more likely letters are used instead of the letters actually tapped. Their approach defaults to the most likely full word given the approximate letters entered, while offering alternative corrections and word completions as well as the letters actually typed (Figure 8). XT9 technologies have been developed by Tegic for multiple platforms, including hand-printing and small physical keyboards.

Handwriting

To many the obvious solution to text entry on handheld devices is handwriting recognition. Modern hand-writing recognition systems, for example on Windows™ Vista™ tablets, are extremely good at recognising in-dictionary words but struggle on words that are not previously known and are inherently limited by writing speeds (about 15 wpm (S. Card, Moran, & Newell, 1983)). Furthermore, handwriting recognition needs a reasonably large physical space people to write in and processing power that is more in line with modern laptops/tablets than phones. To target mobiles better, the unistroke (Goldberg & Richardson, 1993) approach introduced a simplified alphabet to reduce both the processing complexity and the space, and for experienced users the time, needed for writing while increasing accuracy. Here each letter is represented as a single stroke with letters typically drawn on top of each other in a one letter wide slot and requires users to learn a new alphabet (Figure 9). Palm popularised a more intuitive version, Graffiti™, on their palmtops—a mostly unistroke alphabet, Graffiti™ was composed mainly of strokes with high similarity to standard capital letters. CIC's

Figure 7. Fitaly and JustType keyboard layouts

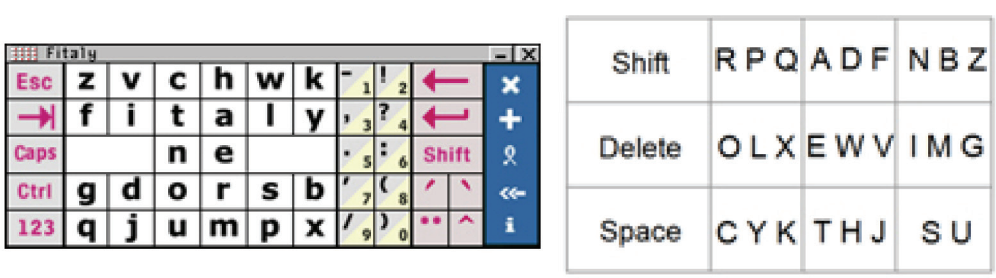


Figure 8. Sample XT9™ Mobile Interface

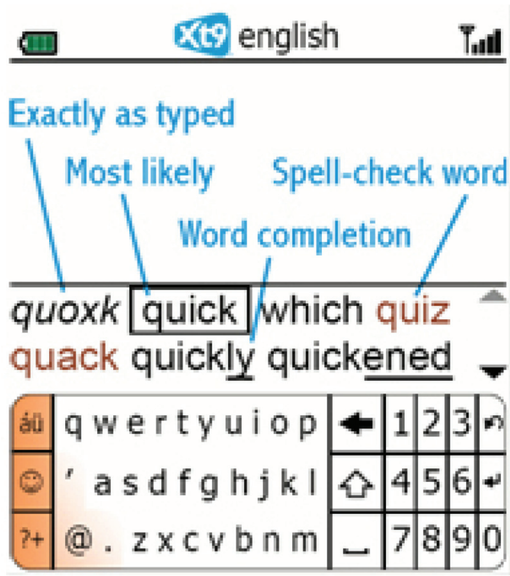
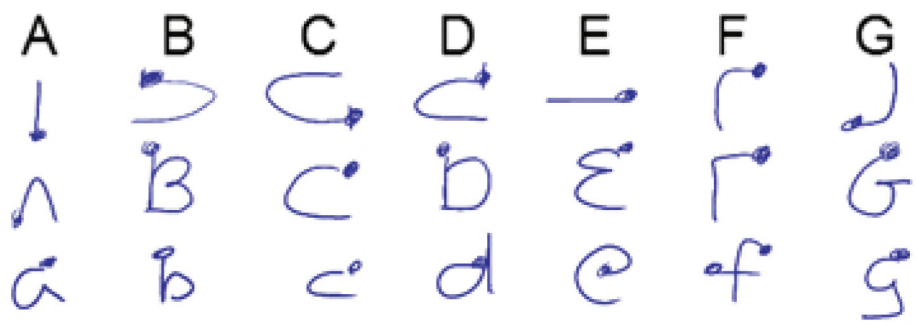


Figure 9. Unistroke, Graffiti™ and Jot™ sample letters

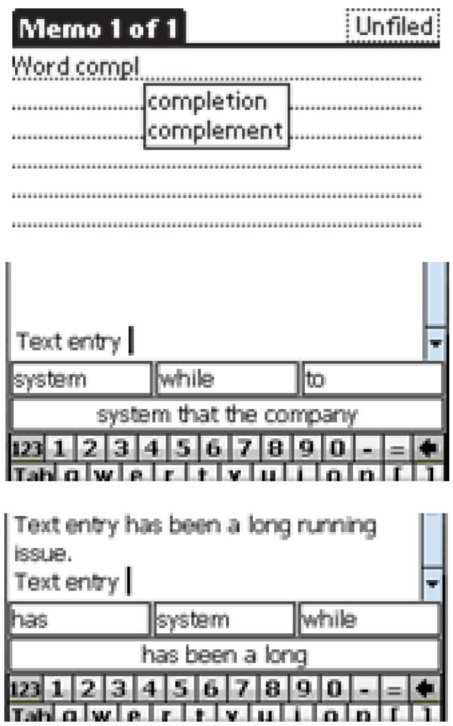


Jot™ alphabet provides a mix of unistroke and multistroke letters and is deployed on a wide range of handhelds. Experiments comparing hand-printing with other text entry methods are rare, but a comparison between hand-printing, QWERTY-tapping and ABC-tapping on pen-based devices (MacKenzie, Nonnecke, McQueen, Riddersma, & Meltz, 1994) showed that a standard QWERTY layout can achieve around 23wpm while hand-printing achieved only 17wpm and alphabetic soft-keyboard only 13wpm.

Word Suggestion

Word completion and suggestion can also be used to help users by allowing them to pick full words without entering all the letters. This was first popularised with CIC's WordComplete™ (Figure 10), which suggested common word completions for partially entered words. Similar technologies are used on the eZiType™ and XT9 technologies deployed on some mobile phones. While tempting, word suggestion and word completion needs to perform very well in order to give users a real benefit—savings in terms of letters entered can

Figure 10. WordComplete™ (top) and AdapTxt™ (centre and bottom)



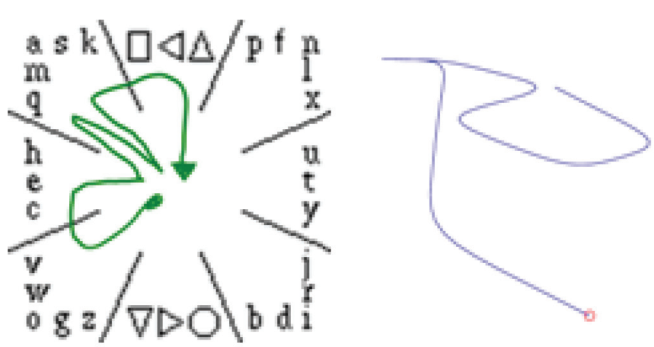
be dominated by extra time reading and reacting to on-screen suggestions. We (Dunlop & Crossan, 2000) estimated that simple word completion would reduce keystrokes by 17% but our model-based evaluation (see section 4.1) predicted an approximate halving of entry speed once user interruption time was taken into account. Some recent advances, however, have shown that when based on more complex language models word suggestion and completion can be beneficial with novice users increasing typing speed by around 35% using AdapTxt™ suggestions on a soft keyboard (Dunlop, Glen, Motaparti, & Patel, 2006). AdapTxt language models also self-tune over time by learning patterns of use in the user's language to further improve suggestions for the individual user and his/her context of use (Figure 10 centre and right shows off the shelf suggestions and those after repeating a single phrase).

Gesture-Based Input

Gesture-based interaction attempts to combine the best of visual keyboards with easy-to-remember stylus movements to gain faster and smoother, while still easy-to-learn, text entry. Building on our motor-memory for paths, approaches such as Cirrin (Mankoff & Abowd, 1998), Quikwriting (Perlin, 1998) and Hex (Williamson & Murray-Smith, 2005) are based on the user following a path *through* the letters of the word being entered (Figure 11). For on-screen approaches this achieves faster entry rates than single character printing with reduced stress and fatigue when writing. Furthermore, in the case of Hex, the approach can be used in one-handed on devices with accelerometers/tilt sensors.

Gestures can be combined with more conventional soft keyboards so that users can choose to

Figure 11. Quikwriting (left) and the Hex entry for "was" (omitting letter display)(right)



tap individual letters, improving pick-up-and-use usability, or to enter words in one gesture by following the path of the letters on the touch keyboard (experts can then enter the gestures anywhere on screen) (Zhai & Kristensson, 2003).

Dasher is a drastically different approach to text entry that attempts to exploit interactive displays more than traditional text entry approaches. In Dasher (Ward, Blackwell, & MacKay, 2000) (Figure 13), letters scroll towards the user and (s) he picks them by moving the stylus up and down as the letters pass the stylus. The speed of scrolling is controlled by the user moving the stylus left and right with predictive text entry approaches dynamically changing the space allocated to each letter (so that likely next letters are given more space than less likely ones, but all letters are available at each stage). Experiments show that users can enter at over 30 words per minute.

EVALUATION

Unlike many areas of mobile technology where market forces and commercial ingenuity dominate, the field of text entry has benefited from considerable scientific study to establish the benefits of one method over another. These studies have been conducted by academic and industrial research groups, often in collaboration, and are used both to compare techniques and to tune their usage to how users actually enter text. Much of the related evaluation work and results have already been discussed above, in this section we focus on the evaluation methods themselves.

Technical Evaluation

The literature commonly uses three methods for reporting the performance of text entry: *average ranked list position* (ARP), *disambiguation accuracy* (DA) and *keystrokes per character* (KSPC).

The average ranked-list position (e.g. (Dunlop & Crossan, 2000)) for evaluating ambiguous text entry methods is calculated in two phases. First language models, e.g. in the simplest case word frequencies, are learned from a corpus appropriate to the target language. Once trained, the second phase involves processing the same corpus one word at a time. Each word taken from the corpus is encoded using the ambiguous key-coding for the target keypad (e.g. *home* is encoded as *4663*) and a ranked list of suggested words produced for that encoding based on the learned language

Figure 13. Dasher

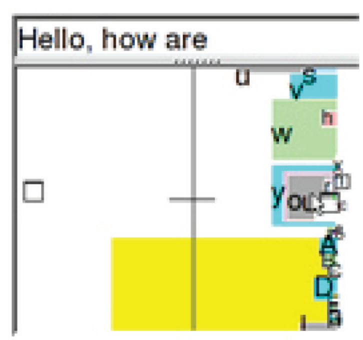
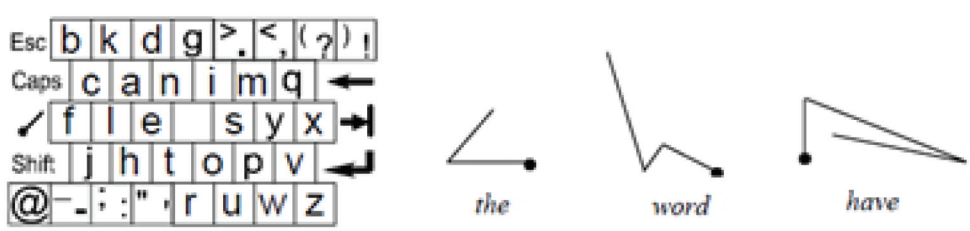


Figure 12. The ATOMIK keyboard with SHARK shortcuts



model. The position of the target word in this list is averaged over all words to give the average ranked-list position for that corpus and keypad. An ARP value of 1.0 indicates that the correct word was always in the first position in the ranked list of suggestions, a value of 2.0 that, on average, the correct word was second in the ranked list. We predicted an ARP value of around 1.03 for a large corpus of English language newsarticle articles using a standard phone keypad layout. ARP naturally biases the averaging process so that words are taken into account proportionally to their occurrence in the text corpus.

Disambiguation accuracy (e.g. (Gong & Tarasewich, 2005)) reports the percentage of times the first word suggested by the disambiguation process is the word the user intended—a DA value of 100% implies the disambiguation process always give the correct word first, while 50% indicates that it only manages to give the correct word first half of the time. Gong and Tarasewich reported DA of 97% for written English corpus and 92% for SMS messages (both on a phone pad). This is a more intuitive and direct measure than ARP, but does not take into account the performance of words that do not come first in the list.

KSPC (MacKenzie, 2002a) reports the average number of keystrokes required to enter a character, for example *home* followed by a space on a standard T9 mobile phone requires 6 keystrokes—4663* where * is the next suggestion key, giving a KSPC for *hello* of 5/4=1.25. As with ARP and DA the value is normally averaged over a large corpus of appropriate text for the target language. A KSPC value of 1.0 indicates perfect disambiguation as the user never needs to type any additional letters, while a higher figure reflects the proportional need for the next key in disambiguation (and a lower level, successful word completion). Full-sized non-ambiguous keyboards achieve KSPC=1.00, standard date-stamp method for entering text on 3 keys achieves KSPC=6.45, date-stamp like interaction on 5 keys achieves KSPC=3.13 and multitap on a standard 9-key mobile phone achieves a KSPC of around 2.03 (MacKenzie, 2002a). Hasselgren et al. (Hasselgren et al., 2003) reported KSPC of 1.01 and 1.08 for T9 using Swedish news and SMS corpora respectively, improving to 0.88 and 1.01 respectively for their bigram model with word completion. KSPC does take into account ranked list position for all words and compares easily with non-predictive text entry approaches; however, it is a rather abstract measure being based on letters, especially for dictionary-based approaches that are inherently word-based.

To gain an insight into potential expert user behaviour with different keyboards, different approaches have been taken to modelling interaction in order to predict expert (trained, error-free) performance. There are two basic approaches: physical movement modelling and keystroke level modelling. We (Dunlop & Crossan, 2000) proposed a keystroke level model based on Card, Moran and Newall's work (S. K. Card, Moran, & Newell, 1980). Our model was based on predicting the time *T(P)* taken by an expert user to enter a given phrase. The model calculates this in an equation that combines a set of small time measurements for elements of the user interaction. In the case of text entry: the homing time for the user to settle on the keyboard T_h (0.40 seconds); the time it takes a user to press a key T_k (0.28s); the time it takes the user to mentally respond to a system action T_m (1.35s); the length of an average word k_w (in our study, 4.98); and the number of words in the phrase *w* (in our model, 10). In addition, for predictive text entry where disambiguation occurs by the user moving through the ranked list of suggestions, the ARP value is required here given as *a*=1.03). The overall time equation for entering a phrase is then given as follows:

$$T(P) = T_h + w\,(k_w T_k + a(T_m + T_k)) \qquad (1)$$

Equation 1: Dunlop and Crossan's keystroke model. This model, as reported in (Dunlop & Crossan, 2000) and corrected by (Pavlovych &

Stuerzlinger, 2004), predicts a text entry time for a 10 word phrase at 31.2 seconds, equating to a speed of 19.3wpm—matching closely with experienced user experiments with T9 of 20.4 wpm (James & Reischel, 2001).

In this work we modelled keystroke speed at 0.28s based on a fixed figure from Card et al.'s work that is equivalent to "an average non-secretary typist" on a full QWERTY keypad. This gives fairly accurate predictions but cannot take into account fine grained keyboard design elements that can have a considerable impact on typing speed in practice: for example different keyboard layouts clearly affect the average time it takes a user to move his/her fingers to the correct keys. Mackenzie's group have conducted considerable work using Fitt's law (Fitts, 1954) to calculate the limit of performance given distance between keys (e.g. (Silfverberg, MacKenzie, & Korhonen, 2000)). The basic form of their distance-based modelling predicts 40.6 wpm for thumb-based predictive input—assuming no *next* key operations (essentially equivalent to no thinking or homing times in equation 1). Later work modifies the Fitt's distance models to take into account two inaccuracies that can noticeably affect predictions: repeated letters on the same key (Soukoreff & MacKenzie, 2002) and parallel finger movements where users move one finger at the same time as pressing with another (MacKenzie & Soukoreff, 2002).

These models are useful in predicting performance but focus on expert error-free performance. More complex modelling approaches have been researched to support novices to model more complete interaction, and to model error behaviour (e.g. (How & Kan, 2005; Pavlovych & Stuerzlinger, 2004; Sandnes, 2005)). Although users studies are the acid test for any interactive system, these models are valuable either in the early stages of design or to understand methods where user experiments are difficult, e.g. by being biased by users' prior experience of current technologies.

User Studies

Models that predict text entry performance only give us part of the picture, proper user studies often give a truer indication of how text entry methods perform in reality. While there are many parameters that can affect the design of user studies, the two prominent issues for text entry experiments are the environment in which the experiments are conducted and the phrases that users enter.

Most user studies into text entry have been conducted in laboratories. A laboratory is a controlled environment that leads to a more consistent user experience than the real world and, thus, considerably easier statistical analysis as there are fewer confounding variables from the environment to interfere with measurements taken. However, conducting experiments on people entering text on mobile phones in quiet office-like settings where they can focus exclusively on the text entry tasks is arguably not representative of normal use! There is a growing debate in mobile HCI research on the validity of laboratory experiments with some researchers arguing that, while the focus of most common errors is different in the real world, laboratory experiments do not miss errors that are found in real-world experiments (Kaikkonen, Kekäläinen, Cankar, Kallio, & Kankainen, 2005) while others claim a wider range of errors were found in the real-world than in laboratories (Duh, Tan, & Chen, 2006). (Kjeldskov & Graham, 2003) report that "71% [of studied evaluations were] done through laboratory experiments, 19% through field experiments and the remaining 10% through surveys". As a specific example, (Brewster, 2002) showed usability and text entry rates were significantly reduced for users performing an outdoor walking circuit, while entering on a soft numeric key-pad, than those conducting the same experiment in a traditional laboratory. Whereas (Mizobuchi, Chignell, & Newton, 2005) showed that, while walking was slowed down when using a device, it did not impinge upon the text entry rate or accuracy. Some researchers have tried to get the best of both worlds by conducting experiments indoors that attempt to mimic some of the distractions from the real world, while maintaining the controlled laboratory environment (e.g. Lumsden, Kondratova, and Durling 2007).

In experiments users are typically required to enter a set of phrases on devices to measure their text entry speed. While there is no widespread agreement on phrases that are used, (MacKenzie & Soukoreff, 2003) proposed a standard set of short phrases that has been used by other researchers and provides a valuable baseline for comparisons. One problem with mobile phone text entry is that it is often used for short casual messages and testing with formal phrases from a traditional text corpus is not appropriate (see differences discussed above for those who have experimented with formal/newsarticle English and SMS). This is compounded by the original multi-tap text entry approach and short length of SMS messages leading to considerable use of, often obscure, abbreviations that are not normally found in a corpus. To address this, (How & Kan, 2005) developed a large set of phrases extracted from SMS users' real text conversations. Although somewhat skewed to local Singaporean phrases and abbreviations (much of *SMS speak* is heavily localised and even personalised within a group of friends), the corpus is a valuable insight into the language often used on mobile phones.

Finally, it should also be noted that entry speeds of 33wpm for users when transcribing text on desktop keyboards have been found to drop to around 19wpm for composing new text (Karat, Halverson, Horn, & Karat, 1999), so most results from text entry experiments can be assumed to be over-inflating speeds by around 40% as they are typically based on transcription.

CONCLUSION AND FUTURE TRENDS

This article has reviewed a large number of text entry methods that range from standard methods that are very close to desktop keyboards, through slight variations, to radical novel interaction designs. We have looked at different hardware keyboard designs, different on-screen keyboard layouts, handwriting-based approaches and more novel approaches such as gestures. We have also looked at ambiguous and unambiguous designs, and the related approaches to disambiguation. Much of the work reported has experimental backing to show the potential benefits of each approach. However, when comparing the wide diversity of approaches in the literature to widely available implementations on real devices, the overriding message we see is that guessability, the initial pick-up-and-use usability of hardware/software, is paramount to success.

It is extremely hard to predict future trends for mobile devices: while there is considerable research showing the benefits and strengths of different approaches, market forces and the views of customers and their operators have a major role in deciding which techniques become widely adopted. Predicted gains in expert text entry performance are of no use if people do not understand how to use the text entry approach out of the box. To this end, we see considerable scope for entry methods that provide a smooth transition from novice to expert performance: XT9™ is one successful example of novice-to-expert support, as users get faster they'll learn to be sloppier and type faster, without necessarily being consciously aware of why. Context-aware word completion that learns about individuals is another area that shows good potential: good for slow novice typists as they start, but building context and personalising as they gain proficiency.

Finally, looking at current market directions and the increasing desire to enter more text on small devices, we see the 12-key keypad slowly disappearing from phones to be replaced with less number-centric entry methods. Despite its sub-optimality and problems on small devices, both market trends and some user tests point to the QWERTY keyboard taking on this role, either as a physical or an on-screen keyboard.

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REFERENCES

Bellman, T., & MacKenzie, I. S. (1998). *A probabilistic character layout strategy for mobile text entry.* Paper presented at the Graphics Interface '98, Toronto, Canada.

Brewster, S. A. (2002). Overcoming the Lack of Screen Space on Mobile Computers. *Personal and Ubiquitous Computing*, *6*(3), 188–205. doi:10.1007/s007790200019

Card, S., Moran, T., & Newell, A. (1983). *The psychology of human-computer interaction*. Lawrence Erlbaum Associates.

Card, S. K., Moran, T. P., & Newell, A. (1980). The keystroke-level model for user performance time with interactive systems. *Communications of the ACM*, *23*(7), 396–410. doi:10.1145/358886.358895

Clarkson, E., Clawson, J., Lyons, K., & Starner, T. (2005). An empirical study of typing rates on mini-QWERTY keyboards. In *CHI '05 Extended Abstracts*. ACM Press. doi:10.1145/1056808.1056898

Cockburn, A., & Siresena, A. (2003). *Evaluating Mobile Text Entry With The Fastap Keypad.* Paper Presented At The People And Computers Xvii (Volume 2): British Computer Society Conference On Human Computer Interaction, Bath, England.

Duh, H. B., Tan, G. C., & Chen, V. H. (2006). *Usability evaluation for mobile device: a comparison of laboratory and field tests.* Paper presented at the 8th Conference on Human-Computer interaction with Mobile Devices and Services: MobileHCI '06, Helsinki, Finland.

Dunlop, M. D. (2004). *Watch-Top Text-Entry: Can Phone-Style Predictive Text-Entry Work With Only 5 Buttons?* Paper presented at the 6th International Conference on Human Computer Interaction with Mobile Devices and Services: MobileHCI 04, Glasgow.

Dunlop, M. D., & Crossan, A. (2000). Predictive text entry methods for mobile phones. *Personal Technologies*, *4*(2). doi:10.1007/BF01324120

Dunlop, M. D., Glen, A., Motaparti, S., & Patel, S. (2006). *AdapTxt: contextually adaptive text entry for mobiles.* Paper presented at the 8th Conference on Human-Computer interaction with Mobile Devices and Services: MobileHCI '06, Helsinki, Finland.

Engelbart, D. C., & English, W. K. (1968). *A research center for augmenting human intellect.* Paper presented at the AFIPS 1968 Fall Joint Computer Conference, San Francisco, USA.

Evreinova, T., Evreino, G., & Raisamo, R. (2004). *Four-Key Text Entry for Physically Challenged People.* Paper presented at the 8th ERCIM workshop: User Interfaces for All (Adjunct workshop proceedings), Vienna, Austria.

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, *47*(6), 381–391. doi:10.1037/h0055392

Goldberg, D., & Richardson, C. (1993). *Touch-typing with a stylus.* Paper presented at the INTERCHI93.

Gong, J., & Tarasewich, P. (2005). *Alphabetically constrained keypad designs for text entry on mobile devices.* Paper presented at the CHI '05: SIGCHI Conference on Human Factors in Computing Systems Portland, USA.

Grover, D. L., King, M. T., & Kushler, C. A. (1998). USA Patent No. 5818437. I. Tegic Communications.

Hasselgren, J., Montnemery, E., Nugues, P., & Svensson, M. (2003). *HMS: A Predictive Text Entry Method Using Bigrams.* Paper presented at the Workshop on Language Modeling for Text Entry Methods, 10th Conference of the European Chapter of the Association of Computational Linguistics, Budapest, Hungary.

How, Y., & Kan, M.-Y. (2005). *Optimizing predictive text entry for short message service on mobile phones.* Paper presented at the Human Computer Interfaces International (HCII 05), Las Vegas, USA.

James, C. L., & Reischel, K. M. (2001). *Text input for mobile devices: comparing model prediction to actual performance.* Paper presented at the SIGCHI conference on Human factors in computing systems, Seattle, Washington, United States.

Kaikkonen, A., Kekäläinen, A., Cankar, M., Kallio, T., & Kankainen, A. (2005). Usability Testing of Mobile Applications: A Comparison between Laboratory and Field Testing. *Journal of Usability Studies*, *1*(1), 4–17.

Karat, C., Halverson, C., Horn, D., & Karat, J. (1999). *Patterns of Entry and Correction in Large Vocabulary Continuous Speech Recognition Systems.* Paper presented at the ACM CHI99: Human Factors in Computing Systems.

Kjeldskov, J., & Graham, C. (2003). *A Review of Mobile HCI Research methods.* Paper presented at the Fifth International Symposium on Human Computer Interaction with Mobile Devices and Services: MobileHCI 03, Udine, Italy.

Kushler, C. (1998). *AAC Using a Reduced Keyboard.* Paper presented at the Technology and Persons with Disabilities Conference, USA.

Lumsden, J., Kondratova, I., & Durling, S. Investigating Microphone Efficacy for Facilitation of Mobile Speech-Based Data Entry, *Proceedings of The 21rst British Computer Society (BCS) HCI Annual Conference*. Lancaster, UK. 3-7 September 2007.

MacKenzie, I. S. (2002a). *KSPC (keystrokes per character) as a characteristic of text entry techniques.* Paper presented at the MobileHCI 02: Fourth International Symposium on Human-Computer Interaction with Mobile Devices, Pisa, Italy.

MacKenzie, I. S. (2002b). *Mobile text entry using three keys.* Paper presented at the Proceedings of the second Nordic conference on Human-computer interaction, Aarhus, Denmark.

MacKenzie, I. S., Kober, H., Smith, D., Jones, T., & Skepner, E. (2001). *LetterWise: prefix-based disambiguation for mobile text input* Paper presented at the 14th annual ACM symposium on User interface software and technology Orlando, USA.

MacKenzie, I. S., Nonnecke, R. B., McQueen, C., Riddersma, S., & Meltz, M. (1994). *A comparison of three methods of character entry on pen-based computers.* Paper presented at the Factors and Ergonomics Society 38th Annual Meeting, Santa Monica, USA.

MacKenzie, I. S., & Soukoreff, R. W. (2002). *A model of two-thumb text entry.* Paper presented at the Graphics Interface 2002.

MacKenzie, I. S., & Soukoreff, R. W. (2003). *Phrase sets for evaluating text entry techniques.* Paper presented at the ACM Conference on Human Factors in Computing Systems – CHI 2003, New York, USA.

MacKenzie, I. S., Zhang, S. X., & Soukoreff, R. W. (1999). Text entry using soft keyboards. *Behaviour & Information Technology*, *18*, 235–244. doi:10.1080/014492999118995

Mankoff, J., & Abowd, G. D. (1998). *Cirrin: a word-level unistroke keyboard for pen input.* Paper presented at the 11th Annual ACM Symposium on User interface Software and Technology: UIST '98., San Francisco, USA.

Matias, E., MacKenzie, I. S., & Buxton, W. (1996). One-handed touch typing on a QWERTY keyboard. *Human-Computer Interaction*, *11*(1), 1–27. doi:10.1207/s15327051hci1101_1

Mizobuchi, S., Chignell, M., & Newton, D. (2005). *Mobile text entry: relationship between walking speed and text input task difficulty.* Paper presented at the MobileHCI 05: 7th international Conference on Human Computer interaction with Mobile Devices and Services Salzburg, Austria.

Norman, D. A. (2002). *The Design of Everyday Things*: Basic Books. Norman, D. A., & Fisher, D. (1982). Why Alphabetic Keyboards Are Not Easy to Use: Keyboard Layout Doesn't Much Matter. *The Journal of the Human Factors Society*, *25*(5), 509–519.

Pavlovych, A., & Stuerzlinger, W. (2004). *Model for non-expert text entry speed on 12-button phone keypads.* Paper presented at the CHI '04: SIGCHI Conference on Human Factors in Computing Systems, Vienna, Austria.

Perlin, K. (1998). *Quikwriting: continuous stylus-based text entry.* Paper presented at the 11th Annual ACM Symposium on User interface Software and Technology: UIST '98, San Francisco, USA.

Proschowsky, M., Schultz, N., & Jacobsen, N. E. (2006). *An intuitive text input method for touch wheels.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems: CHI '06, Montréal, Canada.

Robinson, B. A., & Longe, M. R. (2000). USA Patent No. 6,801,190 / 7,088,345.

Sandnes, F. E. (2005). *Evaluating mobile text entry strategies with finite state automata.* Paper presented at the MobileHCI 05: 7th international Conference on Human Computer interaction with Mobile Devices and Services, Salzburg, Austria.

Shannon, C. (1951). Prediction and Entropy of Printed English. *The Bell System Technical Journal*, *30*, 50–64.

Silfverberg, M., MacKenzie, I. S., & Korhonen, P. (2000). *Predicting text entry speed on mobile phones.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems (CHI'00), The Hague, The Netherlands.

Soukoreff, R. W., & MacKenzie, I. S. (2002). *Using Fitts' law to model key repeat time in text entry models.* Paper presented at the Graphics Interface 2002.

Ward, D. J., Blackwell, A. F., & MacKay, D. J. (2000). *Dasher - a data entry interface using continuous gestures and language models.* Paper presented at the 13th Annual ACM Symposium on User interface Software and Technology: UIST '00, San Diego, USA.

Wigdor, D., & Balakrishnan, R. (2003). *TiltText: using tilt for text input to mobile phones.* Paper presented at the 16th annual ACM Symposium on User Interface Software and Technology (UIST '03), New York, USA.

Wigdor, D., & Balakrishnan, R. A. (2004). *Comparison of consecutive and concurrent input text entry techniques for mobile phones.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems (CHI '04), New York, USA.

Williamson, J., & Murray-Smith, R. (2005). *Dynamics and probabilistic text entry.* Paper presented at the Hamilton Summer School on Switching and Learning in Feedback systems.

Zhai, S., & Kristensson, P. (2003). *Shorthand writing on stylus keyboard.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems: CHI '03, Ft. Lauderdale, Florida, USA.

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Chapter 4

On-the-Move and in Your Car:
An Overview of HCI Issues for In-Car Computing

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ABSTRACT

The introduction of computing and communications technologies within cars raises a range of novel human-computer interaction (HCI) issues. In particular, it is critical to understand how user-interfaces within cars can best be designed to account for the severe physical, perceptual and cognitive constraints placed on users by the driving context. This article introduces the driving situation and explains the range of computing systems being introduced within cars and their associated user-interfaces. The overall human-focused factors that designers must consider for this technology are raised. Furthermore, the range of methods (e.g. use of simulators, instrumented vehicles) available to designers of in-car user-interfaces are compared and contrasted. Specific guidance for one key system, vehicle navigation, is provided in a case study discussion. To conclude, overall trends in the development of in-car user-interfaces are discussed and the research challenges are raised.

INTRODUCTION

The motor car is an integral part of modern society. These self-propelled driver-guided vehicles transport millions of people every day for a multitude of different purposes, e.g. as part of work, for visiting friends and family, or for leisure activities. Likewise, computers are essential to many peoples' regular lives. It is only relatively recently that these two products have begun to merge, as computing-related technology

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is increasingly implemented within road-going vehicles. The functions of an in-car computing system can be broad, supporting tasks as diverse as navigation, lane keeping, collision avoidance and parking. Ultimately, by implementing such systems car manufacturers aim to improve the safety, efficiency and comfort/entertainment of the driving experience (Bishop, 2005)

Designing the user-interface for in-car computing systems raises many novel challenges, quite unlike those traditionally associated with interface design. For instance, in many situations, the use of an in-car system is secondary to the complex and already demanding primary task of safely controlling a vehicle, whilst simultaneously maintaining an awareness of hazards, largely using the visual sense. Consequently, the level of workload (physical, visual and mental) when using displays and controls becomes a critical safety-related factor. As a further example, in-car computing systems have to be used by a driver (and possible also, a passenger) who is sat in a constrained posture and is unlikely to be able to undertake a two handed operation. Therefore, the design (location, type, size, etc.) of input devices has to be carefully considered, accounting in particular for comfort, as well as safety, requirements.

This article aims primarily to provide the reader with an overall awareness of novel in-car computing systems and the key HCI design and evaluation issues. The focus is on the user-interface, that is, "the means by which the system reveals itself to the users and behaves in relation to the users' needs" (Hackos and Redish, 1998, p.5). Topics of relevance to both researchers and practitioners are raised throughout. Given the complexity of the driving task and the wide range of computing systems of relevance, the article principally provides breadth in its consideration of the subject. Nevertheless, some depth is explored in a case study investigation on the design and evaluation of user-interfaces for vehicle navigation systems.

TYPES OF IN-CAR COMPUTING SYSTEM

Technology is increasingly being seen to have a critical role to play in alleviating the negative aspects of road transport, such as congestion, pollution and road traffic accidents (Bishop, 2005). Many technological initiatives are considered under the umbrella term, Intelligent Transport Systems (ITS), where "ITS provides the intelligent link between travellers, vehicles, and infrastructure" (www.itsa.org, September, 2006). In this respect, in-vehicle computing systems are an important facet of ITS. Specifically, there are two core types of computing and communications systems which are either being implemented or developed for use in vehicles:

- **Information-based systems:** which provide information relevant to components of the driving environment, the vehicle or the driver. Examples of systems include navigation (facilitating route planning and following), travel and traffic information (traffic conditions, car parking availability, etc.), vision enhancement (providing an enhanced view of the road ahead, when driving at night, in fog or in heavy rain), driver alertness monitoring (informing the incapacitated driver if they are unfit to drive) and collision warnings (presenting warnings/advice regarding hazards).
- **Control-based systems:** which affect the routine, operational elements of the driving task. Examples of systems include adaptive cruise control (where the car is kept at a set time gap from a lead vehicle), speed limiting (the car speed cannot exceed the current limit), lane keeping (the driver's vehicle is kept within a given lane), self parking (vehicle automatically steers in low speed operation to position itself within a selected parking space)

and collision avoidance (the vehicle automatically responds to an emergency situation). Clearly, such systems fundamentally change the nature of what we consider to be 'driving'.

It is important to note that there is a third category of in-car computing system, those which do not provide any functionality to support the driving task. These systems are an important consideration though, as they can negatively influence safety, particularly through the potential for distraction (Young, Regan and Hammer, 2003). Such systems may aim to enhance work-oriented productivity whilst driving (e.g. mobile phones, email/internet access) or be primarily conceived for entertainment/comfort purposes (e.g. music/DVD players, games). Moreover, they may be designed for dedicated use in a vehicle or for operation in a range of different contexts, e.g. as a driver and as a pedestrian (often termed nomadic devices).

OVERALL HUMAN FACTORS ISSUES

Driving is a complex task involving a large number of subtasks that can be conceptualised as existing within three levels of an overall hierarchical structure (Michon, 1985):

- **Strategic tasks** (highest level global travel decisions—e.g. which car to take, which route to take);
- **Tactical tasks** (making concrete manoeuvres requiring interaction with other road users –e.g. changing lane, turning at a roundabout);
- **Operational tasks** (motor execution of tasks planned at higher levels—e.g. turning steering wheel, pressing brake).

Inevitably, the introduction of new technologies into the driving context will have a considerable impact across all three levels. As a result, there are many human-focused issues that must be considered in the design and evaluation process for in-car computing systems. To provide structure to a discussion of these issues, two overall scenarios are envisaged which may arise from poor design and/or implementation of the technology.

- **Overload:** Many of these systems (particularly those providing novel types of information and/or interactions) lead to situations in which a driver must divide their attention between core driving tasks (e.g. watching out for hazards) and secondary system tasks (e.g. inputting information). Furthermore, systems may provide excessive information in an inappropriate way leading to high levels of mental workload, stress and frustration. Such issues often manifest themselves as distraction to the driver (biomechanical, visual, auditory and/or cognitive).
- **Underload:** Control-based systems clearly automate certain aspects of driving, transferring certain responsibilities from operator to computer (e.g. staying in lane), whilst potentially providing new tasks for the driver (e.g. monitoring system performance). Automation is a fundamental human factors topic with a considerable research literature (see Wickens et al., 2004). Key concerns in this context relate to the potential for a driver exhibiting reduced situational awareness (e.g. for other road users), negative behavioural adaptation (e.g. by taking greater risks) and de-skilling (e.g. driver not able to resume control in the event of system failure).

THE HUMAN-CENTRED DESIGN PROCESS

The fundamental components of a human-focused approach hold true for in-car computing, as much as for any interactive product or system, that is, early focus on users and tasks, empirical measurement and iterative design (Gould and Lewis, 1985). A comprehensive understanding of the context in which in-car computing devices will be used is especially important early in the design process. Context of use refers to "the users, tasks and equipment (hardware, software and materials), and the physical and social environments in which a product is used" (Maguire, 2001, p.457). A context of use analysis assists in developing the initial requirements for a design and also provides an early basis for testing scenarios. Moreover, context of use analysis provides a focused approach which helps to ensure a shared view among a design team. In the driving situation, there are several context of use issues which will have a significant effect on how an in-car computing system is subsequently designed. Accounting for these raises many unique challenges for in-car user-interface designers.

Users

As with many other consumer products, there will be a large variability in user characteristics (e.g. in perceptual/cognitive abilities, computer experience, anthropometry) to consider when designing in-car computing systems. Car manufacturers may have particular socio-economic groups in mind when designing a vehicle, but the user base may still be extremely large.

One fundamental individual difference factor often addressed in research is driver age - drivers can be as young as 16 (in certain countries) and as old as 90. In this respect, younger drivers may be particularly skilled in the use of computing technology, in comparison with the population at large, but are especially prone to risk taking (Green, 2003). Moreover, studies have shown a limited ability to divide attention and prioritise sources of information, largely due to lack of driving experience (Wickman, Nieminem and Summala, 1998). Subsequently, system block outs, which prevent the use of complex functions in inappropriate driving situations, are likely to be of particular benefit for these individuals.

In contrast, older drivers often suffer from a range of visual impairments which can lead to a range of problems with in-vehicle displays. For instance, presbyopia (loss of elasticity in the lens of the eye) is extremely common amongst older people, as is reduced contrast sensitivity. Studies consistently show that older drivers can take 1.5 to 2 times longer to read information from an in-vehicle display compared to younger drivers (Green, 2003). Given that drivers have a limited ability to change the distance between themselves and an in-vehicle display, the size, luminance and contrast of presented information are obviously critical design factors.

Tasks

A key task-related issue is that the use of an in-car computing system is likely to be discretionary. Drivers do not necessarily have to use the system to achieve their goals and alternatives will be available (e.g. a paper map, using the brake themselves). As a result, the perceived utility of the device is critical. Furthermore, drivers' affective requirements may be particularly important. In certain cases, this requirement may conflict with safety-related needs, for instance, for a simple, rather than flashy or overly engaging user-interface.

The factor that most differentiates the driving context from traditional user-interface design is the multiple-task nature of system use, and in this respect, there are two critical issues that designers must take into consideration. The first concerns the relationship between primary driving tasks and secondary system tasks, as drivers seek to divide their attention between competing sources of information. Driving is largely a performance and time-critical visual-manual task with significant spatial components (e.g. estimating distances). Consequently, secondary tasks must not be overly time consuming to achieve and/or require attentional resources that are largely visual/manual/spatial in nature, if they are to avoid having a significant impact on primary driving.

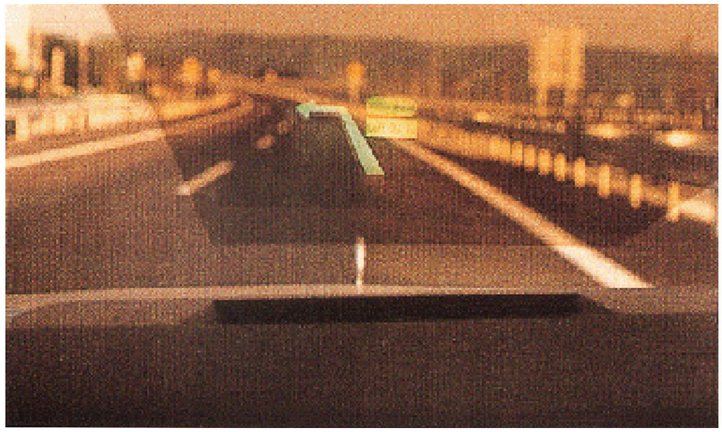
A second fundamental issue is the amount of information processing or decision making required for successful task performance, known as mental workload (Wickens et al., 2004). Novel in-car computing systems may provide functionality of utility to a driver and/or passengers, but interaction with the technology will inevitably increase (or in some cases decrease) overall workload. Context is very important here, as driving is a task in which workload varies considerably from one situation to another (compare driving in city traffic versus on the motorway). In this respect, certain authors (e.g. Jones, 2002; Green, 2004; Markkula, Kutila, and Engström, 2005) have taken the view that workload managers must be developed which make real-time predictions of the workload a driver is under and only present information or enable interactions to occur when overall workload is considered to be at an acceptable level. As an example, an incoming phone call may be sent straight to voice mail when the driver is considered to be particularly loaded (e.g. when driving in an unfamiliar city), but may be permitted in a lower workload scenario (e.g. driving along a dual carriageway and following a lead vehicle). Simple workload managers already exist in some vehicles (e.g. http://driving.timesonline.co.uk/article/0,,12929-2319048,00.html, September 2006), nevertheless, there are several complex research issues which must be addressed to fully realise the benefits of adaptive software in this context. For instance, workload managers need a comprehensive and accurate model of the driver, driving tasks and the driving environment. Given the vast range of variables of relevance to these categories, many of which do not lend themselves to accurate and reliable measurement, extensive workload managers are likely to remain in the research domain for several years.

Equipment

The driving situation necessitates the use of input and output devices which are familiar to the majority of user-interface designers (pushbuttons, rockers, rotaries, LCDs, touchscreens, digitised/synthesised speech), together with equipment which is perhaps less known. For instance, there is a considerable research literature regarding the use of Head-Up Displays (HUDs) within vehicles. A HUD uses projection technology to provide virtual images which can be seen in the driver's line of sight through the front windscreen (see Figure 1). They are widely used within the aviation and military fields, and are now beginning to be implemented on a large-scale within road-based vehicles. HUDs will potentially allow drivers to continue attending to the road ahead whilst taking in secondary information more quickly (Ward and Parkes, 1994). As a consequence, they may be most applicable to situations in which the visual modality is highly loaded (e.g. urban driving), and for older drivers who experience difficulties in rapidly changing accommodation between near and far objects (Burns, 1999).

From a human-focused perspective, there are clear dangers in simply translating a technology from one context to another, given that vehicle-based HUDs will be used by people of varying perceptual/cognitive capabilities within an environment where there is a complex, continually changing visual scene. Specifically, researchers have established that poorly designed HUDs can mask critical road information, disrupt distance perception and visual scanning patterns, and negatively affect the ability of drivers to detect hazards in their peripheral vision (known as perceptual tunnelling) - summarised by Tufano, 1997; and Ward and Parkes, 1994). Critical design fac-

Figure 1. Example of a head-up display (HUD)



tors that emerge from these findings include: display complexity; contrast/luminance; colour/s choice; size of image/s; spatial location; and virtual image distance. Perhaps the most important design-related requirements are to consider carefully what and how much information is most appropriate to present on a HUD. There are temptations for designers to present ever-increasing amounts of information on HUDs. However, in contrast with traditional in-vehicle displays, a HUD image, by its very presence in the driver's line of sight, will demand focused attention (Burnett, 2003).

Environments

The physical environment is also a specific area that designers need to be aware of. In particular, the light, sound, thermal and vibration environment within a car can be highly variable. A range of design requirements will emerge from a consideration of these factors, for instance, potential for glare, problems with speech interfaces, use with gloves, and so on.

From anthropometric and biomechanical perspectives, the vehicle cabin environment provides many challenges for designers. This is an area in which designers make considerable use of CAD modelling to analyse different locations for displays and controls, ultimately aiming to ensure good fit for the design population. However, drivers sit in a constrained posture, often for several hours and have limited physical mobility (e.g. to comfortably viewing displays or reach controls). Consequently, there is limited space within a vehicle for the placement of a physical user-interface, a key problem for designers hoping to implement additional functionality within the vehicle.

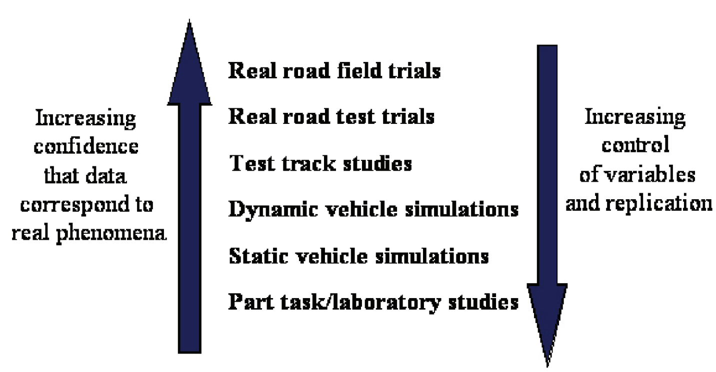
To a large extent, this factor has fuelled the development of multi-modal user-interfaces, where a small number of controls, together with menu-driven screens, provide access to many functions within the vehicle. Clearly, such visually-oriented user-interfaces are likely to promote a considerable amount of "eyes-off-road" time, and empirical studies have confirmed this prediction (Dewar, 2002). Moreover, there is a clear potential for users to mistake the current mode (a well established problem in user-interface design), and clear feedback is an important design requirement (Preece, Rogers and Sharp, 2002). In many respects, there is a trade-off in design between the number of discrete controls that a user must scan within a vehicle and the number of levels within a menu-based system that must be explored and understood. This is a very similar problem to that considered by HCI researchers in the 1980s and 1990s interested in the breadth versus depth of menus in graphical user-interfaces (Shneiderman, 1998). An overall recommendation from such HCI research is that breadth should generally be favoured over depth, as excessive depth can cause considerably more problems for the user than an equivalent breadth, largely due to the cognitive problems of navigation (Shneiderman, 1998). Whilst such guidance is considered to be of relevance to the design of in-car computing, research is still required which considers the trade-off existing in the multiple-task driving environment.

METHODS FOR USE IN DESIGN AND EVALUATION

In considering the range of methods that a designer can utilise when designing and evaluating in-car computing systems, the first difficulty is in establishing what is meant by a method. In this respect, a "human factors method for testing in-car systems" can be seen to be a combination of three factors:

1. Which environment is the method used in (road, test track, simulator, laboratory, etc.). As can be seen in Figure 2 (redrawn and adapted from Parkes, 1991), there is a fundamental trade off in choosing a method environment between the need for control and the validity of results. Choosing an environment will also be largely influenced by practical considerations, the knowledge/ skills of the design/evaluation team and resource limitations.
2. Which task manipulations occur (multiple task, single task loading, no tasks given, etc.). In certain methods, there is an attempt to replicate or simulate the multiple task nature of driving. For other methods, performance and/or behaviour on a single task may be assessed and the potential impact on other tasks inferred from this. Most removed from actual driving, some methods do not involve users, but instead aim to predict impacts or issues, for instance through the use of expert ratings or modelling techniques.
3. Which dependent variables (operationalised as metrics) are of interest. In assessing an in-car computing user-interface, a large range of possible metrics could be implemented. Some will relate to drivers' performance with primary driving tasks (e.g. lane position, hazard detection) or their use of primary vehicle controls (e.g. use of brake, steering wheel). Other metrics focus on driver performance and/or the demand of secondary tasks (e.g. task times, errors, display glances). As noted by Parkes (1991),

Figure 2. Environments for evaluation of in-car computing devices and the relationship between validity and control (adapted from Parkes, 1991)



> usability evaluations of in-car computing devices should incorporate a wide range of measures relevant to the different levels of the driving task. For instance, at the strategic level, observation techniques and surveys are of relevance, whereas verbal protocols, interviews and questionnaires can capture the behaviour of drivers at the tactical level. As noted by Parkes, such an approach provides "complete, rather than partial, pictures of product usability" (p.1445).

There is presently considerable research investigating specific methods for use in the design and evaluation of in-car user-interfaces. As noted by Preece, Rogers and Sharp (2002), in deciding on any HCI method, the design team must consider the overall goals of the work, specific questions to be addressed, the practical and ethical issues and how data will need to be analysed and reported. For in-car computing, these principles still hold, and many of the same global techniques used in the HCI area (for example, questionnaires, interviews, guidelines/checklists) will be used. However, by necessity, bespoke methods (or at least specific versions of generic methods) are required that account for the particular complex, safety-critical characteristics of the driving context. The following section summarises key methods currently used and highlights some of the important research issues under investigation. Moreover, primary advantages and disadvantages are given. Table 1 summarises some of the key issues.

Field Trials

Participants are given a car fitted with an operational system for several months for use in everyday activities. This method tends to look at broad issues relating to the long-term use of a system, for example, drivers' acceptance of the technology, and whether any behavioural adaptation effects arise. Objective data can be measured using on-board instrumentation (e.g. cameras, speed sensors) whereas subjective data is often captured using survey or interview-based approaches. Clearly, such a method provides an ecologically valid test of a system, and is particularly appropriate to the late stages of the design process where a robust prototype is available. Nevertheless, field trials can be extremely expensive and various ethical and liability considerations must be accounted for. An example of a field trial that was carried out in Sweden concerned drivers' use of intelligent speed adaptation systems (whereby a vehicle's speed is automatically kept within the speed limit for the current area)—Wallen, Warner and Aberg (2005).

Road Trials

Drivers take part in a short-term (normally less than one day) focused study using a system in an instrumented car on public roads (occasionally on test tracks). For such trials, a wide range of variables may be measured and analysed (e.g. visual behaviour, workload, vehicle control, subjective preference) depending on the aims of the study. Road trials enable more experimental control than field trials, but are still potentially affected by a wide range of confounding variables (e.g. traffic conditions, weather). Furthermore, such a method remains costly to implement and requires robust protocols to ensure the safety of all concerned. Many road trials are reported in the literature, particularly concerning information and entertainment/productivity oriented systems. For instance, Burnett and Joyner (1997) describe a study which evaluated two different user-interfaces for vehicle navigation systems.

Simulator Trials

Drivers take part in a short-term (normally less than one day) focused study using a system fitted or mocked up within a driving simulator. The faithfulness that a simulator represents the driving task (known as its fidelity) can vary considerably,

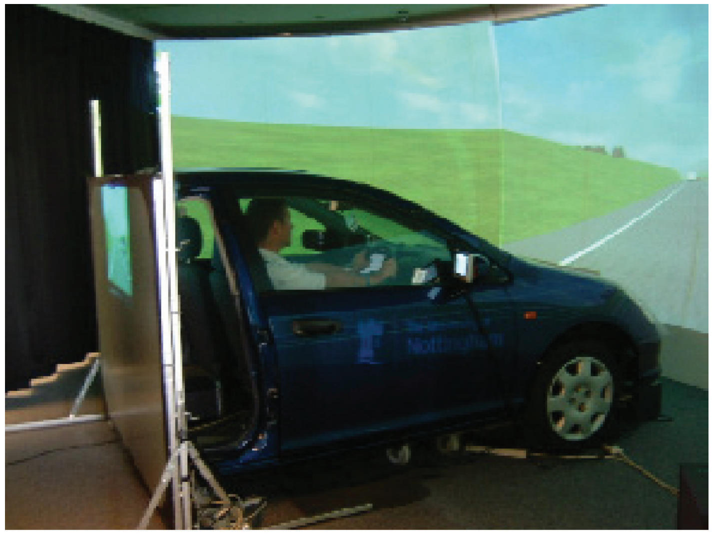
Table 1. Overview of methods used to evaluate the user-interface for in-car computing systems

Method	Environment	Task manipulations	Overall Measures	Primary Advantages	Primary Disadvantages
Field trials	Real road (in everyday driving)	Multi-task (according to driver motivation)	Primary/ secondary task performance/ behaviour, user opinions, etc.	Ecological validity, can assess behavioural adaptation	Resource intensive, ethical/liability issues to consider
Road trials	Real road (in predefined settings)	Multi-task (commonly, evaluator-manipulated)	Primary/ secondary task performance/ behaviour, user opinions, etc.	Balance of ecological validity with control	Resource intensive, ethical/liability issues to consider
Simulator trials	Virtual driving environment (varying in fidelity)	Multi-task (commonly, evaluator-manipulated)	Primary/ secondary task performance/ behaviour, user opinions, etc.	Control over variables, safe environment, cost-effective	Validity of driver behaviour, simulator sickness
Occlusion	Laboratory/ statically in car	Secondary task achieved in controlled visual experience	Visual demand of user-interface	Standardised approach, control over variables	Limited scope, concern over validity of approach and metrics
Peripheral detection	Road/virtual driving environment	Multi-task (although commonly, evaluator-manipulated)	Visual/ cognitive workload	Assesses cognitive, as well as visual demand	Can be resource intensive, range of approaches
Lane change task	Specific lo-fidelity virtual driving environment	Multi-task motorway driving scenario	Primary lateral control of vehicle	Standardised approach, control over variables	Difficult to relate results to interface characteristics
15 second rule	Laboratory/ statically in car	Secondary task achieved without presence of driving task	Secondary task time (whilst stationary)	Simple approach	Only relates to certain aspects of visual demand
Keystroke-Level Model (KLM)	Modelling exercise	No user trials take place - models expert performance	Secondary task time (whilst stationary)	Quick/cheap, analysis explains results	Only relates to certain aspects of visual demand
Extended KLM	Modelling exercise	As for KLM, but with additional assumptions	Visual demand of user-interface	Quick/cheap, analysis explains results	Requires reliability assessments

and configurations range from those with single computer screens and game controller configurations, through to real car cabins with multiple projections and motion systems. An example of a medium fidelity driving simulator is shown in Figure 3.

Driving simulators have become increasingly popular in recent years as a result of reduced hardware and software costs, and potentially offer an extremely cost-effective way of investigating many different design and evaluation issues in a safe and controlled environment (Reed and Green, 1999). Nevertheless, there are two key research issues concerning the use of driving simulators. Firstly, it is well known that individuals can experience symptoms of sickness in driving simulators, manifested as feelings of nausea, dizziness and headaches. There has been considerable research regarding such sickness in virtual environments, and whilst there is still debate regarding the theoretical basis for the phenomenon (see for instance Nichols and Patel, 2002), there is practical guidance for those using driving simulators. For instance, screening questionnaires can be used to eliminate individuals who are most likely to experience sickness during a trial (Kennedy et

Figure 3. Example of a medium fidelity driving simulator



al., 2001). Furthermore, various countermeasures can be used in the development of the simulator and its environment to reduce the prevalence of sickness (e.g. high, consistent frame rate, air-conditioning, natural background lighting)—Nichols and Patel (2002).

A second and more complex issue concerns validity, particularly behavioural (or construct) validity, that is, the extent to which drivers behave in the simulator as they would in the real world (Blaauw, 1982; Reed and Green, 1999). Driving simulator validity is problematic to study for several reasons. Running both road and simulator trials which are comparable (in terms of participants, tasks, measures, procedures, etc.) can be extremely difficult to achieve, and ultimately will be resource intensive. Furthermore, validity in this area is widely recognised to be a function of a large number of variables, including those relating to how the vehicle is represented (e.g. primary and secondary control design, the sense of enclosure, viewing angles, engine noise, vibration, motion, etc.) and those concerning the driving environment (e.g. visual field of view, screen resolution, graphical complexity, traffic representation, wind/road noise, etc.) - Kaptein et al. (1996); Peters and Peters (2002). Most importantly, our understanding of validity must consider the driving task itself. Driving is a complex task, involving a substantial number of discrete physical, perceptual and cognitive behaviours, and a specific simulator configuration will only enable a subset of these to be investigated (e.g. speed control, headway maintenance).

As a consequence, despite the importance of the topic, there are few driving simulator validity studies in the open literature. Moreover, various limitations can be expressed for previous research in this area:

- It is difficult to generalise from existing validity studies, as they tend to be very specific to a) the simulator configuration under investigation, and b) the technology (hardware and software) available at that time (see for instance, Tornros (1998) compared with Blaauw (1982)).
- Studies inevitably only concern a small number of variables, for instance the effect of screen resolution and forward field of view on speed and headway choice (Jamson, 2001); or the effect of character-

Figure 4. The occlusion method with participant wearing occlusion goggles, with shutters open (left) and closed (right)

istics of torque feedback for steering on curve negotiation (Toffin et al., 2003).

- Studies often do not report critical data regarding the simulator configuration (e.g. steering sensitivity, max/min acceleration, driver eye height) which, for given types of study will be critical in results interpretation and cross-study comparison.

Occlusion

This is a laboratory-based method which focuses on the visual demand of in-vehicle systems. Participants carry out tasks with an in-vehicle system (stationary within a vehicle or vehicle mock up) whilst wearing computer-controlled goggles with LCDs as lenses which can open and shut in a precise manner (see Figure 4). Consequently, by stipulating a cycle of vision for a short period of time (e.g. 1.5 seconds), followed by an occlusion interval (e.g. 1.5 seconds), glancing behaviour is mimicked in a controlled fashion. Occlusion offers a relatively simple method of predicting visual demand, but is has been pointed out that its emphasis on user trials and performance data means that it requires a robust prototype and is therefore of limited use early in the design process (Pettit et al., 2006).

Following considerable research, the occlusion method has recently been formalised as an international standard (ISO, 2005). In particular, guidance is given on how many participants are required, how much training to give, how many task variations to set, data analysis procedures, and so on. Moreover, two key metrics are stipulated: total shutter open time (the total time required to carry out tasks when vision is available); and resumability (the ratio of total shutter open time to task time when full vision is provided). For resumability, there is considerable debate regarding the merit of the measure. Advocates believe the metric provides an indication of the ease by which a task can be resumed following a period without vision (Baumann et al., 2004). Critics point out that the metric is also influenced by the degree to which participants are able to achieve tasks during occluded (non vision) periods (Pettit et al., 2006). Consequently, it can be difficult for a design team to interpret the results of an occlusion trial.

Peripheral Detection Task

This method requires drivers to carry out tasks with an in-car system (either on road or in a simulator) and to respond to the presence of lights within their periphery. The speed and accuracy of responses are considered to relate to the mental workload and distraction associated with secondary tasks (Young, Regan and Hammer, 2003). The advantage of this method over occlusion is that it offers an assessment of cognitive, as well as visual demand (of relevance to the assessment of speech interfaces, for instance). The primary disadvantage is that the method still requires some form of driving task. Moreover, in contrast with occlusion, the method has not been fully standardised, and the ability to make cross study comparisons is severely limited by the specific choice of driving task scenarios (affecting task load and the conspicuity of the peripheral stimuli). It has also been noted that it is very difficult to discern between the level of cognitive demand and the visual demand for a given user-interface (Young, Regan and Hammer, 2003).

An interesting recent development addresses some of these limitations. Engstrom, Aberg and Johansson (2005) considered the potential for the use of a haptic peripheral detection task, where drivers respond to vibro-tactile stimulation through the wrist whilst interacting with an in-vehicle system. Clearly, such a variation of peripheral detection is not affected by variations in lighting conditions. Furthermore, the authors argue on the basis of their validation work that this method provides "a "pure" measure of cognitive load not mixed up with the effect of simply looking away" (p.233).

Lane Change Task

This method occurs in a basic PC simulated environment in which drivers are requested to make various lane change manoeuvres whilst engaging with an in-vehicle system. The extent to which the profile of manoeuvre made by a driver varies from the optimum manoeuvre (the normative model) is considered to be a measure of the quality of their driving. Specifically, the method has the ability to assess the impact of an in-car computing system on a driver's awareness of the driving environment (perception, reaction), and, their ability to safely control the vehicle (manoeuvring, lane keeping)—Mattes (2003). Considerable research is ongoing with the lane change task in an attempt to develop an international standard (Transport Canada, 2006). Key research issues concern participant choice, training requirements and developing acceptable limits for performance.

15 Second Rule

Participants carry out tasks with an in-car computing system whilst stationary within a vehicle or mock up (i.e. with no driving task) and with full vision. The mean time to undertake a task is considered to be a basic measure of how demanding visually it is likely to be when driving (Green, 1999). A "cut-off" of 15 seconds has been set by the Society for Automotive Engineers (SAE) - if the task on average takes longer than 15 seconds to achieve when stationary, it should not be allowed in a moving vehicle. The method is simple to implement and has the key advantage that it has been formalised in an SAE statement of best practice (SAE, 2000).

Research by Green (1999) and other research teams (e.g. Pettitt et al., 2006) has shown strong correlations between static task times and the total amount of time spent looking away from the road at displays/controls, both in simulator and road studies. However, the correlation between static task times and the duration of single glances towards an in-vehicle display is generally poor. This is important because a user-interface may promote a small number of very long glances (e.g. as a result of dynamically changing visual information) which can have a considerable negative effect on driving performance (Burnett and Joyner, 1997). It is for this primary reason that many authors advocate the use of the occlusion method as a better low-cost method for investigating the visual demand of an in-car user-interface (Pettitt et al., 2006; Stevens et al., 2004).

Keystroke Level Model (KLM)

The KLM method from the GOMs family of techniques is well known to HCI researchers and (to a lesser extent) practitioners (Shneiderman, 1998; Preece, Rogers and Sharp, 2002). It is a form of task analysis in which system tasks with a given user-interface are broken down into their underlying physical and mental operators, e.g. pressing buttons, moving hand between controls, scanning for information. This is a method that is extremely cheap to implement, as there is no need for participants, and the method can be used with very basic prototypes early in the design process. Time values are associated with each operator and summed to give a prediction of task times. Researchers have developed new operator values relevant to the in-car situation (e.g. time to search a visual display, locate a control, move hand back to steering wheel) and have reported strong correlations between predicted task times and times based on user trials (Green, 2003; Pettitt, Burnett and Karbossioun, 2005). As noted above, task times can be related to certain measures of visual demand for in-car user-interfaces.

In an extension of the KLM method, Pettitt, Burnett and Stevens (2007) recently developed new rules that enable designers to develop predictions for a broader range of visual demand measures. In particular, the extended KLM considers a time-line view of an interaction in which a cycle of vision/non-vision occurs with a user-interface (similar to the occlusion protocol). The authors have found that their version of KLM can differentiate between tasks as effectively as does the occlusion technique, but recommend that further development is carried out to ensure that practitioners can utilise the method reliably.

CASE STUDY: VEHICLE NAVIGATION SYSTEMS

To ground many of the issues raised above, a specific system type has been chosen for further discussion (vehicle navigation systems). Many of the individual points made for this system can be generalised and are applicable to other in-car computing technologies.

Vehicle navigation systems aim to support the strategic (e.g. route planning) and tactical (e.g. route following) components of the overall driving task. They have the greatest potential to assist drivers who undertake many unfamiliar journeys, for instance as part of work, or during leisure trips (e.g. when on holiday) and those who experience extreme difficulties with existing methods of navigation (particularly paper maps). When linked with reliable, real-time traffic information (thus providing dynamic guidance), the perceived utility of navigation systems to the everyday motorist is significantly enhanced (Bishop, 2005).

The market potential for vehicle navigation systems has already been demonstrated in Japan, where the technology has been available since the early 1990s. Approximately 40% of all vehicles on Japan's roads now have a navigation system installed (http://www.jetro.go.jp/en/market/trend/topic/2004_12_carnavi.html, September 2006). In many other countries, the popularity of navigation systems is currently reduced in relation to Japan, but is predicted to rise rapidly over the next few years (Bishop, 2005).

The majority of human factors issues relevant to this form of technology relate to overload, although as shall be seen, underload is increasingly being researched. With respect to overload, clearly, a key concern is the potential for driver distraction and there has been considerable research on this topic since the mid 1980s (see Young, Regan and Hammer (2003) and Srinivisan (1999) for reviews). In using a vehicle navigation system, drivers must interact with controls (e.g. to enter a destination, change map scale) and view/understand displays (e.g. to decide which turn to make, to examine options within a menu). In many cases, these interactions will arise when the vehicle is in motion. Consequently, to provide guidance for designers, researchers have aimed to understand how the user-interface design for a vehicle navigation system impacts on both navigating and primary driving performance. Specifically, research has aimed to answer the following three design-oriented questions:

What Information Should a Navigation System Provide?

To support route following, there are a wide range of different information types that a system could present, either referring to something real in the road environment (junction representations, street/road signs, landmarks, etc.) or indirectly referring to or pointing at aspects of the environment (distance to turn, directions, etc.). In this respect, researchers have established through a range of methodologies that the use of distinctive features of the environment (landmarks) within navigation instructions (e.g. "turn right at the church") offer considerable advantages over the use of distance to turn information (e.g. "turn right in 300 metres")—Burnett (2000); Ross, May and Grimsley (2004). Moreover, research has identified the fundamental characteristics of landmarks which designers of vehicle navigation systems and providers of underlying map databases must consider in choosing appropriate landmarks for presentation by a navigation system (Burnett, Smith and May, 2001).

How Should Information be Presented?

Navigation and related information has to be presented to the driver in some way, and there has been considerable research on a range of topics. One key concern has been the impact of system modality (voice and/or visual) on driving/navigating performance. The general consensus here is the primary modality for presentation of navigation instructions should be auditory to reduce the conflict with the predominately visual driving task. However, information should also be presented visually, in particular, to support driver's understanding of more spatially complex manoeuvres which cannot be represented easily in voice directions (Ross et al., 1995). Recently, Van Erp (2005) investigated empirically the potential for the use of passive touch as a novel modality for presentation of navigation instructions (specifically, vibro-tactile direction and distance to turn presented through the driver's seat). They concluded that haptic navigation displays offer various advantages over visual displays, for example, they provide a 'private' display to the driver appropriate for very simple manoeuvres. Nevertheless, it must be noted that the authors did not make comparisons with the prevailing visual and auditory interfaces. Other research related to information presentation has considered a wide range of issues, such as the format of information (map-based vs turn-by-turn based), the scheduling of information (when to present instructions), and the location of information (positioning of displays). On these topics, the reader is directed to Ross et al. (1995) and Srinivisan (1999).

How Should Drivers Interact with a Navigation System?

For drivers (or passengers) to interact with a vehicle navigation system, there must be a means by which they can enter data (e.g. postcode for an address), select from continuous/discrete options (e.g. voice volume levels, stored destinations), request/repeat information (e.g. voice directions), and move through the system (e.g. within and between menu screens). There is understandably a natural tendency for designers to utilise the familiar desktop computing paradigms, thus utilising specific hardware devices (e.g. joysticks, touchscreens, buttons) and associated software approaches (e.g. use of menus, lists, scrolling). Historically, such paradigms were conceived as a means of overcoming the significant limitations of command-line user-interfaces and provided a what-you-see-is-what-you-get (WYSIWYG) experience for the user (Shneiderman, 1998). In the driving context, several studies have shown that such highly visual-manual user-interfaces can have a considerable impact on safety (Nowakowski, Utsui and Green, 2000; Tijerina, Palmer and Goodman, 1998).

As an alternative to such user-interfaces, speech shows promise as a largely non-visual/manual input method for navigation systems (Tsimhoni, Smith, and Green, 2002). Nevertheless, research has also shown that there is considerable potential for cognitive distraction with speech interfaces (Gärtner, König, and Wittig, 2001), and it is critical that recognition accuracy is very high. Moreover, designers must provide clear dialogue structures, familiar vocabulary, strong feedback and error recovery strategies. These issues are of particular importance given the potentially large number of terms (e.g. towns, street names) that might be uttered and the difficulties that a speech recognition system can experience with alphabet spelling (specifically, the 'e-set'—b, c, d, e, g etc.).

Recent research has also shown the potential for handwriting recognition in a driving context for menu negotiation and inputting alphanumeric data (Kamp et al., 2001; Burnett et al., 2005). Whilst handwriting requires manual input, there is a reduced cognitive component and it is a more familiar method for users in contrast with speech interfaces. Nevertheless, issues relating to recognition accuracy remain and it is critical to place a handwriting touchpad in a location that facilitates the use of a driver's preferred hand (Burnett et al., 2005).

The difficulties for complex interactions with vehicle navigation systems are considered to be so significant that many authors believe that systems should disable "overly demanding" functionality when the vehicle is in motion (e.g. by "greying out" options when the vehicle is moving)—Green (2003); Burnett, Summerskill and Porter (2004). This is currently a rich area for research, requiring an understanding of a) what is meant by "overly demanding", b) establishing valid/reliable metrics for the assessment of demand and finally, c) deciding where to put limits on acceptability (Burnett, Summerskill and Porter, 2004).

Underload for Vehicle Navigation Systems

In contrast with the overload perspective, over the last five years some researchers have viewed navigation systems as a form of automation, where underload issues become central. Vehicle navigation systems calculate a route for a driver according to pre-defined algorithms. Subsequently, drivers do not plan a journey to a destination, rather they confirm a computer-generated route. Systems then present filtered information during the journey, often via paced visual and auditory instructions. Two related concerns are emerging as important research questions, of particular relevance to user-interfaces which place a reliance on turn-by-turn guidance.

Firstly, it has been noted that there may be a poor calibration in the perceived versus objective reliability of in-car computing systems (Lee and See, 2004). This is of relevance as a navigation system (particularly the underlying digital map) is unlikely ever to be 100% reliable. Nevertheless, drivers, largely based on their accumulated experience, may believe this to be the case. In certain situations, such overtrust in a system (commonly referred to as complacency) may lead to drivers following inappropriate routes and potentially making dangerous decisions, for instance, turning the wrong way down a one-way street. There is plenty of anecdotal evidence for such behaviour in the popular press (e.g. http://

www.timesonline.co.uk/article/0,,2-2142179,00.html, September 2006). Recently, a survey of 872 vehicle navigation system owners revealed that 82% had received inaccurate guidance from the technology (Forbes and Burnett, 2007). For these users, 23% admitted to following dangerous or misleading instructions on at last one occasion. Further research is considering what role the extended user-interface (training procedures, manuals, marketing information) can have in reducing such complacency effects.

Secondly, drivers who use vehicle navigation systems may not develop a strong mental representation of the environments in which they travel, commonly referred to as a cognitive map. It has been stressed that traditional methods (e.g. using a paper map) require drivers to be active in the navigation task (route planning and following)—Jackson (1998); Burnett and Lee (2005). Whilst the demands (particularly the cognitive demands) can initially be high, drivers who are engaged are able to develop landmark, then route knowledge, ultimately progressing to a map-like mental understanding (survey knowledge). Such a well-developed cognitive map means that drivers are able to navigate independent of any external source of information. Empirical research in this area has shown that drivers using current forms of user-interface for vehicle navigation system do indeed experience reduced environmental knowledge in relation to drivers using traditional methods (Jackson, 1998; Burnett and Lee, 2005). A key research question here is how user-interfaces can be developed which balance the need for low demands (workload) whilst simultaneously aiding drivers in developing a well-formed cognitive map (Burnett and Lee, 2005). In this respect, recent research by Oliver and Burnett (2008) has suggested that systems incorporating a range of landmarks within the user-interface can assist in the development of a cognitive map, without having a negative impact on interface visual demand.

FUTURE TRENDS AND CONCLUSION

The incessant growth in the use of cars and worries about road safety have led car manufacturers to offer more intelligent cars providing a range of novel functions to drivers. Moreover, existing mobile technologies such as PDAs, MP3 players, mobile phones, and so on, are increasingly being used within cars, as drivers seek to be more productive and to enjoy the time spent in their vehicles.

All of these computing-based systems offer potential benefits to drivers. This article has focused on some key design issues for user-interfaces from the perspective of the individual driver. However, as systems become commonplace within vehicles, there are fundamental conflicts to resolve between the requirements of an individual versus the overall traffic system. In this respect, the design of an in-car computing user-interface will be a critical consideration. As an example scenario, one can envisage many drivers using information systems providing the same information at the same time. Such a situation may lead to a range of problems, for instance the use of roads not designed for high volumes of traffic. Clearly, there is a need for overall management and an understanding of the impact that specific styles of user-interface will have on driver behaviour.

A second broad issue for research concerns the interaction between multiple systems. This article has introduced the overload and underload concepts and discussed them in turn relating them to different individual systems. It is highly likely that in the short to medium term, overload will be given a prominent position in research and development work, whereas underload will emerge as an increasingly important topic in the medium to long term. However, this singular view neglects the fact that information and control-based systems are likely to be used together in a vehicle. Clearly, there will be various interaction effects for researchers to investigate. Moreover, there is a fundamental need to find the right balance between the two extremes of overload and underload. As noted by Dewar (2002, p. 330) "humans operate best at an optimal level of arousal, and either too much or too little workload can be detrimental to performance".

The development of suitable methods for designing and evaluating in-car computing user-interfaces will continue to be an important research topic. Reliable and valid methods are required which are accepted within industry. A key motivation will be to establish 'quick and dirty' methods (and associated metrics) enabling designers to understand the likely demands of their user-interfaces early in the design process when very rudimentary prototypes are available. A further critical requirement is for "benchmarking", that is, establishing a point of reference from which user-interfaces can be compared or assessed. Such benchmarks will be of particular benefit when identifying user-interface designs that are considered acceptable or unacceptable, particularly from a safety perspective.

REFERENCES

Baumann, M., Keinath, A., Krems, J. F., & Bengler, K. (2004). Evaluation of in-vehicle HMI using occlusion techniques: experimental results and practical implications. *Applied Ergonomics*, *35*(3), 197–205. doi:10.1016/j.apergo.2003.11.011

Bishop, R. (2005). *Intelligent vehicle technology and trends*. London: Artech House Publishers.

Blaauw, G. J. (1982). Driving experience and task demands in simulator and instrumented car: a validation study. *Human Factors*, *24*(4), 473–486.

Burnett, G. E. (2000). "Turn right at the traffic lights" The requirement for landmarks in vehicle navigation systems. *Journal of Navigation*, *53*(3), 499–510. doi:10.1017/S0373463300001028

Burnett, G. E. (2003) A road-based evaluation of a Head-Up Display for presenting navigation information, In Proceedings of HCI International conference, Vol 3 (Human-Centred Computing), pp. 180-184.

Burnett, G. E., & Joyner, S. M. (1997). An Assessment of Moving Map and Symbol-Based Route Guidance Systems. In Noy, Y. I. (Ed.), *Ergonomics and Safety of Intelligent Driver Interfaces* (pp. 115–137). Lawrence Erlbaum.

Burnett, G. E., & Lee, K. (2005). The effect of vehicle navigation systems on the formation of cognitive maps. In Underwood, G. (Ed.), *Traffic and Transport Psychology: Theory and Application* (pp. 407–418). Elsevier. doi:10.1016/B978-008044379-9/50188-6

Burnett, G. E., Lomas, S., Mason, B., Porter, J. M., & Summerskill, S. J. (2005) Writing and driving: An assessment of handwriting recognition as a means of alphanumeric data entry in a driving context, Advances in Transportation Studies, 2005 Special Issue, pp. 59-72

Burnett, G. E., Smith, D., & May, A. J. (2001) Supporting the navigation task: Characteristics of 'good' landmarks, In Proceedings of the Annual Conference of the Ergonomics Society, Hanson, M.A. (ed), Taylor & Francis, pp 441-446.

Burnett, G. E., Summerskill, S. J., & Porter, J. M. (2004). On-the-move destination entry for vehicle navigation systems: Unsafe by any means? *Behaviour & Information Technology*, *23*(4), 265–272. doi:10.1080/01449290410001669950

Burns, P. (1999) Navigation and the mobility of older drivers. Journal of Gerontology. Series B, Psychological sciences and social sciences, 54 (1), 49-55

Dewar, R. E. (2002). Vehicle Design. In Dewar, R. E., & Olson, P. L. (Eds.), *Human Factors in Traffic Safety* (pp. 303–339). USA: Lawyers & Judges Publishing Company, Inc.

Engstrom, J., Aberg, N., & Johansson, E. (2005). Comparison between visual and tactile signal detection tasks applied to the safety assessment of in-vehicle information systems. In Proceedings of the third international driving symposium on Human Factors in driver assessment, training and vehicle design. (University of Iowa public policy center, Iowa)

Forbes, N. L., & Burnett, G. E. (2007). Investigating the contexts in which in-vehicle navigation system users have received and followed inaccurate route guidance instructions, In Proceedings of Third International Conference in Driver Behaviour and Training, Held in Dublin, November, 2007.

Gärtner, U., König, W., & Wittig, T. (2001). Evaluation of manual vs. speech input when using a driver information system in real traffic, in: Proceedings of International driving symposium on human factors in driver assessment, training and vehicle design. (University of Iowa public policy center, Iowa), Available at: http://ppc.uiowa.edu/driving-assessment//2001/index.html

Gould, J. D., & Lewis, C. H. (1985). Designing for usability: key principles and what designers think. *Communications of the ACM*, *28*(3), 300–311. doi:10.1145/3166.3170

Green, P. (1999). The 15 second rule for driver information systems. Proceedings of the ITS America ninth annual meeting, Washington, D.C.

Green, P. (2004). Driver Distraction, Telematics Design, and Workload Managers: Safety Issues and Solutions. (SAE paper 2004-21-0022), Proceedings of the 2004 International Congress on Transportation Electronics (Convergence 2004, SAE publication P-387), 165-180. Warrendale, PA: Society of Automotive Engineers.

Hackos, J. T., & Redish, J. C. (1998). *User and task analysis for interface design*. NY: John Wiley and Sons.

ISO, 2005, Road vehicles – Ergonomic aspects of transport information and control systems – Occlusion method to assess visual distraction due to the use of in-vehicle information and communication systems. Draft International Standard ISO/DIS 16673. ISO/TC 22/SC 13.

Jackson, P. G. (1998). In search of better route guidance instructions. *Ergonomics*, *41*(7), 1000–1013. doi:10.1080/001401398186559

Jamson, H. (2001). Image characteristics and their effect on driving simulator validity. In Proceedings of International driving symposium on Human Factors in driver assessment, training and vehicle design. (University of Iowa public policy center, Iowa).

Jones, W. D. (2002). Building safer cars. *IEEE Spectrum*, *39*(1), 82–85. doi:10.1109/6.975028

Kamp, J. F., Marin-Lamellet, C., Forzy, J. F., & Causeur, D. (2001). HMI aspects of the usability of internet services with an in-car terminal on a driving simulator. *IATSS Research*, *25*(2), 29–39.

Kaptein, N. A., Theeuwes, J., and van der Horst, R. (1996). "Driving simulator validity: Some considerations." Transp. Res. Rec., 1550, Transportation Research Board, Washington, D.C., 30–36

Kennedy, R. S., Lane, N. E., Stanney, K. M., Lanham, S., & Kingdon, K. (2001). Use of a motion experience questionnaire to predict simulator sickness. In Proceedings of HCI International, 8-10 May, 2001, New Orelans, LA.

Lee, J. D., & See, K. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors*, *46*(1), 50–80.

Maguire, M. (2001). Context of use within usability activities. *International Journal of Human-Computer Studies*, *55*, 453–483. doi:10.1006/ijhc.2001.0486

Markkula, G., Kutila, M., & Engström, J. (2005). Online Detection of Driver Distraction - Preliminary Results from the AIDE Project, Proceedings of International Truck & Bus Safety & Security Symposium Alexandria, Virginia, USA, 14 - 16 November 2005.

Mattes, S. (2003). The Lane Change Task as a Tool for driver Distraction Evaluation. IHRA-ITS Workshop on Driving Simulator Scenarios, October 2003 - Dearborn, Michigan. Available at: www. nrd.nhtsa.dot.gov/IHRA/ITS/MATTES.pdf

Michon, J. A. (1985). A critical view of driver behaviour models. In Evans, L., & Schwing, R. S. (Eds.), *Human behaviour and traffic safety*. NY: Plenum Press.

Nichols, S., & Patel, H. (2002). Health and safety implications of virtual reality: A review of empirical evidence. *Applied Ergonomics*, *33*(3), 251–271. doi:10.1016/S0003-6870(02)00020-0

Nowakowski, C., Utsui, Y., & Green, P. (2000). Navigation system evaluation: The Effects of Driver Workload and Input Devices on Destination Entry Time and Driving Performance and Their Implications to the SAE Recommended Practice. Technical Report UMTRI-2000-20, The University of Michigan Transportation Research Institute, USA.

Oliver, K. J., & Burnett, G. E. (2008). Learning-oriented vehicle navigation systems: A preliminary investigation in a driving simulator, In Proceedings of ACM Mobile HCI conference, To be held in Amsterdam, September, 2008.

Parkes, A. M. (1991). Data capture techniques for RTI usability evaluation. In *Advanced telematics in road transport - the DRIVE conference* (*Vol. 2*, pp. 1440–1456). Amsterdam: Elsevier Science Publishers B.V.

Peters, G. A., & Peters, B. J. (2002). *Automotive vehicle safety*. London: Taylor and Francis. doi:10.1201/9780203166307

Pettitt, M. A., Burnett, G. E., Bayer, S., & Stevens, A. (2006). Assessment of the occlusion technique as a means for evaluating the distraction potential of driver support systems. *IEE Proceedings in Intelligent Transport Systems*, *4*(1), 259–266. doi:10.1049/ip-its:20060027

Pettitt, M. A., Burnett, G. E., & Karbassioun, D. (2006). Applying the Keystroke Level Model in a driving context. In Proceedings of the Ergonomics Society Annual conference, Bust, P.D. (ed), Taylor & Francis, Contemporary Ergonomics 2006, pp. 219-223.

Pettitt, M. A., Burnett, G. E., & Stevens, A. (2007) An extended Keystroke Level Model (KLM) for predicting the visual demand of in-vehicle information systems, To appear in Proceedings of the ACM Computer-Human Interaction (CHI) conference, To be held San Jose, May 2007.

Preece, J., Rogers, Y., and Sharp. H. (2002) Interaction design: Beyond human-computer interaction. NY: John Wiley and sons.

Reed, M. P., & Green, P. A. (1999). Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialling task. *Ergonomics*, *42*(8), 1015–1037. doi:10.1080/001401399185117

Ross, T., May, A. J., & Grimsley, P. J. (2004). Using traffic light information as navigation cues: implications for navigation system design. *Transportation Research Part F: Traffic Psychology and Behaviour*, *7*(2), 119–134. doi:10.1016/j.trf.2004.02.004

Ross, T., Vaughan, G., Engert, A., Peters, H., Burnett, G. E., & May, A. J. (1995). *Human factors guidelines for information presentation by route guidance and navigation systems (DRIVE II V2008 HARDIE, Deliverable 19)*. Loughborough, UK: HUSAT Research Institute.

Shneiderman, B. (1998). *Designing the user-interface* (3rd ed.). Addison Wesley.

Society of Automotive Engineers (SAE). (2000). *Navigation and Route Guidance Function Accessibility While Driving (SAE Recommended Practice J2364), version of January 20th, 2000*. Warrendale, PA: Society of Automotive Engineers.

Srinivisan, R. (1999). Overview of some human factors design issues for in-vehicle navigation and route guidance systems. Transportation Research Record 1694 (paper no. 99-0884), (Washington, DC: National Academy Press).

Stevens, A., Bygrave, S., Brook-Carter, N., & Luke, T. (2004). *Occlusion as a technique for measuring in-vehicle information system (IVIS) visual distraction: a research literature review. Transport Research Laboratory (TRL) report no. TRL609. TRL*. Berkshire, United Kingdom: Crowthorne.

Tijerina, L., Palmer, E., & Goodman, M. J. (1998). Driver workload assessment of route guidance system destination entry while driving. Technical Report UMTRI-96-30, The University of Michigan Transportation Research Institute, USA.

Toffin, D., Reymond, G., Kemeny, A., & Droulez, J. (2003). Influence of steering wheel torque feedback in a dynamic driving simulator. In Proceedings of the Driving Simulation Conference North America 8-10 Oct 2003, Dearborn, USA.

Tornros, J. (1998). Driving behaviour in a real and a simulated road tunnel – A validation study. *Accident; Analysis and Prevention*, *30*(4), 497–503. doi:10.1016/S0001-4575(97)00099-7

Transport Canada (2006). R Occlusion Research. Presentation given to the AAM driver focus task force, Detroit June 2006.

Tsimhoni, O., Smith, D., & Green, P. (2002). Destination entry while driving: Speech recognition versus a touch-screen keyboard. Technical Report UMTRI-2001-24, The University of Michigan Transportation Research Institute, USA.

Tufano, D. R. (1997). Automotive HUDs: The overlooked safety issues. *Human Factors*, *39*(2), 303–311. doi:10.1518/001872097778543840

Van Erp, J. B. F. (2005). Presenting directions with a vibrotactile torso display. *Ergonomics*, *48*(3), 302–313. doi:10.1080/0014013042000327670

Wallen Warner, H. M., & Aberg, L. (2005). Why do drivers speed? In Underwood, G. (Ed.), *Traffic and transport psychology: theory and application* (pp. 505–511). Oxford, UK: Elsevier. doi:10.1016/B978-008044379-9/50195-3

Ward, N. J., & Parkes, A. M. (1994). Head-up displays and their automotive application: An overview of human factors issues affecting safety. *Accident; Analysis and Prevention*, *26*(6), 703–717. doi:10.1016/0001-4575(94)90049-3

Wickens, C. D. Lee, J.D., Liu, Y., and Becker, S.E.G. (2004). An Introduction to Human Factors Engineering (2nd Edition). New Jersey, USA: Pearson.

Wikman, A., Nieminen, T., & Summala, H. (1998). Driving experience and time-sharing during in-car tasks on roads of different width. *Ergonomics*, *41*(3), 358–372. doi:10.1080/001401398187080

Young, K., Regan, M., & Hammer, M. (2003). Driver distraction: a review of the literature, Monash University Accident Research Centre, Report No. 206, November 2003.

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Chapter 5
Technology Acceptance Model for Mobile Services as a Design Framework

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ABSTRACT

Personal mobile devices are increasingly being used as platforms for interactive services. Ease of use is important, but the services should also provide clear value to the user and they should be trustworthy and easy to adopt. These user acceptance factors form the core of the Technology Acceptance Model for Mobile Services introduced in this chapter. The model has been set up based on field trials of several mobile services with altogether more than 200 test users. This chapter presents the technology acceptance model and describes four case studies of applying the model in practice as a design and evaluation framework.

INTRODUCTION

Research on mobile services has for long concentrated on the usability of alternative user interface implementations. Small mobile devices pose significant usability challenges and the usability of the services is still worth studying. However, more attention should be paid to user acceptance of the planned services. The reason for many

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Figure 1. Taking user evaluations from the laboratory to the field makes it possible to evaluate user acceptance on new services

commercial failures can be traced back to the wrongly assessed value of the services to the users (Kaasinen, 2005b).

User evaluations of mobile services often have to be taken into the field as the service would not function properly otherwise or it would not make sense to evaluate it in laboratory conditions. This would be the case, for instance, with GPS systems and route guidance systems. In long-term field trials with users, it is possible to gather feedback on the adoption of the service in the users' everyday lives. Such studies gather usage data beyond mere usability and pre-defined test tasks (Figure 1). Field trials help in studying which features the users start using, how they use them and how often, and which factors affect user acceptance of the service.

Business and marketing research already have approaches whereby new technology is studied on a wider scale. The Technology Acceptance Model by Davis (1989) defines a framework to study user acceptance of a new technology based on perceived utility and perceived ease of use. Each user perceives the characteristics of the technology in his/her own way, based for instance on his/her personal characteristics, his/her attitudes, his/her previous experiences and his/her social environment. The Technology Acceptance Model has evolved and been applied widely, but mainly in the context of introducing ready-made products rather than in designing new technologies.

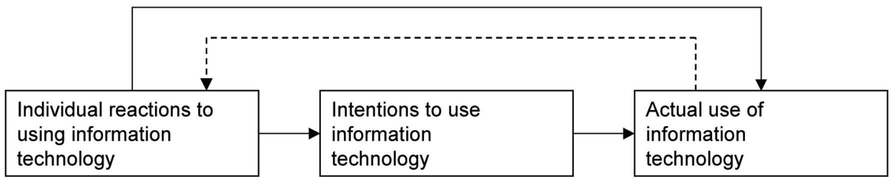
The Technology Acceptance Model for Mobile Services is an extension to the Technology Acceptance Model. The model is based on a series of field trials and other evaluation activities with different mobile Internet and personal navigation services and over 200 test users (Kaasinen, 2005b). The Technology Acceptance Model for Mobile Services constitutes a framework for the design and evaluation of mobile services.

BACKGROUND

Technology acceptance models aim at studying how individual perceptions affect the intentions to use information technology as well as actual usage (Figure 2).

In 1989 Fred Davis presented the initial Technology Acceptance Model (TAM) to explain the determinants of user acceptance of a wide range of end-user computing technologies (Davis 1989). The model is based on the Theory of Reasoned Action by Ajzen and Fishbein (1980). TAM points out that perceived ease of use and perceived use-

Figure 2. The basic concept underlying technology acceptance models (Venkatesh, Morris, Davis, & Davis, 2003).



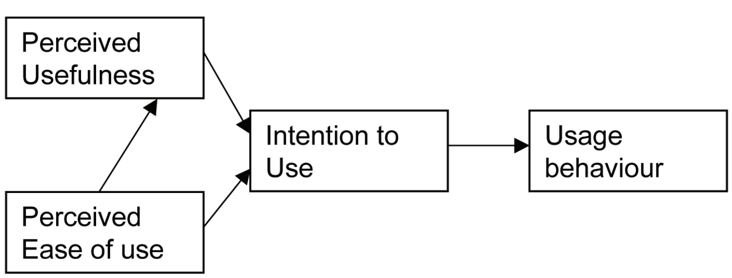
fulness affect the intention to use. Davis (1989) defines perceived ease of use as "*the degree to which a person believes that using a particular system would be free from effort*" and perceived usefulness as "*the degree to which a person believes that using a particular system would enhance his or her job performance"*. Perceived ease of use also affects the perceived usefulness (Figure 3). The intention to use affects the real usage behavior. TAM was designed to study information systems at work to predict whether the users will actually take a certain system into use in their jobs. The model provides a tool to study the impact of external variables on internal beliefs, attitudes and intentions.

TAM deals with perceptions; it is not based on observing real usage but on users reporting their conceptions. The instruments used in connection with TAM are surveys, where the questions are constructed in such a way that they reflect the different aspects of TAM. The survey questions related to usefulness can be, for instance: "Using this system improves the quality of the work I do" or "Using this system saves my time". The survey questions related to ease of use can be, for instance: "The system often behaves in unexpected ways" or "It is easy for me to remember how to perform tasks using this system".

TAM was originally developed for studying technology at work, but it has often been used to study user acceptance of Internet services as well (Gefen, Karahanna, & Straub, 2003; Barnes & Huff, 2003; Chen, Gillenson, & Sherell, 2004). Gefen et al. (2003) have studied TAM in connection with e-commerce. They have extended TAM to this application area and propose that trust should be included in the research model to predict the purchase intentions of on-line customers.

The Technology Acceptance Model constitutes a solid framework to identify issues that may affect user acceptance of technical solutions. Davis and Venkatesh (2004) have proved that the model can be enhanced from the original purpose of studying user acceptance of existing products to study planned product concepts, e.g. in the form of mock-ups. This suggests that TAM could also be used in connection with technology development projects and processes to assess the usefulness of proposed solutions.

Figure 3. Technology acceptance model (Davis, 1989).



Applicability of Earlier Approaches for Mobile Services

The focus of traditional usability studies is on specified users performing specified tasks in specified contexts of use as defined by the International Standardization Organization (ISO13407, 1999). In field trials the users can use prototype services as part of their everyday life. The research framework can then be enhanced to identify the actual tasks that users want to perform and the actual contexts of use. Technology acceptance models provide a framework for such studies.

Mobile services targeted at consumers have several specific characteristics that may mean that their user acceptance cannot be studied using the same models as with information systems in the workplace. When dealing with consumer services, individuals make voluntary adoption decisions and thus the acceptance includes assessing the benefits provided compared with either competing solutions or the non-acquisition of the service in question. As pointed out by Funk (2004), mobile services are a disruptive technology that may find their innovation adopters elsewhere than expected, as highlighted by the experiences with the Japanese i-mode. Focusing too early on only limited user groups may miss possible early adopters. With the Japanese i-mode, other services were boosted through e-mail and personal home pages (Funk, 2004). This suggests that the focus of user acceptance studies of mobile services should be extended to interrelated innovations, as proposed by Rogers (1995).

Perceived usefulness included in TAM may not indicate an adequate purchase intention in a market situation. Product value has been proposed as a wider design target both in software engineering and HCI approaches. A value-centered software engineering approach was proposed by Boehm (2003) to define more clearly what the design process is targeted at, and identifying the values that different stakeholders – including end-users – expect of the product. Although not using the actual term "value", Norman (1998) emphasizes the importance of identifying big phenomena related to user needs and communicating them early on to the design. Cockton (2004) points out that in value-centered HCI existing HCI research components, design guidance, quality in use and fit to context need to be reshaped to subordinate them to the delivery of product value to end-users and other stakeholders.

Mobile services are increasingly handling personal information of the user, for instance due to the personalization and context-awareness of the services. The functionalities of the increasingly complex systems are not always easy for the users to comprehend. Context-aware services may include uncertainty factors that the users should be able to assess. Mobile service networks are getting quite complex and the users may not know with whom they are transacting. Technical infrastructures as well as the rapidly developed services are prone to errors. All these issues raise trust as a user acceptance factor, similar to TAM applied in e-commerce (Gefen et al., 2003; Chen et al., 2004). Trust has been proposed as an additional acceptance criterion for mobile services by Kindberg, Sellen and Geelhoed (2004) and also by Barnes and Huff (2003). Trust has also been included in studies of personalization in mobile services (Billsus, Brunk, Evans, Gladish, & Pazzani, 2002) and studies of context-aware services (Antifakos, Schwaninger, & Schiele, 2004).

Ease of adoption is included in the studies by Sarker and Wells (2003) as well as by Barnes and Huff (2003). Sarker and Wells (2003) propose a totally new acceptance model that is based on user adoption. Barnes and Huff (2003) cover adoption in their model within the wider themes of compatibility and trialability. *Perceived user resources* in the extension of TAM by Mathieson, Peacock and Chin (2001) and *Facilitating conditions*, in the Unified Theory of Acceptance and Use (Venkatesh et al., 2003) also include elements related to ease of adoption.

In the following, the Technology Acceptance Model for Mobile Services (Kaasinen, 2005b) is described. The model aims at taking into account the aforementioned special characteristics of mobile consumer services, and previous studies on user acceptance described in this chapter. The model can be utilized when designing new services and assessing them to ensure that key user acceptance factors are considered in the design.

Technology Acceptance Model for Mobile Services (TAMM)

The Technology Acceptance Model for Mobile Services (TAMM) was constituted on the basis of a series of field trials and other user evaluation activities involving over 200 users. The studies were carried out as parts of technology development projects in 1999-2002 by project usability teams comprising altogether 13 researchers from VTT and three researchers from other research organizations. The main focus of the studies was on mobile Internet services and location-based services targeted at consumers (Kaasinen, 2005b). Table 1 gives an overview of the user evaluation activities that the Technology Acceptance Model for Mobile Services is based on.

The original Technology Acceptance Model was chosen as the starting point for the new model because it provided a framework for connecting field study findings on ease of use and usefulness. The user acceptance framework is

Table 1. The user evaluation activities that the technology acceptance model for mobile services was based on.

Service, application or device	Research methods	Users	Original results published in
WAP services	Laboratory evaluation with phone simulator	6	Kaasinen, Aaltonen, Kolari, Melakoski, & Laakko, 2000
WAP-converted Web services	Laboratory evaluation with phone simulator	4	
WAP services WAP-converted Web services	Field trial 2 months	40	Kaasinen, Kasesniemi, Kolari, Suihkonen, & Laakko, 2001
	Interviews with service providers	25	
WAP services WAP-converted Web services Web/WAP Message board for group communication	Field trial 2 months	40	
	Interviews with service providers	11	
Scenarios of personal navigation services	Group interviews	55	Kaasinen, 2003
Benefon GPS phone and services	Field evaluation	6	
Sonera Pointer location-aware WAP services	Laboratory evaluation	5	
Garmin GPS device	Field evaluation	5	
Magellan GPS device	Field evaluation	5	
Location-aware SMS services	Field evaluation	6	
Weather and road conditions by SMS	Field trial, 1 month	10	Kaasinen, 2005a
Location-aware integrated service directory	Field trial, 3 weeks	7	
Mobile topographic maps	Field evaluation	6	
Mobile 3D maps	Laboratory evaluation	6	
	Field evaluation	4	
Scenarios of context-aware consumer services	Interviews in anticipated contexts of use	28	

especially suitable for field trials where the focus is on how different users start using the mobile services in their everyday lives and which features make the services acceptable in actual usage. As not all the field study findings could be fit to the original TAM model, it was necessary to update the model according to the repeated field study findings and themes identified in related research. The new model extends the original core model by Davis (1989) by identifying two new perceived product characteristics that affect the intention to use, i.e. trust and ease of adoption, and by redefining the theme of usefulness as value to the user.

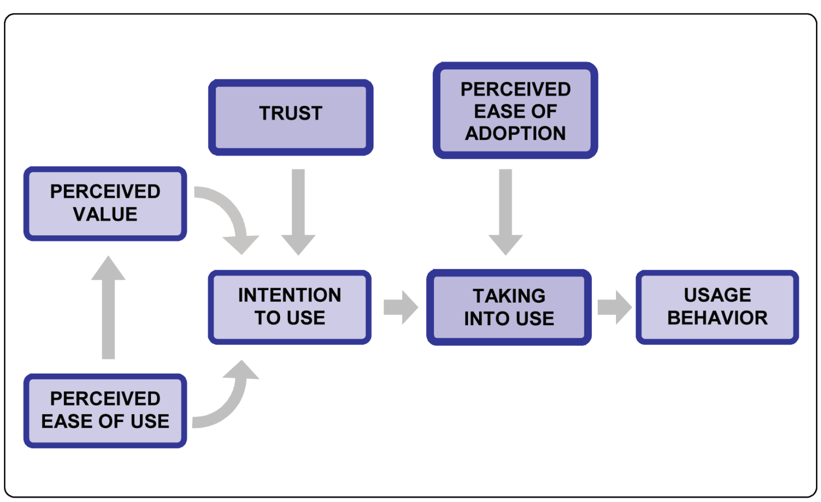
The framework (Figure 4) suggests that perceived ease of use, perceived value and trust affect the intention to use a mobile service. To get from an intention to use to real usage, the user has to take the service into use. This transition is affected by the perceived ease of adoption. Perceived value, perceived ease of use, trust and perceived ease of adoption need to be studied in order to assess user acceptance of mobile services.

The Technology Acceptance Model for Mobile Services (Kaasinen, 2005b) constitutes a framework that helps designers of mobile services to identify key issues that should be focused on in the design to ensure user acceptance. Thus the motivation of the model is not the same as the motivation of the original TAM, which was built to explain user acceptance and underlying forces for existing technical solutions.

Perceived ease of use was included in the original TAM and it is also included in the TAMM model. Davis (1989) defined perceived ease of use as "*the degree to which a person believes that using a particular system would be free from effort*". At first, perceived ease of use is based on external factors such as the user's attitude towards technology in general, experiences of using similar services and information from other people. In actual use and sustained use, perceived ease of use is increasingly affected by the user's own experiences of using the system in different contexts of use.

In the case of mobile services that are used on small devices such as mobile phones or PDAs, the limitations of the device have a major influence on perceived ease of use. The limitations include the small screen, small and limited keyboard, the absence or limited functionality of pointing devices, limited amount of memory, limited battery power and slow connections. As new devices and mobile

Figure 4. Technology acceptance model for mobile services (Kaasinen, 2005b) as an extension and modification of TAM by Davis (1989).



networks are being introduced to the market, these limitations have somewhat diminished but still mobile networks are slower than fixed ones and the requirements for ease of carrying and holding the device do not allow very large screens or large keyboards. Designing mobile services for ease of use is to a large extent about coping with the limitations of the device. In addition, the design should adapt to the variety of client devices and available networks and other infrastructures.

The ease of use of mobile services has been studied quite a lot and different usability guidelines are available e.g. by the World Wide Web Consortium (W3C, 2008). It is a pleasure to note that many of the usability problems identified in early mobile Internet studies have already been corrected in current mobile devices, browsers and services. However, location-aware services pose even more challenges for ease of use. Location-aware services are not just mobile in the sense that they can be easily carried around but, typically, they are used while the user is on the move. These kinds of usage situations require extreme ease of use. Personalization and context-awareness are expected to improve ease of use, but they may also introduce new usability problems, e.g. in the form of personalization dialogues.

Perceived value replaces perceived usefulness in the TAMM model because in our field trials with consumers it became evident that in the consumer market, perceived usefulness may not indicate adequate motivation to acquire the mobile service. As the focus group studies by Järvenpää, Lang, Takeda and Tuunanen (2003) point out, consumers may lack a compelling motivation to adopt new mobile services unless those services create new choices where mobility really matters and manages to affect people's lives positively. In a value-neutral setting each requirement is treated as equally important in the design (Boehm, 2003). This easily leads to featurism – the product becomes a collection of useful features but as a whole it may not provide enough value to the user. Value not only includes rational utility but also defines the key features of the product that are appreciated by the users and other stakeholders, i.e. the main reasons why the users are interested in the new product. As Roto (2006) points out, costs of using the service also affect the perceived value, as user expectations tend to be higher for more expensive products. Values are made explicit by the identification of objectives, which are statements about what the user wants to achieve. Fundamental objectives are directly related to the user's current problem or situation at hand, whereas means objectives help to achieve the fundamental objectives (Nah, Siau, & Sheng, 2005).

Defining the targeted values and concentrating on them in design and evaluation helps to focus the design on the most essential issues. This is in line with the concept of value-centered software engineering proposed by Boehm (2003) and value-centered HCI proposed by Cockton (2004). Focusing on perceived value in user acceptance studies supports the wider scope of value-centered design, where user value can be studied in parallel with business value and strategic value as proposed by Henderson (2005).

Trust is added as a new element of user acceptance in the TAMM model. The original TAM (Davis, 1989) was defined for information systems at work, and in those usage environments the end-users could rely on the information and services provided and the ways their personal data was used. When assessing user acceptance of e-commerce applications, Gefen et al. (2003) proposed to enhance TAM with trust in the service provider, as in their studies trust-related issues turned out to have a considerable effect on user acceptance. In our studies with mobile Internet, consumers were using mobile services that were provided to them via complex mobile service networks. In this environment trust in the service providers turned out to be an issue. As location-based services collect and use more and more information about the usage environment and the user, ethical issues arise. Ensuring the privacy of the user was a common concern of our test users. Tsai et al. (2009) found in their user study of a location-sharing application that giving users feedback of who was requesting their location data, improved users' comfort level and allayed privacy concerns. As the users get increasingly dependent on mobile services, the reliability of the technology and conveying information about reliability to the user become more important.

In the Technology Acceptance Model for Mobile Services, trust is defined according to Fogg and Tseng (1999). Trust is an indicator of a positive belief about the perceived reliability of, dependability of, and confidence in a person, object or process. User trust in mobile services includes perceived reliability of the technology and the service provider, reliance on the service in planned usage situations, and the user's confidence that (s)he can keep the service under control and that the service will not misuse his/her personal data.

Perceived ease of adoption is related to taking the services into use. In the original TAM settings with information systems at work, this certainly was not an issue as users typically got their applications ready installed. In our field trials it turned out that a major obstacle in adopting commercial mobile services was the users' unawareness of available services, as well as problems anticipated in taking services into use (Kaasinen, 2005b). Furthermore, as usage needs were typically quite occasional, people often did not have enough motivation to find out about these issues. And finally, configuration and personalization seemed to require almost overwhelming effort (Kaasinen, 2005b). Introducing the services to users would definitely require more attention in service design (Kaasinen et al., 2002).

As mobile services are typically used occasionally and some services may be available only locally in certain usage environments, ease of taking the services into use becomes even more important. The user should easily get information about available services and should be able to install and start to use the services easily. Finally, (s)he should be able to get rid of unnecessary services. The context may also impact on user acceptance as found by Mallat et al. (2009) in their studies of mobile ticketing.

Compared with the original TAM (Davis, 1989), the Technology Acceptance Model for Mobile Services includes an additional phase between the intention to use and the actual usage behavior. Taking a service into use may constitute a major gap hindering the transition from usage intention to actual usage (Kaasinen, 2005b). Perceived ease of adoption is added to the model at the stage when the user's attention shifts from intention to use to actually taking the service into use.

In the following, the Technology Acceptance Model for Mobile Services is analyzed further and design implications are briefly presented for each user acceptance factor. A more thorough description of the design implications is given in an earlier publication (Kaasinen, 2008).

DESIGN IMPLICATIONS

The Technology Acceptance Model for Mobile Services includes four main acceptance factors: perceived value, perceived ease of use, trust and perceived ease of adoption. How these factors are actually realized in individual mobile services depends on the service in question. However, there are many attributes of the acceptance factors that repeat from one service to another. These attributes form a set of design guidelines that can be used in the design of mobile services. The guidelines can additionally be used in designing user acceptance evaluations to define the issues to be studied in the evaluation. In the following, the design implications of each user acceptance factor are briefly described.

Perceived value of mobile services is not based on featurism – having more and more features in the service. Instead, the key values that the service is supposed to bring to the end users, service providers or other stakeholders should be identified.

The following list gives some ideas where the value can be found:

- Mobile devices are above all personal communication devices. Key values include personally relevant and interesting content and communication. The communication value can be related to communication-based services such as discussion groups, but it may also be related to the possibility to spice up the service with user-generated content.
- Mobile services need to provide the users with topical information. If the information is not topical, the user can have it elsewhere and at other times.
- Mobile services need to provide the user with enough information. If the information is not comprehensive, the user has to get the rest of the information elsewhere, and soon (s)he learns to go elsewhere in the first place.
- Seamless service entities support the user throughout an activity, even from one service to another and from one device to another.
- The usage needs are often occasional, even if the service would be very useful in those occasional usage situations.

Perceived ease of use of mobile services has been studied a lot, and several usability guidelines are available. However, personalization, context-awareness and on-the-move use still pose new usability challenges. Key issues regarding ease of use of mobile services include:

- A clear overview of the service entity, fluent navigation on a small screen and smooth user interaction with the service are crucial, and their importance is emphasized with occasional usage needs and on-the-move use.
- Users appreciate personally and contextually relevant information and services but they do not want to expend effort on setting up the personalization. Context-awareness can be utilized in providing the users with easy access to situationally relevant information and services.
- The services should be designed to facilitate momentary usage sessions on the move.
- The services should support and adapt to the growing variety of devices, networks and technical infrastructures.

Trust becomes increasingly important as mobile services get more and more involved in people's personal lives and as these services increasingly collect, analyze and store personal data:

- It should be ensured that the user feels and really is in control. This requires that the user has a clear conception of the functionality of the service even if (s)he does not need to know all the details.
- The user needs information on the reliability and accuracy of the service to be able to assess in which usage contexts (s)he can rely on the service.
- The design should include strategies for preventing, predicting and identifying error situations, informing the user about them and providing him/her with guidance on how to overcome the problem.
- The privacy of the user should be protected even if the user would not require it. The user should get clear feedback on which personal data is collected, where it is stored and who is using it and for what purposes.

Perceived ease of adoption becomes important as mobile services may be available only locally or in certain contexts. The user should be able to easily identify, understand and take into use the services:

- The user should be given a clear description of the possibilities that the service would facilitate in his/her everyday life.
- The installation should be effortless, even on the move. Services should increasingly be provided as disposable packages: easy to find, take into use, use and get rid of when no longer needed.
- The services should fit into existing usage cultures but they should also provide a basis for user innovations and new usage cultures.

Because of the quality of the case study material, the design principles cover best mobile information services targeted at consumers. For other kinds of services, the Technology Acceptance Model for Mobile Services as well as the design implications can certainly be used as a starting point, but they may need to be revised. In the following, four case studies illustrate how TAMM can be used as a design and evaluation framework in practice.

RELATED RECENT RESEARCH

Platzer and Petrovic (2010) and Platzer (2009) report a review of user acceptance research in the area of mobile services. The main criteria in their research has been scientific rigor and practical relevance. TAMM was unfortunately not included in their review. Platzer and Petrovic (2010) conclude that TAM is still the most often used model to explain technology acceptance. Based on the review, they claim that results of technology acceptance research are mostly prepared to other researchers. The results are rarely communicated to practioners who could use them for the actual design. TAMM is addressing this concern as the aim has been from the very beginning to define TAMM as a design framework that would help in the design process of mobile services both as design guidelines and as an evaluation framework. Platzer (2009) points out that current technology acceptance research is limited to surveys as the main data gathering method. TAMM as a design tool supports various data gathering methods.

After the publishing of the Technology Acceptance Model for Mobile Services, other mobile specific technology acceptance models have been published. Those recent models highlight some complementary issues compared to TAMM. Mallat et al. (2009) were using a TAM-based research model for studying mobile ticketing. Their model is using Ease of use and Perceived usefulness from the original TAM, and complements them with Compatibility. These three factors affect directly to Use intention, whereas Mobility and Perceived usefulness affect Use intention also via Use context. Mallat et al. concluded that use context was a significant determinant for consumers' intention to use a mobile ticketing service. Furthermore, use context fully mediated the effect of mobility and usefulness on use intention. In the study by Mallat et al. compatibility was the most important adoption determinant. It implied that consumers want to get additional options to existing practices rather than substitutes and dramatic changes. Mallet at al concluded that compatibility of mobile services with users' habits and their ways to access and use services with the mobile phone can be considered as a precondition for service adoption and therefore independent of context. When comparing these results to TAMM, compatibility is related to the Ease of adoption, especially fitting new services to existing usage cultures. The affect of context is important issue for future research. Actually all TAMM acceptance factors may be mediated through the usage context.

Kuo and Yen (2009) have studied user acceptance of 3G mobile value-added services in Taiwan. They emphasise in their acceptance model personal innovativeness. They define innovativeness according to Rogers (1995) as the degree of interest in trying a new thing, a new concept or an innovative product or service. In the model by Kuo and Yen, Personal Innovativeness affects both Perceived usefulness and Perceived ease of use. Ease of use and usefulness from the original TAM are complemented with Perceived cost. TAMM was developed based on the results of research projects and that is why in the case studies cost was not an issue. In actual service design, cost certainly needs to be taken into account. TAMM research was focused on issues that generally affect user acceptance. It is clear that there are personal differences in readiness to adopt new things.

Zhang et al. (2010) have studied user acceptance of mobile searches. Their mobile search acceptance model is based on UTAUT and Task Technology Fit models. Based on a survey with 195 respondents in China, Zhang et al. concluded that Perceived cost, Performance expectancy (usefulness) and Social influence all had significant effect on the use intention, whereas Effort expectancy (ease of use) had only a weak effect. The finding is in line with the findings of Tsai et al. (2009) who found that peers have a significant effect on whether or not a user will accept and continue to use mobile location-sharing technology. Social influence and peer opinions are related to the TAMM factor Trust, as users often base their trust on the opinions of other people.

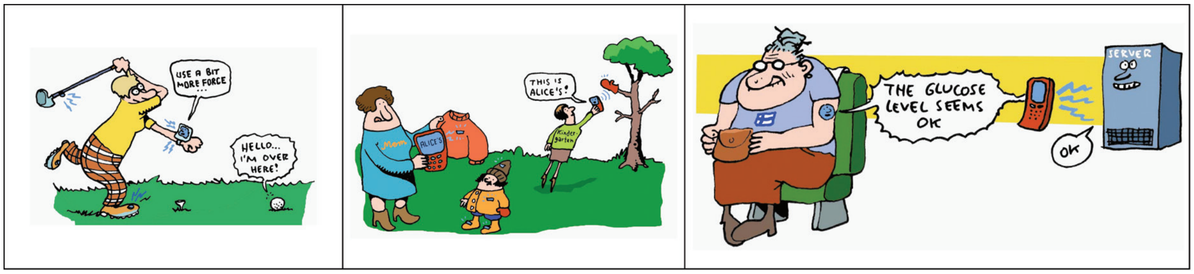
PUTTING TAMM INTO PRACTICE: FOUR CASE STUDIES

As examples of utilizing TAMM in the development of mobile services, the following four case studies illustrate using the research framework. The first case deals with an architectural design where the mobile phone is extended to a platform for different ubiquitous services. User acceptance of these kinds of services was studied with an extensive scenario definition and evaluation study. The second case deals with mobile television and related add-on interactive services. In a field study, a user panel was assessing different pilot services. The aim was to get feedback on user acceptance of different service concepts and mobile TV as a whole. In both studies, TAMM constituted a framework that facilitated the comparison of different services and the identification of key issues affecting user acceptance. The third case is using TAMM as the evaluation framework to study user acceptance of a new mobile interaction concept. Touch-based interaction was illustrated with a proof of concept prototype with which the users carried out test tasks. TAMM facilitated comparing two alternative variations of the input concept in addition to assessing the overall interaction concept. The fourth case illustrates using TAMM as a design guideline when designing a mobile wellness diary to support the management of personal wellbeing. TAMM helped to identify key values and targeted characteristics for the wellness service. The design choices were proved successful by the high adoption rates by different types of users in long-term field trials of the resulting Wellness Diary service.

Case 1: Scenario Evaluation of Future Ubiquitous Services

In future visions, mobile devices are increasingly interacting with their environment and are transforming into tools with which the user can orient in and interact with the environment (Kaasinen, Ermolov, Niemelä, Tuomisto, & Välkkynen, 2006). The target of the MIMOSA project was to develop an open architecture based on low-power tags and sensors that can be read with a mobile phone equipped with readers (Kaasinen et al., 2006). The approach is based on short-range connectivity that can be set up with relatively modest investments in the infrastructure. The mobile terminal can collect information from the sensors automatically or by user initiation. The terminal can also read different RFID (Radio Frequency Identifier) tags. Optional remote connectivity allows connections to remote application servers on the Internet.

Figure 5. Scenarios were illustrated as comic strips. Examples from the left: Golf club equipped with motion sensors, embedded tags in clothes and smart plaster to monitor glucose level.



In the MIMOSA project user acceptance of forthcoming applications was studied to identify the implications of user acceptance requirements for platform design. The focus was put on four representative consumer application fields where user mobility can be combined with measurements of the user and his/her environment: sports, fitness, health care and housing. In addition, general everyday applications were studied.

Right at the beginning of the project we organized scenario workshops where the project partners together defined different usage scenarios for the selected application fields. On the one hand the scenarios illustrated the ideas of the participating technology developer companies of how the new technologies would work. On the other hand the scenarios described how the participating companies representing the selected application fields saw those possibilities being utilized in their forthcoming products. Finally, five to six representative scenarios for each application field were selected and they were described as written stories with comic-strip illustrations (Figure 5). The scenarios were evaluated in focus groups, 2-3 groups of 4-7 people for each application field (Figure 6).

Figure 6. Health care professionals and ordinary users assessing the health care scenarios in focus groups.

To be able to compare user acceptance of the scenarios, a questionnaire was designed based on TAMM. The focus groups first discussed each scenario, and then each participant filled in the questionnaire. The questionnaire included five claims on a five-grade Likert scale (Table 2). The claims covered ease of use, value and trust. Ease of adoption was not included as the scenarios described actual usage situations and not how the systems had been taken into use.

The issues raised in the focus group interviews gave an insight into the quantitative feedback collected on the questionnaires. Even though ease of adoption was left out of the questionnaire, the participants raised it as a discussion theme in almost all the focus groups Although the scenarios described ready-made installations, the interviewees referred to problems that they expected to face in installing and configuring the systems. Especially in relation to sports and fitness scenarios, the interviewees pointed out that they would not have time for complex set-up operations. The system should get started "with a single button". These comments confirm the importance of ease of adoption in user acceptance of mobile services.

Figure 7 highlights the results of the questionnaires regarding the scenarios illustrated in Figure 5. The results indicate the main user acceptance problems in the selected application fields. The golf scenario described how measurement information on the movement of the golf club was analyzed to give the player guidance on improving his drive. Similar to other sports scenarios the interviewees doubted whether the system would be easy enough to use, and in spoken comments also ease of setting up the system was doubted. The interviewees wondered whether additional information on sports performance would make the sports more enjoyable. On the other hand, the scenario was found useful by sports enthusiasts.

Table 2. Claims in the scenario evaluation questionnaire

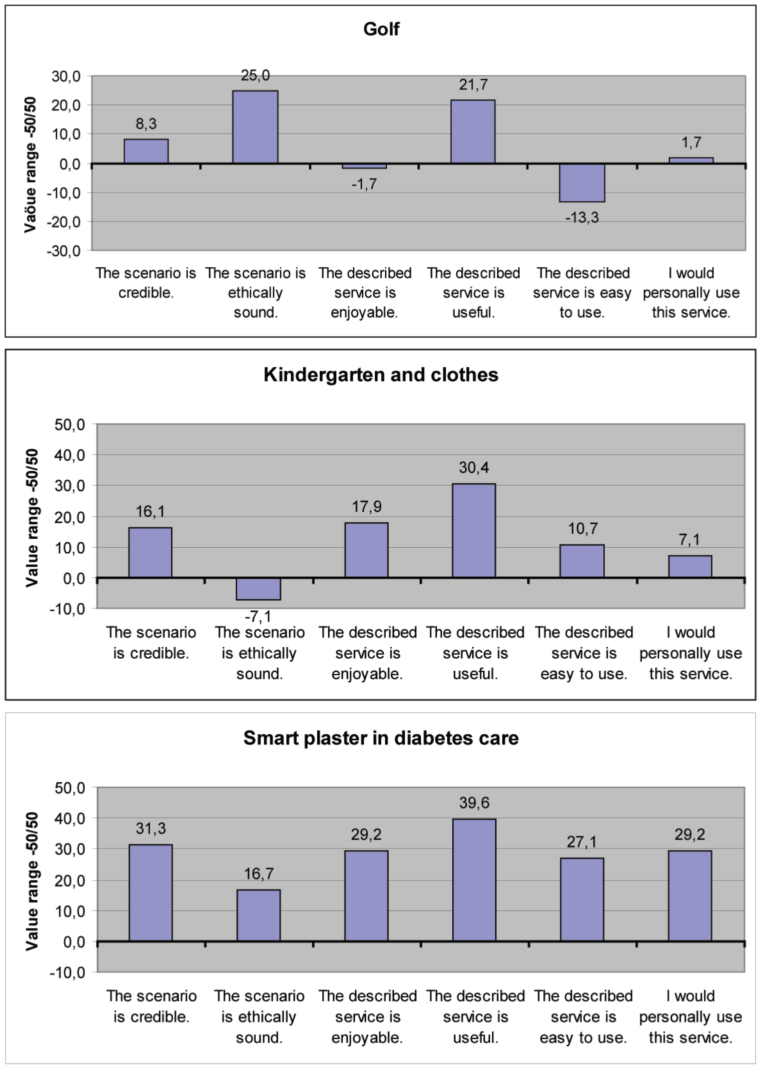
TAMM	*Claim*
Perceived ease of use	The described service is easy to use
Perceived value	The described service is useful The described service is enjoyable I would personally use the service
Trust	The scenario is credible The scenario is ethically sound
Ease of adoption	-

In the Kindergarten scenario, the nurses utilized tags embedded in children's cloths to identify lost and found gloves and other clothes. Although the service was found enjoyable and useful, trust was raised in this as well as in other everyday scenarios where embedded tags were utilized. The interviewees discussed privacy problems: who is allowed to read the data, can the data be used for hostile purposes and so on. User acceptance will require technical securing mechanisms as well as societal practices for acceptable utilization of RFID tags.

A smart plaster that monitored the glucose level of a lady with diabetes scored high marks, as did the other health care scenarios. This encouraged further study on the usage possibilities for the platform on health care applications.

In the MIMOSA project, real-life scenarios facilitated the study of user acceptance of forthcoming applications in the early phases of architectural design. The results clearly indicated how different user acceptance factors are emphasized, depending on the application field. The applications will require extreme ease of adoption, and, as the services will increasingly deal with personal data, the user's trust in the services will become an even more important user acceptance factor. The results provided valuable feedback both to the development of the basic architecture and to applications development. The results also helped in identifying the application fields with the greatest potential.

Figure 7 There were clear differences in user acceptance of the scenarios



Case 2: Evaluation of Mobile TV and Add-on Interactive Services with a User Panel

A mobile TV broadcast network based on DVB-H (Digital Video Broadcasting – Handheld) technology was commercially launched in Finland in late 2006. In early 2007, mobile phones with integrated DVB-H receivers were launched on the market. Some media companies had put their commercial TV channels on mobile TV. A lot of service development plans and work was ongoing in different companies and organizations. In this situation the Finnish Mobile TV project, involving the key actors in the field, wanted to support the service development work by providing a common field evaluation environment to the developers.

A user panel was set up with 14 men and 13 women, aged 19-63 and representing different professions(Figure 8). The panelists were given Nokia N77 DVB-H media phones for their own use for six months. During the evaluation period they regularly received information on new pilot services. They used the services as part of their other mobile TV usage and after two weeks of usage, they were asked to give feedback on each evaluated service by filling in a web questionnaire. The focus of the study was on local TV content as well as add-on interactive services (Figure 9). Altogether 10 pilot services were evaluated (Kaasinen et al., 2009).

In the questionnaire the panelists first graded eight qualities of the service based on TAMM (Table 4.) on a scale "Agree, Somewhat agree, Neither agree nor disagree, Somewhat disagree, Disagree". The questionnaire also included open questions about problems in use, suggestions for improvements as well as service-specific questions planned together with the service providers.

The TAMM-based questionnaire facilitated comparison of different services and identification of the main user acceptance enablers and disablers for different service types. At the end of the trial, we used the same questionnaire to evaluate mobile TV in general and the interactive services in

Figure 8. Typical mobile TV usage situation: having breakfast with the morning paper and Nokia N77

Figure 9. Some of the pilot add-on interactive services: From the left: Jukebox to order music, Radio with interactive services, Teletext service

general. The results are shown in figures 10 and 11.

Mobile TV got very high user acceptance grades (Figure 10). As the TV could be switched on from a dedicated key or from the phone's application menu, finding mobile TV and taking it into use was found easy or quite easy by a clear majority of the panelists. Mobile TV was also found easy and effortless to use. The role of mobile TV was perceived as entertainment rather than as a means of accessing useful information. Information content was found reliable but one third of the panelists did not agree that mobile TV was functionally reliable. The panelists mentioned the limited coverage area, inconsistent functionality in some places, and problems with device storage capacity in the pilot test setup as the main reasons for these opinions.

Taking into use was the main problem with add-on services (Figure 11). In the pilot test setting the users had to carry out some additional tasks related to installation, and some services even required updating the phone's firmware. This partially explains the grades. However, the panelists also had problems finding the actual mobile TV add-on services. Add-on radio services that were available only during a certain program confused the users. It seems that the mere existence of add-on services and their connections to the TV programs will require learning from the users.

Most panelists, however, found add-on services easy to find and the offered information was experienced to be reliable. Panelists thought that add-on services complemented mobile TV well. Even though the content was considered reliable, it was not felt to be especially useful, except for the commercial teletext services.

Problems in ease of use were reported in the surveys of the individual services. These problems included getting an overview of what the service offered, and getting an idea of what was behind individual links, e.g. length and content of the available videos in a video-on-demand service. Familiar teletext services got positive comments concerning ease of use as the services provided both the familiar way to select pages by giving the page number and a faster way by pointing and selecting on the page.

The results of the pilot test indicate that mobile TV as such has potential, but add-on services should be easier to adopt. The users did not get a clear overview of what was available as add-on

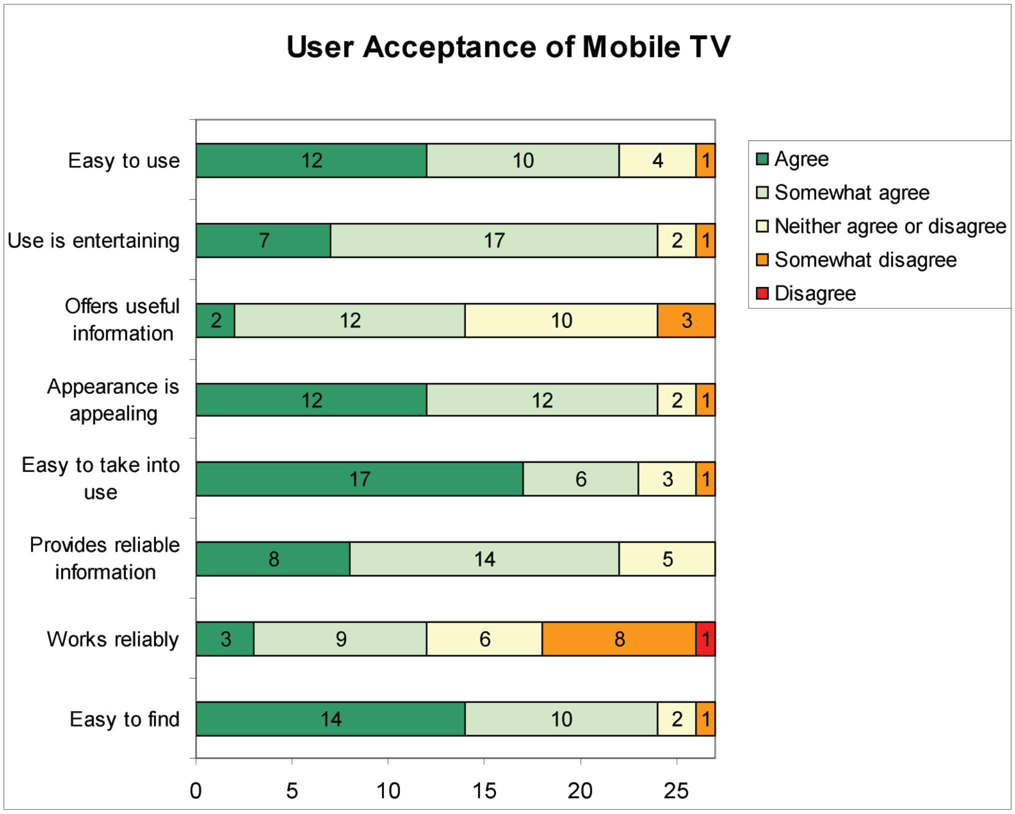
Table 3. Claims in the service evaluation questionnaire

TAMM	*Claim*
Perceived ease of use	The service is easy to use
Perceived value	The service provides me with useful information Using the service is entertaining The appearance of the service is appealing
Trust	The service worked reliably The service provides reliable information
Ease of adoption	The service was easy to find The service was easy to take into use

Table 4. Claims in TAMM questionnaires

TAMM	*Interaction in general*	*Touch-based vs. Button-based default action*
Perceived ease of use	Uploading photos was easy	Uploading was easy
Perceived value	Uploading photos is useful Uploading photos is fun Uploading photos is fast enough	Uploading was fast
Trust		Uploading worked reliably I could control the uploading
Ease of adoption	-	-

Figure 10. User acceptance of mobile TV



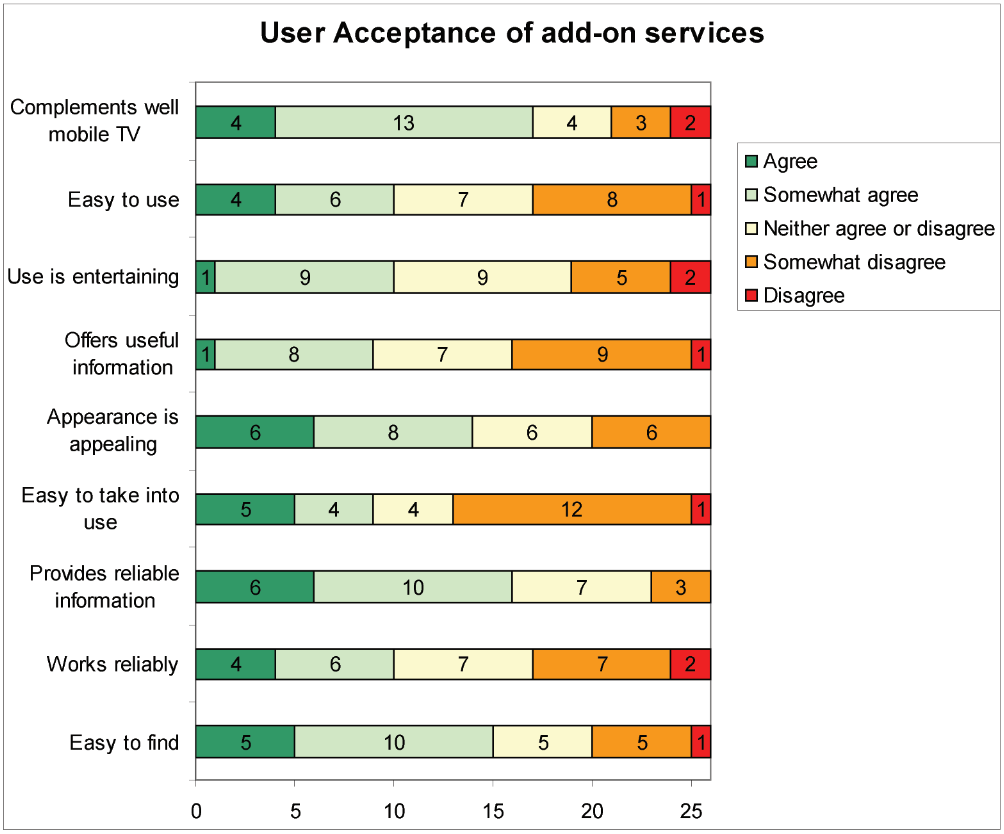
services. Users thought that the mobile TV may not be the media where it is reasonable to launch new services. Mobile TV is used only during short breaks and usage time is limited, so there is not much time to get acquainted with new services. Familiar elements clearly eased adoption, for example with teletext services. Users can learn and adopt the services on other media, where they have better tools for getting an overview, and then extend their usage to mobile. Also usage practices can be adapted from existing practices on other media.

TAMM turned out to be a good framework to compare user acceptance of different services. It helped to highlight the most critical user acceptance factors. The broadcasting content of mobile TV turned out to be well accepted by the users. With interactive services, however, user adoption is the main challenge. Users have to learn the mere existence of those services so that they will get used to look for those add-on services. A successful user adoption path seems to go from familiar content such as teletext to more diverse services.

Case 3: User Evaluation of a New Mobile Interaction Concept

Ubimedia is a concept where media files are embedded in everyday objects and in the environment. We studied an approach where the user can read and write those files with his/her personal mobile phone simply by touching the physical objects (Kaasinen et al., 2010). The technical development of the ubimedia concept was focused on a mobile phone platform with a radio tag reader/writer, memory tags with large storage capacity,

Figure 11. User acceptance of mobile TV add-on services



and the communication between the phone and the tags. Parallel to the technical development, we were studying the interaction concepts related to ubimedia.

A memory tag may include gigabytes of memory, thus facilitating local storage of media files. The user can access this kind of ubimedia with his/her mobile phone just by touching the memory tag. The concept facilitates easy access to media related to physical objects: for instance, music files can be provided as a bonus on a concert ticket or a movie trailer can be downloaded from a movie poster. The users can access the content but they can also take the content with them on their personal mobile devices. This feature is different from locally installed ubiquitous media services such as embedded large screens with significantly lower requirements on the local infrastructure (memory tags vs. large public screens). Writeable memory tags also extend the application possibilities as users can themselves produce content to memory tags. This facilitates, for instance, attaching messages on digital objects as digital post-it notes or social ubimedia where people can interact with each other and share content via actual physical environments. The difference with data stored locally on a memory tag compared to a more traditional technique of storing just a link to the data in a common RFID tag is that the transfer speed of a memory tag is higher by orders of magnitude and it does not burden the network.

We studied user acceptance of ubimedia with two proofs-of-concept. The first of them, Readable memory tag, demonstrated reading or downloading contents (video) from the memory tag to the mobile phone of the user. The second, Writable memory tag, illustrated writing or uploading content to the tag in addition to reading. The proofs-of-concept were both built based on existing technology: Nokia 6131 NFC mobile phone and common (small storage) NFC tag emulating the forthcoming memory tag. The data that is supposedly stored in the memory tag is, in these prototypes, stored in the mobile phone itself. The downloading and uploading times were simulated to correspond to estimated reading and writing speeds with real ubimedia applications.

The long download and upload times were simulated by requiring the user to keep the mobile phone close to the tag for the assumed duration of the data transfer. The mobile phone continuously sensed the presence/absence of the selected tag, thus the data transfer proceeded only when the tag was present close by. For example downloading a photo from a tag took around 2 seconds and uploading a photo to a tag took around 17 seconds, which respond to the actual initial targeted reading speed of 10 Mbps and writing speed ten times slower.

In the following, we will describe user acceptance studies of the interaction with a writeable tag. Seven adult users, 3 male and 4 female, participated in the evaluation. The user evaluation was carried out in a media museum. A photo frame with an embedded memory tag acted as a virtual guest book at the museum (Figure 12). The test user first viewed photos and comments by previous visitors. (S)he could access those by touching the photo frame with the phone. Then the user could take a photo of a point of interest in the museum with the mobile phone camera. Finally the photo was uploaded to the memory tag and the user could optionally add a caption to it. The user was observed and interviewed during the test session. In the end of each test session, the user filled in a TAMM questionnaire.

To study the feasibility of touching a tag as a part of the interaction, the application was implemented so that on each screen there was a sensible default action that would progress the interaction. For example, when the user had taken a photo, the default action was to add a caption to it. The default action was accessible by either touching the tag, or pressing the middle navigation button of the phone. The goal was to provide the user the "path of least astonishment", that is, the default action was selected so that it would follow the natural flow of work and the presumed user expectations. We studied both the new touch-based interaction concept for default actions and the "traditional" button based approach. The test us-

Figure 12. Interaction with ubimedia was evaluated with a proof of concept

ers were able to intuitively choose the interaction concept. After the user had filled in a user acceptance questionnaire, we then asked them to repeat the test task with the other interaction concept. After trying the alternative interaction concept, the user filled in another user acceptance questionnaire. The test included three questionnaires: Interaction in general, Interaction with touch-based default action and Interaction with button-based default action. The questionnaires are illustrated in Table 7. For each claim the user could choose a grade on the scale "Fully agree, Agree, Do not know, Disagree, Fully disagree". Ease of adoption was not included in the questionnaires as in the evaluation setup everything was installed ready for the user. It was assumed that this kind of application would be launched as an integrated part of the operating system of a mobile phone with a memory tag reader.

Figures 13 and 14 illustrate the results of the evaluation. Overall, the writeable ubimedia concept was found easy and fun (Figure 13). The opinions varied regarding if the concept was useful and whether it was fast enough.

Comparing the two interaction alternatives (Figure 14), touch-based default action was found easier to use and faster. With the other user acceptance factors the differences were small but trust on button-based interaction was a bit better than on touch-based interaction.

TAMM turned out to be a good framework for the evaluation. TAMM questionnaire was simple enough to be used three times during the test procedure. The results quickly show the benefits and problem areas of the interaction concept. The results of user observations and interviews give detailed reasons for the acceptance.

Case 4: Design and Evaluation of a Mobile Wellness Management Application

Mobile technologies are increasingly being used in the management of personal well-being and wellness technology development is largely being focused on the mobile platform. Wellness Diary (WD), developed in 2004–2008, is a mobile phone application for the personal self-management of health and well-being (Figure 15). WD was designed to support long-term self-monitoring of health-related behaviours and well-being to help the users learn about their lifestyles and their effects on health. WD provides feedback on the self-observations, enabling the users to evaluate

Figure 13. User acceptance of the interaction concept

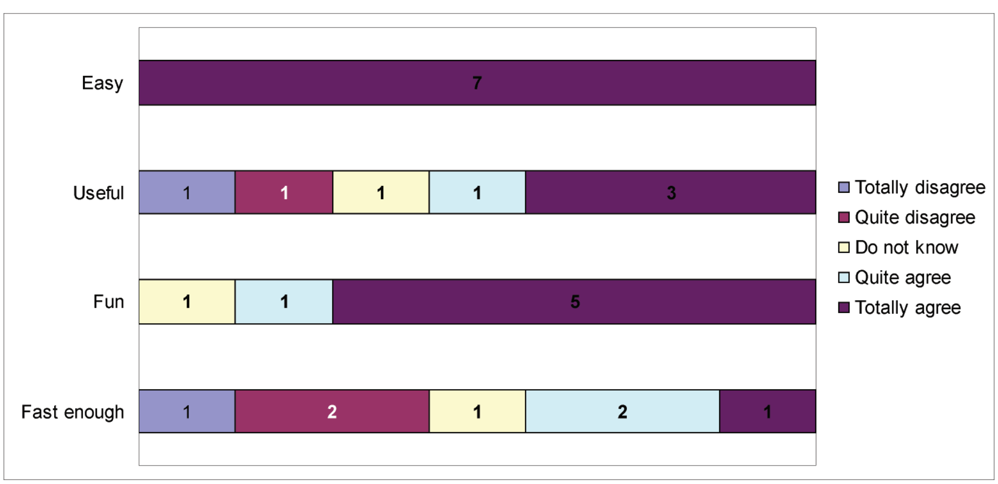


Figure 14. User acceptance of the default action interaction concept. Top: Default action with button, Bottom: default action with touch.

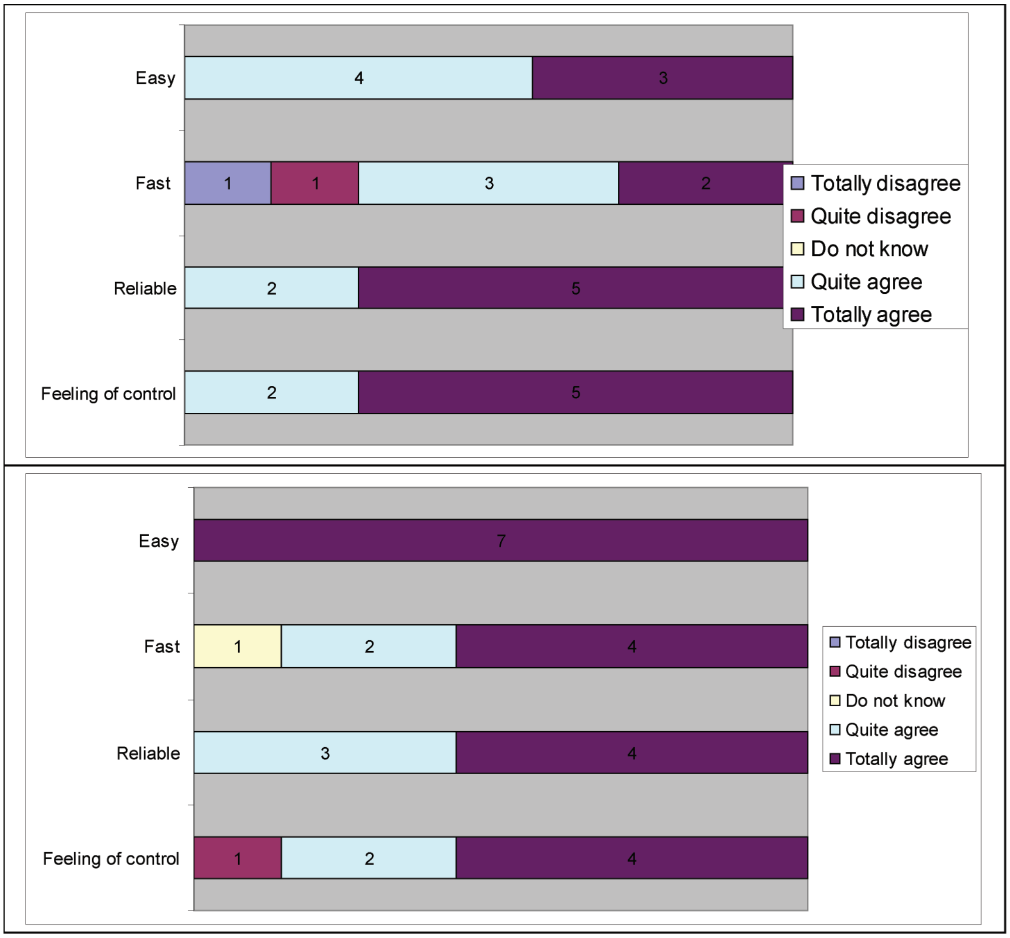
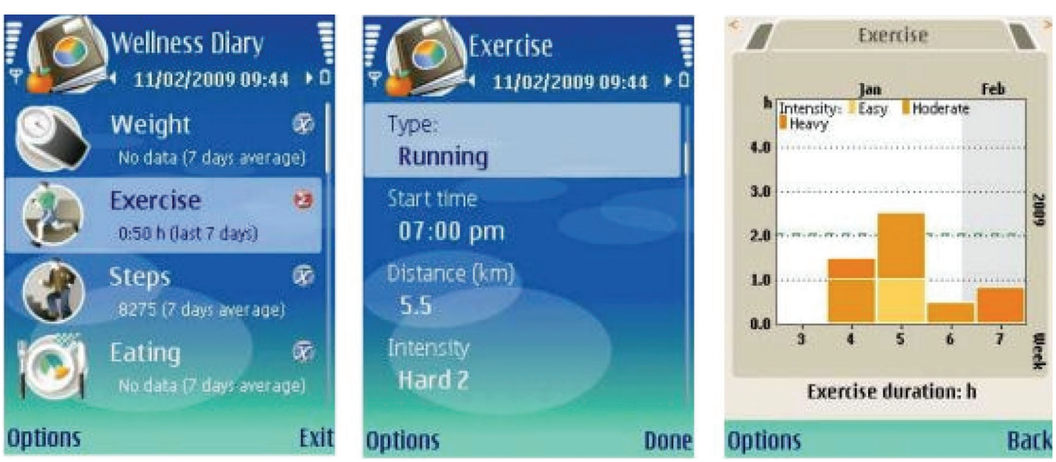


Figure 15. Screenshots of WD: the main view, exercise entry form, and exercise feedback graph.



their well-being status and progress and make informed decisions on their health. The user can use WD to manage different aspects of well-being by selecting among various health variables. The use can adjust WD according to the needs that may change over time. The user can also set individual goals (Mattila et al., 2008; Mattila 2010).

Mobility is a key aspect of WD, allowing well-being management to be integrated to everyday life. As a mobile phone application, WD is always on hand, enabling users to perform health management related tasks anytime and anywhere, both during the idle moments of life and when making lifestyle choices. On the other hand, mobility poses several challenges, such as the limited input and output facilities of mobile devices and the frequent interruptions and multitasking typical of mobile usage situations (Dunlop & Brewster, 2002).

The main design requirement for self-monitoring in WD was that it should enable long-term usage despite the limitations of the mobile platform. Technology Acceptance Model for Mobile services (TAMM) and the related design implications were selected as the design and evaluation guidelines for WD (Kaasinen, 2005b).

The main design target regarding ease of use was supporting momentary use. WD self-observations were designed to be simple and have only a few parameters for the user to fill in. Data entry was designed as numeric fields, drop-down menus, or sliders; it was considered too laborious to require the user to enter text using the small keypad of a mobile phone, especially the numeric T9 keypad. Data entry was further facilitated by automatically time-stamping the entries, but allowing the user to alter them if needed. As a result of these design choices, each entry takes less than 30 seconds to make. Entries can also be made automatically by enabling data transfer from measurement devices.

Momentary usage was facilitated by providing shortcuts from the main view to all of the main functionalities of the application. Stand-alone implementation of WD also supported momentary usage by making its usage free of charge and independent of location, time and network coverage.

The value of WD to the user was planned to be mainly well-being-related, i.e. the application should help its users in self-management through self-monitoring and feedback. The diary should also feel personal. Although the self-observations needed to be simple to facilitate use, it was acknowledged that too strict limitation of inputs did not allow users to enter all the data they considered relevant to them, and therefore optional fields were also included. For example in the exercise entry, in addition to the required duration parameter, fields for entering the sport, intensity, distance, and average heart rate were included. A free text note field was included in all entries to allow entering any personally relevant information.

Feedback was designed to enable efficient self-evaluation with respect to personal goals and to illustrate the effects of user's actions. The main requirements for feedback were that it should be easy to interpret, that the status and progress in health-related parameters should be shown explicitly and immediately, and that the feedback should enable the evaluation of the effects of behavioural changes on well-being. Simple graphs such as line and bar charts that display the status with respect to personal goals formed the basis of the feedback. Flexible viewing and browsing options were implemented in order to enable different types of visual analyses by the user. For example, options to view graphs on different time scales, scroll graphs in time, view individual points in the graph, and overlay graphs of different parameters in the same view were provided. Also simple statistics of entries were included to provide another form of feedback. For example, in the main view, weekly sums or averages of entries provide a quick summary of the status of different health variables.

As WD is a health-related service, privacy protection was the main trust related design target. The user owns the data he/she enters in WD and has total control over the data. All data are stored locally in the mobile phone, and thus can be accessed, viewed, modified and deleted at anytime. The users can transfer their WD data wirelessly via the Multimedia Messaging Service (MMS), Bluetooth, or email to researchers, experts or peers. Also a two-way data synchronisation was enabled between WD and its web-based counterpart, Wellness Diary Connected (WDC; Nokia Corp., Helsinki, Finland). In this case, user's data is secured and can be viewed and manipulated by the user also in the web service. All modes of data transmission from WD are user-initiated to ensure the user's control over his/her data. These choices were made in order to increase the users' control and ensure their privacy, and thereby enhance their trust in the application.

A trust-related design decision was to protect users from their own, over-ambitious targets. Goal setting was designed to enable the user to commit to a change by setting personal targets. In order to prevent unrealistic targets, an algorithm to check the weight target for safety was included. The algorithm checks the user's target against healthy BMI limits and weight management recommendations. The rules aim to discourage underweight users to lose weight and to discourage normal or overweight users to gain weight or lose weight too dramatically. This feature was designed to help the user avoid potentially unhealthy targets.

Another trust related design target was preventing user errors. A simple validation mechanism was designed to prevent the user from unintentionally saving empty entries. The application detects if a mandatory field has not been filled in and asks the user whether he/she really wants to save the entry.

Taking a new application into use is always a challenge requiring learning and should be made as effortless as possible. To facilitate the adoption, the first versions of WD were integrated into the standard Symbian Series 60 calendar. This design provided users with a recognisable user interface and a familiar way of using the application. In later versions, the calendar integration was redesigned in order to emphasize well-being management. Still, sharing data between WD and the calendar, calendar-like usage logic and many calendar-like views were maintained. Another motivation for the calendar paradigm was to provide a fit to the existing usage culture of the mobile phone (daily time management) and an opportunity to extend it to daily well-being management, following one of the TAMM design guidelines for facilitating adoption.

The user acceptance of WD was evaluated in three user studies as detailed in Table 10. The user acceptance of WD in these studies was examined based on the dimensions of TAMM, perceived ease of use, ease of adoption, value, and trust.

Perceived ease of use of WD was high in all studies. In Study I, about 90% of participants perceived WD as a simple application and in Study II, 100% of participants reported that it was easy to make entries with a mobile phone. In Study III, WD was perceived as easy to use by 60% of respondents.

Table 5. User acceptance of the wellness diary was studied in three field trials

Health issue targeted	**Population**	**Participants**	*Duration*
Study I: Weight management (Mattila et al., 2008) E	Working-age adults, mean age 40 years	30 (21 males, 9 females)	*12 wk*
Study II: Occupational rehabilitation for stress-related problems (Mattila et al., 2008)	Working-age, mean age 55 years	17 (3 males, 14 females)	*12 wk*
Study III: Occupational health promotion for multiple health risks (Ahtinen et al. 2009)	Working-age, mean age 45 years	*118 (35 males, 83 females)*	*12 mo*

Ease of adoption of WD was confirmed in all of the studies. About 90% of participants in Study I and 76% of participants in Study II reported that it was easy to learn to use WD. In Study III, ease of adoption was expressed by the fact that 65% of participants took WD into use at the beginning of the study with very little guidance.

Perceived value of WD was tied to the value of WD in self-management. In Study I, more than 70% of participants reported that WD was useful, motivated them to observe their eating and be more physically active, and helped them in weight management. The weight management results of Study I were also encouraging; about half of participants lost weight and the rest approximately maintained their baseline weight despite the fact that the study period included Christmas, which is a known risk period for weight gain. In Study III, two-thirds of respondents reported that WD contained appropriate functions for them and more than half felt that WD motivated them to maintain or enhance their well-being. WD was perceived as useful by participants with different types of goals, including weight management, exercise, sleep, and stress, indicating that WD is applicable for supporting many different health management goals.

Although the fourth component of acceptance, trust, was not formally studied, the participants did not seem to have problems in trusting WD to store their health-related data. Indications of this are the high overall acceptance and usage rates of the application as well as the very few negative user comments related to privacy or trust issues. On the other hand, many participants commented that they did not perceive their self-observations, e.g. weight, physical activity, or sleep, as particularly sensitive information.

TAMM was a useful framework for the design and evaluation of a wellness management application. The design choices were proved successful by the high adoption rates by different types of users. However, for wellness management applications, augmenting the model with factors that promote long-term engagement would be useful.

CONCLUSION

According to the Technology Acceptance Model for Mobile services, user acceptance of mobile services is built on three factors: perceived value of the service, perceived ease of use, and trust. A fourth user acceptance factor: perceived ease of adoption is required to get the users from intention-to-use to actual usage. Based on the Technology Acceptance Model for Mobile Services, design implications for each user acceptance factor have been proposed in this paper.

Instead of implementing collections of useful features, the design of mobile services should be focused on key values provided to the user. The value of mobile services can be built on utility, communication or fun. Successful service content is comprehensive, topical and familiar, and it includes personal and user-generated content. The users appreciate seamless service entities rather than separate services. Ease of use requires a clear overview of the service entity, fluent navigation on a small display, and smooth user interaction with the service. The users should get personally and situationally relevant services and information without needing to expend effort on personalization. The services should be designed to be adaptive to a wide variety of devices and networks. As the services increasingly support individual users in their daily tasks and increasingly deal with personal data, user trust in the services is becoming more and more important. The user should be able to assess whether (s)he can rely on the service in the intended contexts of use. The user needs to feel and really be in control, and the privacy of the user must be protected.

Occasional usage and momentary usage sessions on the move are typical of mobile services. In addition, services are increasingly available only locally or in certain contexts of use. This indicates the need for disposable services: services that are easy to find, take into use, use and get rid of when no longer needed. The user needs realistic information about the actual values of the services, so that (s)he can realize how to utilize the service in his/her everyday life and to innovate new usage possibilities.

The Technology Acceptance Model for Mobile Services provides a tool to communicate key user acceptance factors and their implications for the design. The model together with the design implications can be used as a user acceptance design guideline. As the case studies illustrate, the model also works as an evaluation framework that facilitates comparison of different services or service ideas for user acceptance. Used during early phases of the design, the model can be used in scenario evaluations to identify the applications or applications fields with the greatest potential. The model also helps in identifying the most critical user acceptance factors, which can then be further analyzed in user interviews. Taking user acceptance as the research framework extends the design and evaluation focus. The adoption of the services in the users' everyday lives can then be studied from the very beginning and throughout the design process.

Future research challenges include studying how the context of use and usage costs could be taken into account in the Technology Acceptance Model for Mobile Services. Social influence and peer opinions are important factors especially when setting up services that will require a critical mass of users, for instance services based on social media. It would be interesting to study how TAMM could be utilized to predict the adoption of these kinds of services. Furthermore, additional acceptance models will be needed to facilitate studying engagement to long-term use after the initial adoption.

REFERENCES

W3C. (2008). Mobile Web Best Practices 1.0. Basic Guidelines. W3C Recommendation 29 July 2008. http://www.w3.org/TR/mobile-bp/

Ahtinen, A., Mattila, E., Väätänen, A., Hynninen, L., Salminen, J., Koskinen, E., & Laine, K. (2009). User experiences of mobile wellness applications in health promotion. User study of Wellness Diary, Mobile Coach and SelfRelax. *Proceedings of the 3rd International Conference on Pervasive Computing Technologies for Healthcare*. PCTHealth 2009. London, UK.

Ajzen, I., & Fishbein, M. (1980). *Understanding attitudes and predicting social behaviour*. Upper Saddle River, NJ: Prentice Hall.

Antifakos, S., Schwaninger, A., & Schiele, B. (2004). Evaluating the effects of displaying uncertainty in context-aware applications. In Davies, N., Mynatt, E. & Siio, I. (eds.). *Proceedings of Ubicomp 2004: Ubiquitous Computing 6th International Conference* (pp. 54-69). New York: Springer-Verlag.

Barnes, S. J., & Huff, S. L. (2003). Rising Sun: imode and the wireless internet. *Communications of the ACM*, *46*(11), 79–84.

Billsus, D., Brunk, C. A., Evans, C., Gladish, B., & Pazzani, M. (2002). Adaptive interfaces for ubiquitous Web access. *Communications of the ACM*, *45*(5), 34–38. doi:10.1145/506218.506240

Boehm, B. (2003). Value-based software engineering. *Software Engineering Notes*, *28*(2), 1–12.

Chen, L., Gillenson, M. L. & Sherell, D. (2004). Consumer acceptance of virtual stores: a theoretical model and critical success factors for virtual stores. *ACM SIGMIS Database archive,* 35, *(2), Spring,* 8–31.

Cockton, G. (2004). Value-Centred HCI. *Proceedings of the Third Nordic Conference on Human-Computer Interaction* (pp.149–160).

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quartely*, *13/1989*, 319–339. doi:10.2307/249008

Davis, F. D., & Venkatesh, V. (2004). Toward preprototype user acceptance testing of new information systems: implications for software project management. *IEEE Transactions on Engineering Management*, *51*(1). doi:10.1109/TEM.2003.822468

Dunlop, M., & Brewster, S. (2002). The challenge of mobile devices for human computer interaction. *Personal and Ubiquitous Computing*, *6*(4), 235–236. doi:10.1007/s007790200022

Fogg, B. J., & Tseng, H. (1999). The elements of computer credibility. *Proceedings of CHI 99 Conference* (pp. 80–87).

Funk, J. L. (2004). *Mobile disruption. The technologies and applications driving the mobile Internet*. Wiley-Interscience.

Gefen, D., Karahanna, E., & Straub, D. W. (2003, August). Inexperience and experience with online stores: the importance of TAM and Trust. *IEEE Transactions on Engineering Management*, *50*(3), 307–321. doi:10.1109/TEM.2003.817277

Henderson, A. (2005). Design: The innovation pipeline: design collaborations between design and development. *Interactions (New York, N.Y.)*, *12*(1), 24–29. doi:10.1145/1041280.1041295

ISO 13407. (1999). *Human-centred design processes for interactive systems.* International standard. International Standardization Organization. Geneve.

Järvenpää, S. L., Lang, K. R., Takeda, Y., & Tuunanen, V. K. (2003). Mobile commerce at crossroads. *Communications of the ACM*, *46*(12), 41–44. doi:10.1145/953460.953485

Kaasinen, E. (2003). User needs for location-aware mobile services. *Personal and Ubiquitous Computing*, (6): 70–79. doi:10.1007/s00779-002-0214-7

Kaasinen, E. (2005a, January–February). User acceptance of location-aware mobile guides based on seven field studies. *Behaviour & Information Technology*, *24*(1), 37–49. doi:10.1080/01449290512331319049

Kaasinen, E. (2005b). *User acceptance of mobile services - value, ease of use, trust and ease of adoption.* Doctoral dissertation. VTT Publications 566. Espoo: VTT Information Technology.

Kaasinen, E. (2008). User Acceptance of Mobile Services. In Lumsden, J. (Ed.), *Handbook of Research on User Interface Design and Evaluation for Mobile Technology* (*Vol. 1*, pp. 102–121). Hershey, PA: IGI Global.

Kaasinen, E., Aaltonen, M., Kolari, J., Melakoski, S., & Laakko, T. (2000). Two Approaches to Bringing Internet Services to WAP Devices. [New York: Elsevier Science B. V.]. *Computer Networks*, *33*, 231–246. doi:10.1016/S1389-1286(00)00041-4

Kaasinen, E., Ermolov, V., Niemelä, M., Tuomisto, T., & Välkkynen, P. (2006). *Identifying User Requirements for a Mobile Terminal Centric Ubiquitous Computing Architecture.* FUMCA 2006: System Support for Future Mobile Computing Applications. Workshop at Ubicomp 2006.

Kaasinen, E., Ikonen, V., Ahonen, A., Anttila, V., Kulju, M., Luoma, J., & Södergård, R. (2002). *Products and Services for Personal Navigation – Classification from the User's Point of View.* Publications of the NAVI programme. Retrieved January 4, 2005, from www.vtt.fi/virtual/navi

Kaasinen, E., Kasesniemi, E.-L., Kolari, J., Suihkonen, R., & Laakko, T. (2001). *Mobile-Transparent Access to Web Services – Acceptance of Users and Service Providers.* Proceedings of International Symposium on Human Factors in Telecommunication. Bergen, Norway. 5.–7.11.2001.

Kaasinen, E., Kulju, M., Kivinen, T., & Oksman, V. (2009). *User acceptance of mobile TV services*. In Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services.

Kaasinen, E., Niemelä, M., Tuomisto, T., Välkkynen, P., Jantunen, I., & Sierra, J. (2010). Ubimedia based on readable and writable memory tags. *Multimedia Systems*, *16*(1), 57–74. doi:10.1007/s00530-009-0171-3

Kindberg, T., Sellen, A., & Geelhoed, E. (2004). Security and trust in mobile interactions – a study of users' perceptions and reasoning. In Davies, N., Mynatt, E. & Siio, I. (eds.). *Proceedings of Ubicomp 2004: Ubiquitous Computing 6th International Conference* (pp. 196-213). New York: Springer-Verlag.

Kuo, Y. F., & Yen, S. N. (2009). Towards an understanding of the behavioral intention to use 3G mobile value-added services. *Computers in Human Behavior*, *25*, 103–110. doi:10.1016/j.chb.2008.07.007

Mallat, N., Rossi, M., Tuunainen, V. K., & Öörni, A. (2009). The impact of use context on mobile services acceptance: the case of mobile ticketing. *Information & Management*, *46*, 190–195. doi:10.1016/j.im.2008.11.008

Mathieson, K., Peacock, E., & Chin, W. W. (2001). Extending the Technology Acceptance Model: the influence of perceived user resources. *The Data Base for Advances in Information Systems*, *32*(3), 86–112.

Mattila, E. (2010). *Design and evaluation of a mobile phone diary for personal health management.* Doctoral dissertation. VTT Publications 742. Espoo: VTT.

Mattila, E., Pärkkä, J., Hermersdorf, M., Kaasinen, J., Samposalo, K., & Vainio, J. (2008). Mobile diary for wellness management – Results on usage and usability in two user studies. *IEEE Transactions on Information Technology in Biomedicine*, *12*(4), 501–512. doi:10.1109/TITB.2007.908237

Nah, F. F.-H., Siau, K., & Sheng, H. (2005). The value of mobile applications: a utility company study. *Communications of the ACM*, *48*(2), 85–90. doi:10.1145/1042091.1042095

Norman, D. A. (1998). *The Invisible Computer*. Cambridge, MA: MIT Press.

Platzer, E. (2009). A Critical Review of User Acceptance Research in the Area of Mobile Services. *Libri*, *59*, 213–227. doi:10.1515/libr.2009.019

Platzer, E., & Petrovic, O. (2010). Development of technology acceptance research for mobile services. *Proceedings of MIPRO*, *2010*, 1154–1159.

Rogers, E. M. (1995). *The diffusion of innovations* (4th ed.). New York: Free Press.

Roto, V. (2006). *Web browsing on mobile phones – characteristics of user experience*. Doctoral dissertation. Helsinki University of Technology. Espoo 2006.

Sarker, S., & Wells, J. D. (2003). Understanding mobile handheld device use and adoption. *Communications of the ACM*, *46*(12), 35–40. doi:10.1145/953460.953484

Tsai, J. Y., Kelley, P., Drielsma, P., Cranor, L., Hong, J., & Sadeh, N. (2009). Who's Viewed You? The Impact of Feedback in a Mobile Location Sharing System. *Proceedings of*, *CHI2009*, 2003–2012.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *Management Information Systems Quarterly*, *27*(3), 425–478.

Zhang, J., Huang, J. & Chen, J. (2010). Empirical Research on User Acceptance of Mobile Searches. *Tsinghua Science and Technology,* 15,. *(2)*, 235-245.

Chapter 6

Experiences of Supporting Local and Remote Mobile Phone Interaction in Situated Public Display Deployments

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ABSTRACT

Public displays and mobile phones are ubiquitous technologies that are already weaving themselves into the everyday life of urban citizens. The combination of the two enables new and novel possibilities, such as interaction with displays that are not physically accessible, extending screen real estate for mobile phones or transferring user content to and from public displays. However, current usability evaluations of prototype systems have explored only a small part of this design space, as usage of such systems is deeply embedded in and dependent on social and everyday context. In order to investigate issues surrounding appropriation and real use in social context field studies are necessary. In this paper

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we present our experiences with field deployments in a continuum between exploratory prototypes and technology probes. We present benefits and drawbacks of different evaluation methods, and provide a number of validated lessons from our deployments.

INTRODUCTION

The use of mobile phones provides a range of new and novel opportunities for supporting interaction with public displays. Furthermore, such interaction can help overcome some of the problems associated with interactions with public displays. An example is the potential inability of users to interact with a touch screen display because of its physical placement (e.g. inappropriate height for a wheelchair user). Mobile phones can also support multi-user interaction and act as a means of transferring content to a public display or display content to the user's device. While these issues have been investigated in lab studies it is not clear how they will be appropriated in everyday life. In this article we discuss our explorations of some of these issues and present a number of lessons as a result. The lessons are based on our experiences with supporting both local and remote mobile phone interaction with a number of situated display deployments. Our research approach involves a tight cycle where theoretical issues and understanding, developed through reflection on empirical observations, are used to design deployed systems that test and explore theories. These deployed systems then create a new context for observation of user behaviour and thus lead to fresh insights, discoveries and refinement of theoretical understanding.

RELATED WORK

There is surprisingly little published work relating to the combination of mobile phones and situated public displays, and the vast majority of these systems have only been evaluated in the lab, if at all. ContentCascade (Himanshu, Gossweiler, & Milojicic, 2004) for example enables a user to download content from a public display onto her mobile phone using Bluetooth. The system was tested in a small and informal user study using movie clips. More recent work by Maunder, Marsden and Harper (2007) has investigated the potential for supporting mobile phone interaction with public displays in order to enable users to select and download content without requiring the user to keep their phone in a discoverable state. Their approach required the user to take a picture of the content screen that he/she wishes to download and then send this picture back to the public display server as a Bluetooth transfer, thus providing the server with the user's phone's Bluetooth MAC address. The server then performs image recognition to determine the content required by the user, which is then transferred via Bluetooth to the user's phone. The system has only been evaluated informally. Ballagas, Rohs, Sheridan and Borchers (2005) present a survey of interaction techniques with mobile phones, most of which are used to generate input to a public display. The majority of systems they present have been evaluated only in lab studies. Rukzio, Boll, Leichtenstern and Schmidt (2007) present a comparison of different interaction techniques with mobile phones, which have been evaluated in the lab. Some systems use Bluetooth as a means to detect the presence of people rather than as a means to enable explicit interaction. Two examples of these systems are the BluScreen system (Payne, David, Jennings, & Sharifi, 2006), which links advertisement displays, agents bidding for advertisement space and the detection of presence via Bluetooth, and CityWare (Kindberg & Jones,

Table 1. Overview of deployments

System	Installed From	Installed Until	Number Displays	Location	Functionality	Local Interaction	Remote Interaction
Hermes	March 2002	July 2004	13 displays	Office Doors of Lancaster University	Asynchronous Messaging	Touchscreen	SMS, MMS, Web, E-mail
Hermes II	May 2006	present	40 displays	Office Doors of Lancaster University	Asynchronous Messaging	Touchscreen	SMS, MMS, Web, E-mail
Hermes Photo Display	June 2003	June 2004	1 display	Hallway of Lancaster University	Sharing of Media	Touchscreen	MMS, E-mail
iDisplays	October 2005	present	12 displays	Hallways of Münster University	Textual Information Sharing	Mobile Phone (Java Application)	Web, Email, SMS
Wray Photo Display	August 2006	present	1 display	Post office in Wray Village near Lancaster	Sharing of Media	Touchscreen, Mobile Phone (Bluetooth)	Web, E-mail
MobiDiC	September 2007	present	20 displays	Streets in city centre of Münster	Retail Advertising/ Discount Coupons, Navigation	Mobile Phone (Camera, Bluetooth, Java Application)	Web

2007), where urban activities of users were tracked with Bluetooth scanners.

The majority of systems built have been evaluated only in lab settings and not in field deployments. Therefore, there is little knowledge to date regarding appropriation into everyday life of systems that combine public displays and mobile phones. This general bias has also been identified generally in mobile HCI research (Kjeldskov & Graham, 2003). The focussing on usability issues only and ignoring appropriation has come under increasing critique (Greenberg & Buxton, 2008). Although the added value of field studies for finding usability flaws can be doubted (Kieldskov, Skov, Als, & Høegh, 2004), its unique applicability to study appropriation has been shown (Rogers et al., 2007). For the related field of Ambient Displays, Skog (2006) has shown that many interesting aspects can only be observed from longitudinal field studies. For public displays, Huang, Mynatt and Trimble (2007) have shown that the challenges of the real world lead to unexpected usage patterns that probably cannot be predicted from lab experiments.

CASE STUDIES

We now present six different field deployments in and around the cities and universities of Münster and Lancaster, which have allowed us to investigate appropriation from a number of different angles (see Table 1).

The systems presented first have been installed close to the researchers' offices, which enabled continuous observation and easy access to the user groups, but constrained users to a university population. The latter systems have been installed in sites remote from the researchers' offices, which enabled investigation of different user populations but also hindered continuous observation of the displays.

Figure 1. InfoLab visitor interacting with the Hermes Photo Display (March 2006) (left) and Hermes II Office Door Display (March 2007) (right)

Hermes and Hermes II

Hermes (Cheverst, Dix, Fitton, Friday, & Rouncefield, 2003) and Hermes II (Fitton, 2006; Cheverst, Dix, Fitton, Graham, & Rouncefield, 2008) are electronic office doorplate systems that allow the owner of the office to display notices to visitors as well as visitors to leave messages for the owner. Users can remotely send an SMS for public display, as well as receive hand-drawn visitor messages via MMS. In order to enable wheelchair visitors to leave messages without installing a second lower display we are adding a feature that enables a visitor to leave a message on a door display using his/her mobile phone.

The Hermes Photo Display

The Hermes Photo Display (Cheverst et al., 2005) enabled Hermes users (and more specifically the owners of Hermes displays) to send pictures to the display in a similar manner to sending pictures to their office door display (see Figure 1). Users could use MMS or e-mail in order to 'post' a picture and the subject header of the message was used to stipulate the location of the destination display, e.g. "PUBLIC LOCATION C FLOOR". The initial system did not allow users to cycle through all the pictures received but would instead automatically select a sub-set of pictures to display.

iDisplays

The iDisplays system (Müller, Paczkowski, & Krüger, 2007) is a collection of public displays installed in the hallways of the University of Münster. Faculty can submit information items via a Web application and these items are shown on the displays alongside information like bus departures or weather forecast. We developed a Java application that users can install on their mobile phones. Using the application users can connect via Bluetooth to the displays to request an email with extended information on a news item, send an SMS containing a selected item to a friend, or store the information on the mobile phone's calendar (see Figure 3).

The Wray Photo Display

The Hermes Photo Display was later repurposed and deployed in Wray (Figure 2), a small village near Lancaster, with the intention of investigating how a public display could support a rural community (Taylor et al., 2007). In early design sessions with our user group in the community (members of the village 'Computer Club' with varying levels of computing skills) we discussed deploying a photo display system, and also discussed the idea of supporting the uploading and downloading of pictures to and from the display using mobile phones, which was met with some enthusiasm. We initially intended that this would be the main method for handling display content.

MobiDiC

MobiDiC (Müller, Jentsch, Kray, & Krüger, 2008) is a public display advertising system. The displays show coupons (see Figure 3) that can be photographed by passersby using their mobile phone. To claim a discount at a shop, people can

Figure 2. The leader of the computer club 'playing' with the Bluetooth feature of the Wray photo display, and the screen for selecting a mobile phone to download to (March 2006)

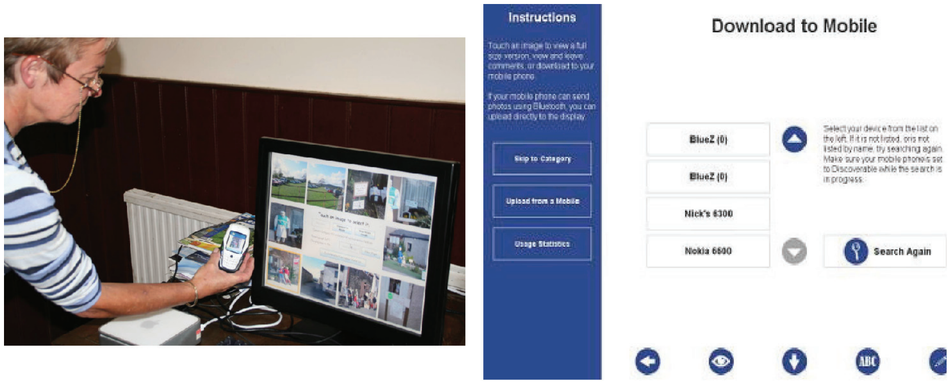


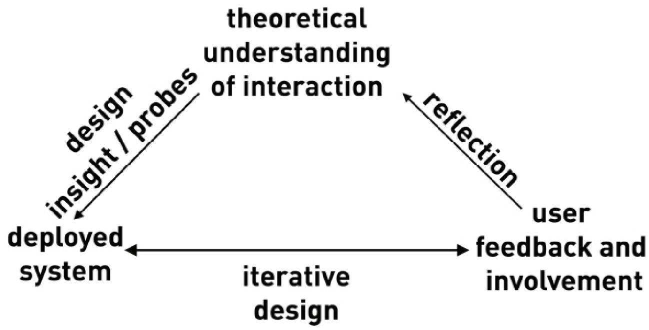
Figure 3. Taking a photo of the MobiDiC Coupon display, and user interacting with the iDisplays system

then present the photographs at a participating shop. Shopfinder is a small companion application supporting the coupon/advertising system. People can download it after having taken a photograph of a coupon in order to get guidance to the shop, which offers the coupon. They initiate the download by sending the coupon to the display via Bluetooth Object Push. The display system then generates a customized Java application and sends it back to the mobile phone. When users launch the Shopfinder application, it shows a series of landmark pictures that help users finding their way to the shop.

EVALUATION/DEVELOPMENT METHODOLOGY

Our research approach involves a tight cycle where theoretical issues and understanding, developed through our reflection on empirical observations, are used to design deployed systems that test and explore the theories (see Figure 4). These

Figure 4. Pattern of deployment based research



deployed systems then create a new context for observation of user behaviour and thus lead to fresh insights, discoveries and refinement of theoretical understanding. The deployed systems take a role on a continuum between technology probes (Hutchinson et al.., 2003; Graham et al., 2006) and traditional field prototypes (i.e. working prototypes evaluated in the field or in-situ) and support a single main functionality and use logging as a main method to generate data. Their goal is to identify long-term user needs as well as to study appropriation of the technology. We adopt an iterative and user centered design based approach to each deployment where the observation and involvement of users serve the dual purpose of traditional user centred design and source for further theoretical analysis The challenges of carrying our such user centred design as part of a rapid prototyping development context is discussed in (Fitton et al., 2005). In order to achieve real use, the systems must meet real or emerging needs, and avoid interfering with the activities usually carried out at the location of their deployment, perhaps even taking advantage of these activities. In order to elicit the empirical data used as part of the reflective process we employ a variety of mostly ethnographic techniques (Bernard, 2005) on a continuum from the informal to formal and qualitative to quantitative. Inductive analysis techniques like grounded theory (Glaser & Strauss, 1967) are then used to code the data, build categories, sort them and build theory. A key aspect of our approach is applying the tenets of existing techniques (technology probes and ethnographic methods) in order to carry out evaluation during a 'real world' deployment at low cost and where traditional usability studies receives higher priority later in the design phase. This contrasts slightly with existing ambient display evaluation research where often heuristic evaluation is carried out with lab-based prototypes (for example (Mankoff et al., 2003)).

BENEFITS AND DRAWBACKS OF EVALUATION TECHNIQUES

To obtain data for analysis, we use a variety of ethnographic methods. In this section we compare our experiences for different techniques for the specific case of public display interaction with mobile phones.

Observing Users

Casual Observations proved a major source of information especially for the displays where we are often in the vicinity. For example, in the iDisplays deployment, it could easily be observed that most people only have very short glimpses between a half and two seconds while they pass the display, without stopping. However, the only available data are field notes, and it can be hard to investigate short interactions in detail. To remedy this, we used *Video Analysis* with cameras installed on top of three displays in the iDisplays deployment. Video capture was triggered by motion detection to record user behaviour. On one day, 378 situations where users passed a display were analyzed. The benefits of this technique were that interactions for an entire day could be observed in detail, allowing quantitative comparison of different displays. However, the cameras capture only a very narrow field in front of the display, and it is necessary to capture multiple days of usage because many users behave unnaturally when first conscious of the fact that their actions are being recorded. To observe even longer periods of time, we used *Automated Face Detection* and logged the times faces were found in front of displays. The main benefit of this automatic technique is that user behaviour can be compared over longer periods of time. However, only the view times are captured, and interesting behaviour may go unnoticed. An in-depth discussion of the challenges associated with the use of video (and other techniques such as usage logs) to produce digital records of interaction in ubiquitous computing environments is presented in (Crabtree et al., 2006).

Asking Users

Unstructured Interviews gave the opportunity to gain further information from the user in-situ after interaction with the display had taken place. To find more detailed answers to specific questions, *Semi-structured Interviews* proved useful. For example it became obvious that most users only used very specific information from the iDisplays. The kind of information used, however, varied greatly for different users. For example, while one user only wished to view the clock another user was not aware of the clock and only viewed the bus departure times. However, because these interviews take place after the user has finished interacting, users are often not able to recall their own behaviour precisely. *Repertory Grid Interviews* proved useful to elicit the dimensions users use to think about a given topic in their own words. In one case, we asked users to compare different displays regarding whether they had used them with a navigation system that combines mobile phones and public displays (Müller et al., 2008). This resulted in an ordered list of dimensions that influence whether people look at the displays, for example whether the user can already see his goal, or whether he currently looks at the phone or the environment. This then helps in determining which research questions may be worth pursuing and which not. However, the interviews tend to be very focused on the categories and lack richness. We employed *Contextual Inquiry* to investigate users' normal procedures when dealing with noticeboards (Müller et al., 2007). From this analysis, it was possible to identify different kinds of posters and displays people are interested in, as well as to identify opportunities for mobile devices to fit into their workflow. However, this kind of analysis is usually constrained to a few typical situations that users believe are important, and does not include in-situ observation. *Probe Packs* proved useful in the Wray deployment for identifying social spaces. A *Comments Book* in the Wray deployment generated over 60 feature requests, experience statements and suggestions.

Logging

Interaction logging was implemented in all our deployments and proved very useful in determining variations in long-term use of the systems. For the MobiDiC Shopfinder for example, the interaction logging showed that in seven weeks the Shopfinder was downloaded 130 times, with peak download times in the afternoon, and some downloads as late as 2am or early as 7am. The main benefit of interaction logging is that a lot of data is generated automatically. When the logs show some interesting patterns however, it is usually not possible to gather more information about the event.

CHALLENGES FOR FIELD STUDIES INVOLVING PUBLIC DISPLAYS AND MOBILE DEVICES

Moving field studies out of the lab and into the 'real world' bring rich and varied findings. However, unexpected challenges are often raised. The following section considers the user-centric challenges which resulted in some of our prototypes receiving relatively small levels of use. Next, the technical challenges that had to be addressed during our field studies are presented. Finally, the remaining pragmatic challenges which emerged from our field studies are discussed.

User-Centric Challenges

The initial challenge concerns the visibility of the system and whether it is high enough for users to notice it. While for example we installed the iDisplays in such a way that users had to walk towards them in hallways, for many MobiDiC Displays users had to turn their head. We tried to advertise the MobiDiC system by posting A4 posters on top of them and distributing 5000 flyers, but this had almost no effect in mitigating the lower visibility of these displays.

Another key challenge for field studies emerges when use of the prototype is not mandated (as was the case with all systems described here). In this case, use of the system relies entirely on the user's own motivation and, unfortunately, some of our prototypes received low levels of use with respect to mobile phone interaction.

When considering initial use, the first challenge to overcome is the difficulty users have in perceiving the affordance(s) (Norman, 1999) of interaction associated with a public display (especially concerning supported interaction with a mobile phone). Currently, mobile phone interaction is an uncommon concept which the general public does not expect. We have attempted to overcome this problem by displaying instructions for interaction on the display (MobiDiC) or on a poster close to the display (Hermes Photo Display and Wray). Once users are aware that they can interact with a display using their mobile phone the second challenge is to mitigate any social issues which may discourage use (such as potential embarrassment (Brignull & Rogers, 2003)). One finding from a questionnaire based study involving the Hermes Photo Display (Cheverst et al., 2005) was that a significant number of users made positive comments about being able to send pictures from their mobile phone from a distance that would effectively make their interaction socially invisible.

One potential 'shortcut' we hoped would overcome these first two issues was that of non-users observing existing users. Unfortunately we found that this was not successful, possibly because the number of existing users did not reach a 'critical mass' or interactions were too seldom and short to be readily observed. However, an enthusiastic user 'champion' existed in the Wray Photo Display deployment who proved effective in encouraging use from others.

The next challenge concerns the motivation of users to expend effort to interact with a display. Typically, in order for a user to interact they must perceive that they will receive some form of benefit (Grudin, 1988) immediately.

The fourth challenge concerns the user's willingness and ability to engage with technology. Communicating instructions to a user with an unknown level of technical experience and unknown make and model of mobile device clearly presents a problem. This problem is compounded when the user may be unwilling or unable to follow seemingly simple instructions such as 'turn on Bluetooth'. In a field study with MobiDiC, for example, five out of twelve users needed more than 10 seconds to activate Bluetooth on their mobile phone. Additionally many passersby wouldn't take part in the study due to security and privacy reasons they were assuming.

Technical Challenges

In order to support remote interaction via mobile phones all of the systems described here utilized Bluetooth. This led to a variety of technical challenges. With multiple devices in range Bluetooth discovery is often an unreliable process and when numerous devices are found (sometimes without the textual 'friendly' name) users find it challenging to identify the desired device. We have found that multiple Bluetooth dongles can be used to increase the probability of discovering mobile phones (but discovery carried out on mobile phones remains problematic). Often multiple public displays are installed next to each other. In the MobiDiC deployment, we gave them descriptive Bluetooth names (e.g. MobiDiC-Domplatz-left), while for the Shopfinder it did not matter which display the coupon is sent to. Another key problem is that of installing applications on user's mobile phones via Bluetooth (mitigated by supplying users which pre-configured phones). Once the problematic processes of Bluetooth discovery and device pairing being completed successfully, the application is sent to the user's phone (typically a Java application packaged in a.jar file) and the user is left with the task of installing and running it (which is often very challenging unless the user is familiar with the process). Another key technical challenge is that of providing high levels of reliability. Often we found it difficult to detect whether a remote display had crashed and that failure may be localized, for example only preventing one aspect of the system (such as an interaction method) from working. For larger deployments (Hermes, iDisplays, MobiDiC) especially we addressed this problem by developing automated detection and notification of failures. One method that proved robust against failures was to take regular screenshots and compare them automatically, so e.g. Windows error messages in front of the display content can be detected.

Pragmatic Challenges

A range of additional pragmatic challenges emerged from experience of our field trials, these included:

- *Difficulty of observing users* – With many users, each interacting only for a small number of seconds, we found it difficult to explore why a user interacted with the system (e.g. for idle investigation or in order to carry out a task).
- *Difficulty to obtain users for evaluation* – Results of user studies are often skewed by certain user groups (e.g. younger people typically being far more prepared to interact and more *au fait* with technology). It is often difficult to find non-users in an open community to explore their motives.
- *Difficulties for data logging* – Collecting, storing and interpreting usage can be challenging in itself but it is also difficult to investigate the 'trace' of genuine users with the background noise of other users idly playing with the system.
- *Study setup problems* – The investigators are faced with decisions such as whether participants should be provided with phones or use their own.
- *Difficulty in providing content* – Our prototype systems require content of interest to potential users, without which adoption is only a remote possibility, and we found providing this content challenging.

COMBINING EVALUATION METHODS

The application of one single evaluation method alone often may highlight an interesting phenomenon, but usually does not provide enough information to understand different facets of the phenomenon. The application of multiple evaluation methods in multiple deployments enables us to observe phenomena from different angles, thereby providing a much richer and more validated image. In the following we discuss three exemplary observations and show how a range of deployments and methods helped uncover the different facets of these observations.

Reasons for Disuse

One finding consistent for all deployments is that mobile phone based interaction with the displays was much less than we expected. In the MobiDiC deployment for example, in the first 7 weeks of deployment the software was downloaded 130 times, and during the first four months 34 coupons were redeemed. The iDisplays interaction has been installed on the mobile phones of 10 users, but in six months was used only 20 times. The Wray Photo Display has logged between 300 and 500 image views a month, but only 4 successful Bluetooth downloads in total and no uploads. While all systems had been lab tested for usability flaws, the inherent social deployment environment and the constraints of everyday life meant that the displays were used in very different ways than in the lab. This meant that other aspects became much more important than pure usability.

- *Users simply don't see or ignore the displays* – While about half of the people passing the iDisplays looked at them, almost nobody noticed the MobiDiC displays. Even when people made a telephone call in close proximity to the displays, their views seemed to systematically avoid the display straight in front of their face. When we asked people who had walked past a display, they mostly stated that they ignored public phones because they owned a mobile. When we interviewed people after making a call, they said that they had not seen the display because they were "not interested in technology". For the Wray Photo Display, when interviewed many Wray residents claimed to have not seen the display, despite its location in the middle of the village's only shop. Especially in the public where many things fight for the users' attention, it seems to be difficult to make displays seen.
- *Users don't like to stop at the displays* – The video observation of the iDisplays allowed quantifying observations that people rarely stop: One display in the entrance was passed by 141 people, 29 looked at it, but only one stopped to look for 5 seconds. Another display in a sofa corner was passed by 114 persons, 47 looked at it, and six people stopped in front of the display. All persons who stopped did so for some other reason than to look at the displays, for instance to wait for someone (looking 45 seconds) or for making a phone call (looking 20 seconds). When asked, users said they have something important to do, and no time just to look at the display.
- *Users don't expect interaction at the displays, especially because there is often no appropriate affordance that such interaction is possible* – When we showed users the interaction, they were usually very surprised and didn't expect that. For example, a user who was shown the MobiDiC display was exited: "Oh, I thought it was just advertising, but instead it is something useful for me!"
- *Users don't prepare* – If users have to prepare interaction is often impossible when needed. The Hermes SMS feature was only useful when users were not at the display, so it was necessary to plan the interaction in advance by storing the phone number of Hermes. With the Wray display, users simply didn't carry their photos (that would be appropriate to upload) on their mobile

phone, rendering Bluetooth interaction functionality useless.

- *Interaction does not fit into everyday life, and the benefit is too small* – We found that only a very small number of users continued to use systems after the initial novelty of a new deployment waned. When users were questioned about this they often had simply forgotten that features existed or how to use them (a very common example was users forgetting the phone number required to 'text' a message to their display). Additionally, many users felt that they didn't have time to interact with systems (especially in the workplace scenarios of Hermes, Hermes II and iDisplays) and, perhaps most importantly, that they felt it was too much effort to interact with a system. In these cases, making relatively trivial changes to reduce the effort required to achieve a task, e.g. setting a message on a door display, resulted in significant increases in usage. It transpired that often users disabled Bluetooth on their mobile phones for power and security reasons. The process of taking out a phone, enabling Bluetooth and starting interaction takes at least one minute, and users commented it was too much effort for the benefit. Even for the MobiDiC coupons, in interviews many people stated that they took the photo to try it, but then did not go to the shop because the benefit was too small. We would argue that the key reasons for lack of continued use are related to the cost/effort required for interaction being too high and the perceived benefit of interaction being too low. However, through the use of iteration and user-centred design techniques (such as those applied in Hermes) we did find it possible to lower the cost of use sufficiently to encourage adoption. In the Hermes system we also found it crucial for users to build up trust in the reliability of a system in order to encourage adoption, when users experienced failure when attempting to interact this proved especially damaging.

Mobile phone based interaction may be eschewed if the same function is available via simpler means. Fore example, for the Wray display, web upload was much more popular than Bluetooth, as was the iDisplays RSS feed than the mobile application.

Additionally, enjoyment seemed to be perceived as a higher benefit than monetary incentives. The value of accessing historical photographs on the Wray Photo Display was cited as valuable numerous times in user feedback. The MobiDiC Coupons were however often not perceived as a big benefit.

The number of uses does not translate directly to usefulness: The Hermes SMS feature was used very seldom, but interviews have shown that in the cases where it has been used it was perceived as very useful and unique.

The Importance of Appropriate and Timely Feedback

Users of the Hermes SMS feature who encountered reliability problems asked for greater feedback. With the Hermes Photo Display, photos uploaded via Bluetooth were queued for display and consequently users whose photos were not shown immediately became frustrated (Cheverst, et al., 2005). Similarly, users who posted content to the iDisplays often walked directly to the displays to check, although a screenshot was presented at the web interface.

The Importance of Social Context and Representation of Self

Interviews revealed that people were only concerned about items that contained photos of people, which they did not want to appear distorted. The theory of social encounters provides a possible explanation (Goffman, 1959): When people submit information, especially photos, to a public display, they put a representation of themselves (or someone else) on the public stage. In order to see how this representation will be interpreted within a social frame, people want to see the full context how this representation appears (e.g. if it is on a public display on a toilet).

Appropriation

We have also observed a continuum of interference from users which affected the displays' primary function, ranging from adding their own features, through to sabotage and vandalism. Some users would switch off the iDisplays every evening, but not switch them on again in the morning. Interviews have shown that the users were concerned for power consumption. For a display near a table, users would switch off the display while taking lunch, because it emitted so much light and heat, but regularly switch it on again after lunch. When we installed cameras on top of the iDisplays, they would be regularly turned away to point at the ceiling or the wall by anonymous users. In the iDisplays deployment users were allowed to modify content and structure of the displays: Next to the table football, a 'football league' module was installed spontaneously where the current high score was kept. In the sofa corner, during the European football championship 2008, another user spontaneously converted the display to a TV that would show the games. In the MobiDiC deployment, some users would post their own stickers on top of the displays. In one case, the text of one coupon shown was scratched into the display glass with a key, thereby making it permanent. The Comments Book revealed that many users viewed the Wray display as a noticeboard, although it was not designed with this functionality in mind.

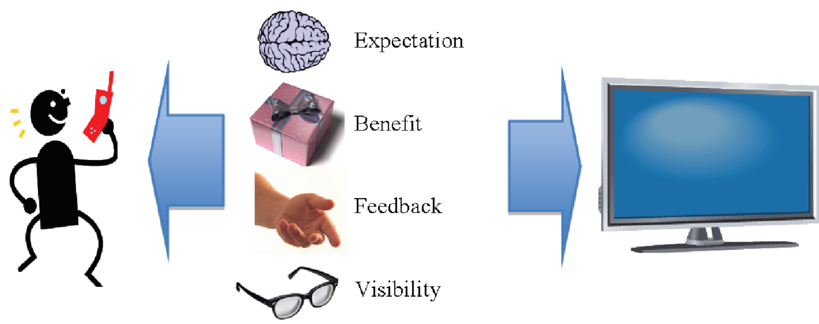
Lessons

Our experiences show that mobile phone interaction with public displays enables simultaneous and synchronous interaction for one or more users, supports interaction by users who, given the positioning of the display, are physically unable to interact directly, and can serve as a useful tool for transferring user content, e.g. pictures, to a display and to transfer display content, e.g. text items, coupons, or guide programs, to the user's mobile phone.

Our research method for deployment-based research proved useful in a number of different deployments. Some of our experiences with methods and challenges reflect experiences of researchers in other subfields of ubiquitous computing (Carter, Mankoff, Klemmer, & Matthews, 2008). For example, the problems of sparse data and reaching a critical mass have been reported for other applications, too. However, our specific experiences with public displays and mobile phones show that for this field slightly different techniques should be used (e.g. automated face detection) and different challenges become more important (e.g. the visibility of the displays or Bluetooth on/off). Some of the exemplary observations we could make combining multiple evaluation methods and multiple deployments could also be made using a single method in multiple deployments (Huang, Koster, & Borchers, 2008). Combining multiple techniques, it is possible to gather more detailed results (e.g. exact display viewing statistics by camera observation) and more depth (e.g. people stating not to look at displays because they expect only advertising). Researchers pursuing such deployments should consider a number of lessons we provide (Figure 5).

1. *Manage User Expectations.* As the interviews indicate, user expectations seem to have played a strong role in the low uptake of interaction. Many users stated that they did not expect anything useful from the

Figure 5. Key areas influencing the relation between users and public displays



displays and therefore ignored them. **Suggestion**: It seems insufficient to provide high benefit and advertise the system. In order to make people look at the displays at all, a paradigm shift for users seems to be necessary so they expect something useful. A coherent system that is installed at multiple locations could help people learn what to expect from the displays.

2. *Provide a high benefit and unique functionality.* Because of technical problems, mobile phone interaction currently requires quite some effort for the user. But even in the future, the necessity of taking the mobile phone out of one's pocket maybe sufficient to prohibit spontaneous interaction with a public display. To warrant spontaneous use, the interaction should provide a high benefit. If the same functionality is provided via an additional channel, like the web, there is a danger that the mobile phone interaction will be eschewed in favour of the channel which requires less effort. **Suggestion**: Monetary benefit may not be best, as even a 10€ coupon was redeemed only by a few users. Until the technical hurdles of interaction become lower, rare interaction with high value, like a SMS notice of being late, may be the only option.
3. *Provide feedback that shows the whole context.* Consistently we observed that users became frustrated if content they submitted to the displays did not appear immediately. If they put a representation of themselves or others on a display, they are eager how it looks in context. **Suggestion**: It may be best for remote interaction to send a photo of the display including surroundings or at least a full screenshot as feedback.
4. *Install displays visibly, so users can stand comfortably in front of them.* Displays in areas where people merely pass by seem to attract much less interaction than in places where people wait. Care should be taken so that people can stand comfortably in front of the displays without disturbing others or blocking the way. However, even in waiting areas displays often seem to be overlooked entirely. **Suggestion**: Displays should be installed at locations where many people will look even without a display, preferably at eye height.
5. *Combine Observations, Interviews and Logging. Casual*, *video* and *automated* observations proved useful to detect patterns in behaviour, and interviews to ask for the 'why'. Logging revealed long-term trends and technology uptake. To obtain a full picture of appropriation and integration into everyday life, a combination of these methods is necessary. For example, logs for the MobiDiC coupons revealed that only

very few coupons were redeemed. Further observations of users showed that people seem to actively ignore the displays, and interviews that they do so because they 'are not interested in technology' or 'expect only advertisements'. **Suggestion**: To obtain a full picture of appropriation and integration into everyday life, a combination of these methods is highly useful.

6. *If possible, use multiple deployments.* Using just a single deployment runs the risk of mistaking problems with that specific deployment for generalisable results and vice versa. **Suggestion**: Wherever possible, the combination of observations from multiple deployments can significantly strengthen observations. For example, the comparison of attention towards iDisplays and MobiDiC displays allowed us to find that in one case people know what is shown on the displays, while in the other case they ignore them because they 'expect only advertisements'.

Applying these lessons, deployment based research promises the uncovering of further insights into the appropriation of public displays and mobile devices. Interesting directions for future research are the relationship and relative importance of social embarrassment and interference with co-present people, further investigations of the specific reasons why people do and don't see and use public displays, and how appropriate feedback can be provided to reassure users of how their personal representation appears in public.

REFERENCES

Ballagas, R., Rohs, M., Sheridan, J. G., & Borchers, J. (2006). The smart phone: A ubiquitous input device. *IEEE Pervasive Computing / IEEE Computer Society [and] IEEE Communications Society*, *5*(1), 70–77. doi:10.1109/MPRV.2006.18

Bernard, H. R. (2005). *Research Methods in Anthropology: Qualitative and Quantitative Approaches*. Walnut Creek: Rowman Altamira.

Brignull, H., & Rogers, Y. (2003). Enticing people to interact with large public displays in public spaces. In [IOS Press.]. *Proceedings of INTERACT*, *2003*, 17–24.

Carter, S., Mankoff, J., Klemmer, S. R., & Matthews, T. (2008). Exiting the cleanroom: On ecological validity and ubiquitous computing. *Human-Computer Interaction*, *23*(1), 47–99. doi:10.1080/07370020701851086

Cheverst, K., & Dix, A. D. Fitton C. Graham, & M. Rouncefield (2008). Situatedness of awareness information: Impact on the design and usage of awareness systems. In P. Markopoulos & B. de Ruyter (Eds.), *Awareness Systems: Advances in theory, methodology and design*. Chapter 17, Springer.

Cheverst, K., Dix, A., Fitton, D., Friday, A., & Rouncefield, M. (2003). Exploring the utility of remote messaging and situated office door displays. In [Springer.]. *Proceedings of MobileHCI*, *2003*, 336–341.

Cheverst, K., Dix, A., Fitton, D., Kray, C., Rouncefield, M., & Sas, C. (2005). Exploring Bluetooth based mobile phone interaction with the Hermes Photo Display. In [Springer.]. *Proceedings of MobileHCI*, *2005*, 47–54. doi:10.1145/1085777.1085786

Crabtree, A., French, A., Greenhalgh, C., Benford, S., Cheverst, K., & Fitton, D. (2006). Developing Digital Records: Early Experiences of Record and Replay. *Computer Supported Cooperative Work*, *15*(4), 281–319. doi:10.1007/s10606-006-9026-z

Fitton, D. (2006). *Exploring the design, deployment and use of Hermes: A system of situated digital interactive office door displays* (Doctoral dissertation, Lancaster University, 2006).

Fitton, D., Cheverst, K., Kray, C., Dix, A., Rouncefield, M., & Saslis-Lagoudakis, G. (2005). Rapid prototyping and user-centered design of interactive display-based systems. *IEEE Pervasive Computing / IEEE Computer Society [and] IEEE Communications Society*, *4*(4), 58–66. doi:10.1109/MPRV.2005.85

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. New Brunswick: Aldine Transaction.

Goffman, E. (1959). *The presentation of self in everyday life*. New York: Anchor Books.

Graham, C. Rouncefield, M Cheverst, K., Gibbs, M. and Vetere., F. (2007) How Probes Work. In *Proceedings of OzCHI 2007* (pp. 29-37). ACM Press.

Greenberg, S., & Buxton, B. (2008). Usability evaluation considered harmful (some of the time). In *Proceedings of CHI 2008* (pp. 111-120). ACM Press.

Grudin, J. (1988). Why CSCW applications fail: problems in the design and evaluation of organization of organizational interfaces. In [Portland, Oregon, USA: ACM Press.]. *Proceedings of CSCW*, *1988*, 85–93.

Himanshu, R., Gossweiler, R., & Milojicic, D. (2004). ContentCascade incremental content exchange between public displays and personal devices. In [IEEE Computer Society.]. *Proceedings of MobiQuitous*, *2004*, 374–381.

Huang, E., Mynatt, E., & Trimble, J. (2007). When design just isn't enough: the unanticipated challenges of the real world for large collaborative displays. *Personal and Ubiquitous Computing*, *11*(7), 537–547. doi:10.1007/s00779-006-0114-3

Huang, E. M., Koster, A., & Borchers, J. (2008). Overcoming assumptions and uncovering practices: When does the public look at public displays? In [Springer.]. *Proceedings of Pervasive*, *2008*, 228–243. doi:10.1007/978-3-540-79576-6_14

Hutchinson, H., Mackay, W., Westerlund, B., Bederson, B. B., Druin, A., Plaisant, C., et al. (2003). Technology probes: Inspiring design for and with families. In *Proceedings of CHI 2003*, (pp. 17-24). ACM Press.

Kindberg, T., & Jones, T. (2007). "Merolyn the Phone": A study of Bluetooth naming practices. In [Springer.]. *Proceedings of Ubicomp*, *2007*, 318–335.

Kjeldskov, J., & Graham, C. (2003). A review of mobile HCI research methods. In [Springer.]. *Proceedings of Mobile HCI*, *2003*, 317–335.

Kjeldskov, J., Skov, M. B., Als, B. S., & Høegh, R. T. (2004). Is it worth the hassle? Exploring the added value of evaluating the usability of context-aware mobile systems in the field. [Springer.]. *Proceedings of MobileHCI*, *2004*, 61–73.

Mankoff, J., Dey, A. K., Hsieh, G., Kientz, J., Lederer, S., & Ames, M. (2003). Heuristic evaluation of ambient displays. In *Proceedings of CHI 2003*, (pp. 169-176), ACM Press.

Maunder, A., Marsden, G., & Harper, R. (2007). Creating and sharing multi-media packages using large situated public displays and mobile phones. In [ACM Press.]. *Proceedings of Mobile HCI*, *2007*, 222–225.

Müller, J., Jentsch, M., Kray, C., & Krüger, A. (2008). Exploring factors that influence the combined use of mobile devices and public displays for pedestrian navigation. In *Proceedings of NordiCHI 2008*. ACM Press. doi:10.1145/1463160.1463194

Müller, J., Paczkowski, O., & Krüger, A. (2007). Situated public news & reminder displays. In *Proceedings of AmI 2007*, (pp. 248-265), Springer.

Norman, D. (1999). Affordances, convention, and design. *Interaction*, *6*(3), 38–43.

Payne, T., David, E., Jennings, N. R., & Sharifi, M. (2006). Auction mechanisms for efficient advertisement selection on public displays. In [IOS Press.]. *Proceedings of ECAI*, *2006*, 285–298.

Rogers, Y., Connelly, K., Tedesco, L., Hazlewood, W., Kurtz, A., & Hall, R. (2007). Why it's worth the hassle: The value of in-situ studies when designing ubicomp. In [Springer.]. *Proceedings of Ubicomp*, *2007*, 336–353.

Rukzio, E., Boll, G., Leichtenstern, K., & Schmidt, A. (2007). Mobile interaction with the real world: An evaluation and comparison of physical mobile interaction techniques. In [Springer.]. *Proceedings of AmI*, *2007*, 1–18.

Skog, T. (2006) *Ambient Information Visualization* (Licenciate Thesis, IT-university of Göteborg, 2006).

Taylor, N., Cheverst, K., Fitton, D., Race, N., Rouncefield, M., & Graham, C. (2007). Probing communities: Study of a village photo display. In [ACM Press.]. *Proceedings of OzCHI*, *2007*, 17–24. doi:10.1145/1324892.1324896

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Chapter 7
Lessons out of Chaos:
Lessons Learned from the Noise of Non-Traditional Environments

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ABSTRACT

The lessons learned from nine years of the testing of a behavioral monitoring system—the Everyday Living Monitoring System (ELMS) — outside the laboratory in the real world are discussed. Initially, the real world was perceived as messy and filled with noise that just delayed and complicated the testing and development of the system. However, over time, it became clear that without embracing the chaos of the world and listening very carefully to its noise, the monitoring system could not be successfully moved from the laboratory to the real world. Specific lessons learned at each stage of development and testing are discussed, as well as the challenges that are associated with the actual commercialization of the system.

INTRODUCTION

Although it is possible to test whether a piece of equipment works in a laboratory, it's not possible to test whether a technology works within a confined laboratory environment. This is because a technology is not equipment alone, but instead a technology is the equipment plus its application: that is, what it does in the real world. However, the problem with the real world is that it is messy; it is inhabited with people who have real needs and real problems and who want a technology that meets these needs and solves their problems in a way that makes sense to them and at a cost in time and money that they can afford. Therefore, it is not surprising that developers of new technology

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are often reluctant to take the technology into this real world where they lose control and a sense of security and where the chaos of real life rears its head and confounds test protocols, schedules and projected costs. "Why can't people behave the way they are supposed to and use the technology the way it was intended", is a phrase often heard when technology is taken from the lab to the real world. Thus, developers spend inordinate amounts of time trying to eliminate the noise of real life, rather than accepting that the noise is the key to making the technology work.

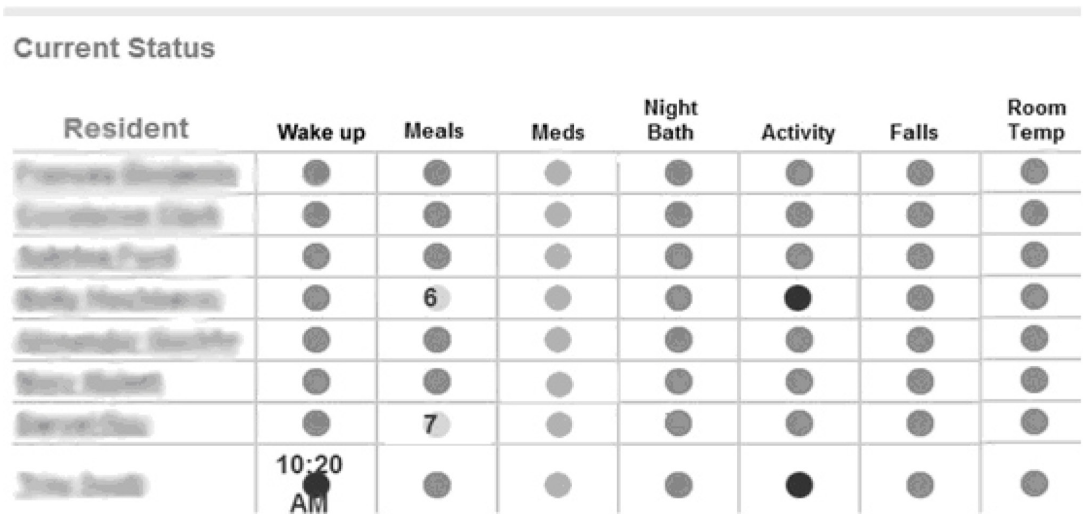
We have spent the last nine years dealing with this noise as we moved a new behavioral monitoring technology from the laboratory to the real world. Initially, we viewed this noise as a hindrance to this successful transition, but over time we became convinced that without embracing the chaos and listening very carefully to the noise, our monitoring system could not be successfully moved from the laboratory to the real world. This process has been painful at times, but we believe that the lessons we have learned can benefit other developers and perhaps, help them embrace the chaos also (see Alwan et al., 2006; Alwan et al., 2007; Biswas, Mokhtari, Dong & Yap, 2010; Blackburn, Brownsell, & Hawley, 2006; Celler, Lovell & Brasilakis, 2003; Cleland, Rigby, Janssens & Balk, 2005; Helal, Cook & Schmaltz, 2009 for other examples of behavioral monitoring approaches).

STAGES OF REAL WORLD TESTING

Over six years of laboratory research and development on behavioral monitoring technology resulted in the first real world ready iteration of the Everyday Living Monitoring System (ELMS) which became QuietCare® when the system was commercialized by Living Independently Group. (In 2009 the patents and associated intellectual property were sold to General Electric and the new product branded GEQuietCare®.) The ELMS was comprised of five motion sensors and a base station connected, via the Internet, to a website that processes the sensor data and converts them to information that is then displayed with graphics and text for caregivers. The PIN secure website provides a daily summary for each person being monitored for six activities: waking time; bathroom falls; the taking of medication; meal preparation; overall level of activity; and nighttime bathroom use, as well as ambient temperature. In addition, the ELMS provides emergency alerts for bathroom falls, non-wake-up, and high or low temperature and has the ability to produce monthly summary charts for all monitored activities. See Figure 1 for an example of a QuietCare® daily summary page.

We developed a five stage real world testing design that would allow us to install the system into increasingly more complex environments. In this way, it was hoped that we would be able, at each stage, to refine the system before moving to the next more challenging environment. We have progressed through four of these stages and our hopes and fears have been more than met as the messiness of the real world has constantly introduced noise and chaos into our well thought out testing protocols. The five environments into which we have tested the ELMS are: (1) an activity of daily living suite at a large regional hospital; (2) the homes of volunteers as part of individual sequential testing; (3) the residences of five elderly individuals in a high rise apartment building with limited care provision; (4) in the independent residences of 34 chronically ill individuals with nursing services provided by a home health care company; and (5) in four different care environments ranging from assisted living to independent households named the Caring Home Initiative (CHI). Although we have learned many things from each of the completed stages, we will limit ourselves to the discussion of the two most illustrative examples from each of the stages.

Figure 1.



Stage 1: Daily Living Suite

ELMS was installed in an activity of daily living suite comprised of a one bedroom apartment with a full kitchen, bedroom, living/dining area and bathroom at a large regional hospital. Elderly patients spent the night in the suite in order to be assessed as to their ability to function independently. ELMS, along with a video camera, was installed in the suite to record activity during the overnight stays. The two most illustrative findings were: first, do not place sensors near heating and air conditioning vents; and second, less is often more. Because it appeared to be the best location to record movement between the bedroom and bathroom, a sensor was initially placed within 12 inches of a heating and air conditioner vent. The result was real noise as approximately every 15-20 minutes there was a flurry of activity recorded which appeared to indicate that the individual being monitored entered and left the bathroom repeatedly. Review of the video tape indicated no such activity and eventually it was determined that it was the air coming from the vent that triggered the sensor.

Initially, every appliance—microwave, dishwasher, stove, television—and every cabinet and drawer in the kitchen was monitored. Also, multiple motion detectors were placed throughout the living/dining room, bedroom, bathroom and kitchen. The result of this was that much of the data proved to be redundant and that the large amount of data actually confused us and concealed important patterns. Consequently, sensors were turned off in a systematic way until we were able to accurately "observe" the task oriented behavior with the use of the smallest number of sensors (Glascock & Kutzik, 2004).

Stage 2: Sequential Installations

In this phase of testing ELMS was installed sequentially into the homes of volunteers. The installations ranged from one to three months and during this period, volunteers were interviewed on a regular basis to determine the validity of the recorded activities and the acceptability of the system. Perhaps the most important finding was that holidays and weekends changed people's activity pattern. In our first installation, we observed what appeared to be aberrant behavior for a single Thursday after three weeks of consistent activity. After pondering whether this was a problem with the hardware or software, or whether ELMS had pinpointed a previously unrecognized health problem, we interviewed the volunteer about his activity on this day. He replied, somewhat dumbfounded, "it was Halloween". Duh, people behave differently during holidays; a finding that has been confirmed over and over again since this revelation, but a finding that has required adjustments in algorithms to avoid false positives resulting in emergency alerts.

A second finding was that the volunteers "played" with the system for the first few days—they opened drawers and the refrigerator, removed medications frequently and waved hands in front of the sensors. When asked why, most volunteers replied that they were just "curious" and wanted to make sure the system was working by seeing the sensors flash. This "play" period lasted no more than two to three days after which the volunteers accepted the system and "forgot" that it was present. However, the increased "activity" affected the running average and we realized that it was not until at least the second or third week that "normal" activity would actually be determined (Glascock & Kutzik, 2006).

Stage 3: Congregate Housing

ELMS was next installed in the residences of five elderly individuals in a high-rise, independent living senior building of one and two bedroom apartments in New York City. Although a social worker had access to a website on which information was displayed, there was limited expectation that ELMS would be an integral part of caregiving. Once again, much noise emerged and much was learned. The first thing learned was that the thresholds for overnight bathroom use and meal activity were too sensitive, thus, generating false positive alerts. In the laboratory and even in the individual sequential testing phase, the thresholds worked well, but with very active people living in the real world of New York City, they were just too sensitive. This problem was easily corrected by adjusting the sigma values used for overnight bathroom use and meal activity.

The second lesson learned was more subtle, in some ways even more important and much more of a challenge to correct than the adjustment of sigma values. Since alert thresholds are based on deviation from an expected value equal to the running average of the number of events for the last 30 days, the thresholds are being continuously adjusted over time. Thus, changes in the number of events for a specific behavior can be of long-term significance, but because the changes are so gradual no alerts may be generated. Using overnight bathroom activity once again, there can be a steady increase in the number of events over a given 30 day period without producing either a single alert as the following series of real data points for a monitored individual shows--2, 2, 3, 2, 3, 3, 3, 2, 4, 3, 3, 4, 4, 3, 5, 4, 4, 5, 4, 5, 5, 4, 5, 6, 6, 5, 6, 6, 5, 6. The system is obeying its own rules for alert generation; however the change in the number of events, even though too gradual to generate daily alerts, may be very significant for the well-being of the monitored individual. Hence the conundrum: if the thresholds are set to be sensitive to these gradual changes, too many false positives are generated; if they are not adjusted, no alerts are generated and potentially serious health problems could be missed.

The solution was to develop a sub-routine that charted the average number of actual events per day for each of the behaviors for a designated time period--one week, two weeks, monthly. The sub-routine automatically counts the number of events for each behavior, produces a daily average and creates a multiple time period graph for each behavior. Therefore, for the example above, the average for the previous thirty days could be 2.2 while the average for the illustrated 30 days is 4.1. The resulting graph would clearly illustrate the magnitude of the change in the number of bathroom events between the two time periods and as a result, allows for gradual and steady changes in behavior to be observed even when no daily alerts were generated (see Glascock and Kutzik, 2006).

Stage 4: Visiting Nurse Care Model

After the field test, we were ready to test ELMS in an environment in which care would be impacted by the information that the system generated. Thus, over an 18 month period, we installed ELMS in the homes of 34 chronically ill individuals living in their own residences in and around Philadelphia, PA. Given the complexity of this environment, both geographically—people lived miles apart, and structurally—visiting nurses had to access and respond to the information as part of their normal work day, the noise and the resulting challenges appeared, at times, insurmountable. However, we persevered and learned many lessons, the two most illustrative of which were: the need to develop a procedure for regular maintenance of the hardware; and that the information had to be customized for each individual care provider.

The maintenance issue, in hindsight, appears obvious, but except for replacing batteries in the sensors every 12-18 months—the sensors would even tell us when the batteries were low—we did not anticipate the need for a procedure for maintaining the hardware. We had not had problems with the hardware in either the laboratory or the more limited real world environments. We were wrong as a combination of poverty, serious health problems and unexpected living conditions conspired to drive home the point that if something can go wrong, it will and therefore, a plan must be in place to correct it. A trained individual must be ready to respond when sensors or base stations stop working; if not, the information generated by ELMS will degrade to the point of uselessness. Two brief examples illustrate the unexpected type of problems/noise we encountered. In the residence of one client, the sensors failed one by one over a two week period, eventually generating invalid information on all activities monitored. Since there was no one “charged” with the responsibility to go to the individual’s residence to determine the problem and fix ELMS, the system was essentially out of action for close to a month. When someone finally went to the residence he found that all sensors and even the base station were infested with cockroach feces. Likewise, after ELMS abruptly stopped working in a second residence, over three weeks elapsed before someone made a special trip to the residence to determine the reason—a cat had chewed through the base station’s power cord—and repair the problem. After these and several other examples, a maintenance protocol was developed that was included in all future installations.

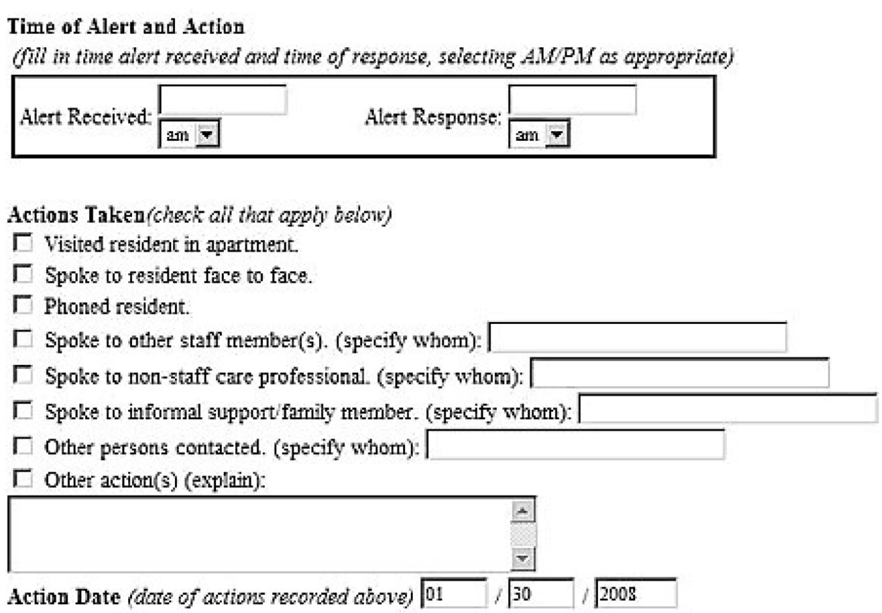
Lastly, we discovered that caregivers have their own preferences as to how they want to receive the information generated. We assumed that the methods that we developed in the laboratory and were vetted by our focus groups, would be appropriate for overworked visiting nurses who would visit eight to ten clients a day. Once again, we were wrong. Our protocol called for email alerts to be sent to the nurses and that after receiving the alerts the nurses would check the client’s web page for more detailed information. Our assumption was that after reviewing all the information, the nurse would then determine what action was necessary. This assumption proved naïve. Each nurse developed his/her own emic protocol and wanted the information presented in a way that conformed to this construct. One nurse did not want alerts sent for a decline in meal activity for a single day. In his opinion, this told him nothing and just wasted his time. He only wanted an alert for meals if there were three consecutive days of abnormally low meal activity. One nurse never checked the client’s web page and instead developed a protocol that required him to make a phone call to each of his clients who had any red alerts while a different care provider found the web pages to be of great use and requested even more detailed information on certain activities, e.g., sleep patterns. This has led us to build an ability to customize the way that information is provided to care givers into the implementation process of all future installations. As one care provider told us, "if it isn't given to me in a way I can use it, I won't even look at it" (Glascock & Kutzik 2007a; Glascock & Kutzik 2007b).

Stage 5: The Caring Home Initiative

After spending so many years designing, developing and testing the ELMS, this quote was very disturbing; what does she mean by "in a way I can use it"? Information is information, isn't it? The ELMS provides it and caregivers use it, our job is done, isn't it? Unfortunately, the real world answer to this is, no. Our assumption and the assumptions of everyone else working to develop remote monitoring systems, was that caregivers would just figure out how to use the information to provide better and more cost-effective care. This turned out not to be the case and over the last two years we have moved from working on the sensor array that is the technological heart of behavioral monitoring, to how the information is displayed, manipulated, stored and retrieved; in other words, we have moved our work from monitoring to informatics (Glascock & Kutzik 2008).

This move was accomplished through the development of a multi-site study (CHI) that employed a methodology that utilized a systematic and comparative data collection at multiple sites for test periods of six months. Over time, this methodology evolved into the Evidence Based Evaluation of Telehomecare Applications or "EBETA" (Glascock & Kutzik, 2009). The EBETA is comprised of three basic components. The first is the TAO, which stands for "trigger-action-outcome". This is a web-based data entry instrument into which the caregiver enters the actions taken and the health outcomes brought about by the actions. In each of the research locations in which the EBETA was employed, the red and yellow alerts are sent to the designated caregiver who initiated the TAO by clicking on the specified server and opening a "form" which is auto-populated with information about the client, the alert(s) in question and which asks the caregiver to check boxes and fill in text fields relating to their actions in response to the alerts (see Figure 2). Each client

Figure 2.



Time of Alert and Action
(fill in time alert received and time of response, selecting AM/PM as appropriate)

Alert Received: am | Alert Response: am

Actions Taken *(check all that apply below)*

- Visited resident in apartment.
- Spoke to resident face to face.
- Phoned resident.
- Spoke to other staff member(s). (specify whom):
- Spoke to non-staff care professional. (specify whom):
- Spoke to informal support/family member. (specify whom):
- Other persons contacted. (specify whom):
- Other action(s) (explain):

Action Date *(date of actions recorded above)* 01 / 30 / 2008 and each caregiver in the TAO system becomes the subject of an electronic record which provides quantitative and qualitative information on care delivered and received, as well as the impact of these interventions on the care recipient.

The data entered into the TAO, along with the specific alerts that triggered the caregiver's actions, are analyzed by the second component of the EBETA, a specialized software package. This software automatically maintains, indexes, links, updates and displays the information and prepares the third component, the Interactive Care Evaluation Tool (ICET), that automatically produces a series of web pages. These pages summarize the condition of each of the individuals being monitored and includes: 1) a daily synopsis of all problems, care delivered and health outcomes; 2) trend charts on any alert, care action and/or health outcome for any designated time period; 3) a narrative of the total care delivered by all caregivers; and 4) a list of all issues to which caregivers need to pay special attention. The pages of the ICET provide comparable information on each monitored individual, both within a single care provision location and across locations. As a consequence, this information can be used to evaluate the effectiveness of the caregiving in order to achieve better practice, as well as by researchers to undertake comparative assessments of different Telehomecare applications in two stages: the first in the United States; and the second in Europe.

APPLICATION OF EBETA

The first study to employ the EBETA methodology described above was conducted in New York City during 2006. Our research partner was a not-for-profit care organization that provides a comprehensive network of social service, senior housing and home care services to over 20,000 aging, frail and "at-risk" clients in the five Boroughs of New York. For the six month evaluation, twenty-nine frail older adult clients from the Queens Borough had QuietCare® installed in their residences. Fifteen of the clients resided in low-income housing and fourteen resided in high-rise apartments.

The care protocol developed specifically for the study provided a set of systematic rules for responding to both urgent (red) and non-urgent (yellow) alerts. Urgent alerts included, late wake-up—the individual being monitored not getting out of bed by one hour later than normal—and falls. Non-urgent alerts included changes in overnight toileting, changes in meal preparation and decline in overall activity. Urgent alerts were simultaneously sent to an ADT call center and to designated staff and family. The study protocol required that the ADT dispatcher contact the client and/or the appropriate responder to take immediate action. Designated responders were staff, family members of the clients and in cases when neither staff nor family members could be reached, e.g., on weekends, emergency response services. Non-urgent alerts were sent via email to the staff, as well as designated family members. The study protocol required that each staff member check her email each work day by 10:00 am and when alert notices were received, navigate to the QuietCare® website to access detailed information on the alert(s). After taking the appropriate care action in response to the alert, e.g., phoning the client in cases of an alert indicating that the client had not gotten out of bed, the staff member accessed the TAO website, entered the care actions taken and any outcomes that were the result of these actions. The EBETA software automatically indexed and linked the entered data and prepared an electronic record. The participating social workers reviewed these care records at periodic staff meetings and discussed how they were using them to better understand relatively subtle changes in behavior or health conditions of the client and deliver more appropriate and timely care.

The second study was undertaken in London during late 2006 and the first half of 2007. The study encompassed two separate care models: sheltered housing; and centralized care management for community dwelling elderly. A total of 56 individuals were included in the study: 21 living in sheltered housing and 35 living within the community. Once again, a specialized care protocol was developed that provided rules for responding to urgent and non-urgent alerts. In the sheltered housing location, all alerts, regardless of time of day or day of week, were sent to a centralized nursing station that dispatched appropriate care to the client. For the community dwelling clients, urgent alerts were sent to staff at a dispatch center who notified emergency services. Non-urgent alerts were sent via email to care managers and to family members. The care managers either took actions themselves or, when needed, contacted a specialist to take the most appropriate actions, e.g., nutritionist if the alert concerned meal preparation. The protocol also required that the care manager review all actions provided by other carers, discuss the actions taken and health outcomes with all carers and family members and modify the client's overall care plan when required. After the care action was taken, the care manager accessed the TAO website and entered the care actions taken and any outcomes that were the result of these actions. It was also the care managers' responsibility to enter TAOs for all urgent alerts that were sent to the dispatch center. In the sheltered housing setting, designated individuals were responsible for accessing the TAO website and entering all of the relevant information. As in the United States, the EBETA software automatically indexed and linked the entered data and prepared an electronic record that was made available to selected carers at both locations.

The third study that employed the EBETA methodology was undertaken in Limburg Province beginning in late 2007. The first stage of this study was a small pilot that ran fOR six months during 2007-2008 and brought together a research institute, an emergency call center, and two care providers—a comprehensive home care organization and a residential care facility. A total of 25 frail and cognitively impaired older adults were selected by the staffs of the two care organizations: twelve of whom lived in the community and thirteen resided in the residential care facility. The second and much larger component began in the fall of 2008 and included, in addition to the organizations participating in the pilot, two care organizations that provided services to people throughout the northern region of Limburg Province. There are presently over 100 frail elderly individuals, all of whom live within the community and receive a wide range of care and services in their own residences, participating in the study.

For both the pilot and the larger study, the care/research protocol developed provided a set of systematic responses to urgent (red) and non-urgent (yellow) alerts. When the QuietCare® system generated an urgent alert, a telephone call was placed to the around-the-clock emergency call center. The dispatcher, who received the phone call, would proceed by checking the QuietCare® website in order to obtain details about the alert, and then, following the protocol, contact the designated responder so that the appropriate action could be taken. Designated responders could be staff, family members or neighbors, or depending on the seriousness of the alert, the ambulance service. Non-urgent alerts were sent via email to the designated staff person who then used this information to take appropriate care actions. In the pilot study, once the appropriate action was completed, by either the dispatcher at the emergency call center or a staff member at the care organizations, that individual accessed the Dutch language website in order to enter the care action(s) and health outcomes. Similarly to the other locations, the EBETA software automatically indexed and linked the entered data and prepared an electronic record, only in this instance the ICET was in Dutch.

Both before and during the early part of the pilot study significant improvements, in addition to changing from English to Dutch, were made in the TAO, which resulted in a largely new informatics system which was renamed the Home Care Informatics System (HCIS). These improvements were made in order to respond to requests made by the Dutch caregivers who had been involved in the pilot study. The first change that was made was to allow data input on a specific mobile device. Secondly, the data input feature was simplified and streamlined (See Figure 3). The individual caregiver accessed her Home-Page by entering her name and password and once accessed, she then clicked the *Data Entry* button at the bottom of the page, navigating to the actual Data Entry Page which prompted data entry through both auto-populated and check-box cues. For example, Figure 3 shows the auto-populated fields as they appear in the Dutch language version of the HCIS for: date of the alert; whether the alert is urgent or non urgent (i.e., "red" or "yellow"), as well as indicating specific type of alert (in this case an excess of over night bathroom visits).

The caregivers also wanted more automated features that would save time in entering data. As a result, the HCIS entered selected fields automatically each time an alert was generated and the caregiver had only to confirm their accuracy through clicking the *Confirm* button. Additional check-box prompts were incorporated in the HCIS to allow the caregivers to quickly check boxes rather than typing words. Finally, the HCIS allowed the caregiver to enter a short narrative summarizing the outcome brought about by the care action, e.g., I checked her blood pressure and made an appointment for her to see her physician. By clicking the *Send Data* button, the data recorded were sent to the server where they were automatically analyzed and updated to the particular client's home care record.

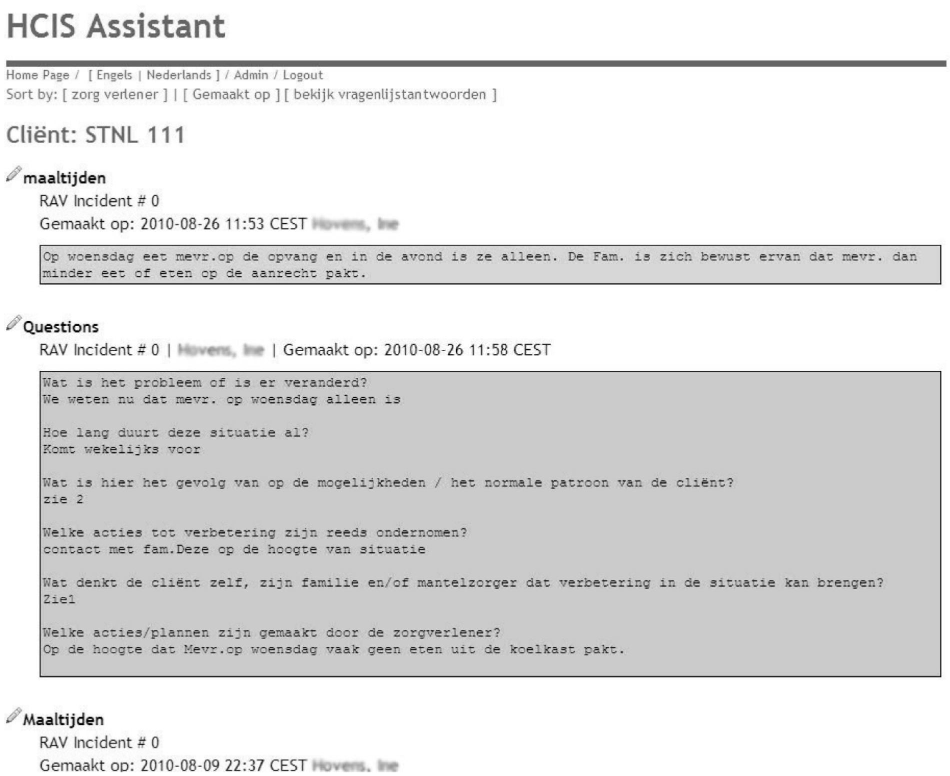
Improvements were also made to the information display feature of the HCIS. The Dutch caregivers who participated in the pilot study requested that a single Care Report Page be created for each client. As a result, a feature was added that allowed each Care Report Page to be customized

Figure 3.

based upon the particular desires of the individual caregiver; not only the look of the page, but also which of the various pages comprising the HCIS is designated as the home-page and how the information is displayed, e.g., charts, tables or only narratives. Figure 4 displays the most common Care Report Page which is actually a narrative, in blog form, of all the care/services that have been delivered to a particular client.

Figure 4 shows only a single page of the total narrative for a given client. In this case it summarizes the caregiver's analysis of the current state of an ongoing nutrition problem with a client. Of course, depending on the length of time and the nature of the services there will be many pages of narrative for any given client. It is possible to scroll through these pages, but there are also three navigation buttons at the bottom of the page that allow the narrative to be manipulated more efficiently. The *Sort* button is a pull-down

Figure 4.



menu that allows the narrative to be sorted by: (1) caregiver, e.g., visiting nurse; (2) date care was provided; (3) type of care action taken, e.g., visited client at residence; (4) nature of outcome, e.g., change in medication; and (5) type of alert. This allows the caregiver to very quickly see patterns and trends in, for example, the type of care actions she or any other caregiver has taken over a given period of time.

DISCUSSION

As the above description of our work with actual caregivers over the last nine years indicates, we have encountered much noise. Much of this noise was in the form of "suggestions" as to how the ELMS or the TAO or the HCA or the HCIS could be modified in order to meet the caregivers' needs, desires and wishes. "Could the ELMS be made to show how long a housekeeper is in the bedroom, can the information from the TAO be shared with supervisors, can you make the HCIS usable on a mobile device?" Each time a suggestion was made we had to rethink the "product" then reconfigure something or reprogram something or build something new. In many ways this led us on an unexpected journey, the path of which was not under our control, but instead, in the hands of the caregivers who were attempting to incorporate the ELMS or the TAO, etcetera into their care delivery models. We continuously responded to their requests by "building" the next thing; whether the next thing was hardware or software our goal was to meet the needs of caregivers in the real world and not to meet some self-generated laboratory objective. This was, from our perspective, the natural thing to do, even if it meant the loss of control over where the journey led.

Perhaps because of a lack of reflection, or perhaps more likely because we were so immersed in the various projects that followed one another without pause or separation, we had no real understanding of where the journey was taking us until we neared its end. Now as we approach what appears to be the end—the patents have been sold, the last project winds down at the end of 2010—we have a better idea of the journey and what happens when control is given to others and the demands of caregiving and the market determine the path rather than the goals determined by some hermetically sealed laboratory protocol. You end up someplace you never imagined.

We began with an apparently simple goal of developing a behavioral monitoring system that could be used to allow at-risk individuals to remain in their own homes longer and more securely and we ended by developing an interactive home care electronic records system that could be used on any commercially available smart phone/mobile device. The development of such an electronic records system was certainly not our goal at the beginning of our testing in the real world of caregiving. In fact, it was never really our goal at any stage of our journey. It just happened as we responded to the "noise" from the people with whom we worked. Apparently, this is what happens when you cede control to others; it leads you to unexpected, at times frustrating, but always interesting, and often rewarding places.

There is, however, a final irony to this ceding of control to others: it turns out that frequently the individuals who request the new sensor array, the new feature, the expanded recording and sorting capability, do not want it after it has been developed. This appears to be the result of the convergence of two laws: the law of unexpected consequences and the law of "be careful what you wish for". Two brief examples illustrate what happened time after time when we responded to the requests of caregivers.

Wish Number 1: Could you develop a way for us to easily see how our caregivers respond to alerts? Since our caregiving culture is that we always respond to the needs of our clients, such a capability will document the high quality of our care.

Result Number 1: The new capability shows that the night staff is not responding to alerts and not providing the care for which family members are being charged.

Consequence Number 1: Staff members are fired; we are asked why don't we just arrange for the data to be sent directly to the lawyers for the family members so that it would make it easier to sue the care organization and the capability is turned off.

Wish Number 2: Could you develop an informatics system that can be used on mobile devices in which caregivers could enter data on the road and which could then be consolidated and used at care review meetings?

Result Number 2: Care organization has to purchase mobile devices for caregivers, an unexpected expense going forward, entering the data on the road is not what the caregivers want to do resulting in incomplete records, the consolidation allows for supervisors to "see" the caregivers work more than anyone anticipated and the scheduling of care review meetings takes caregivers away from providing care.

Consequence Number 2: The anticipated planned roll out of the Telehomecare system that includes the requested informatics component is put on hold while administrators at the care organization wrestle with added cost, changes in work rules and issues surrounding the use of new data in the evaluation of caregivers.

Although initially surprised by these and other similar responses to our attempts to give people what they asked for, we came to the conclusion that this reaction is nothing more than another form of noise. As such, there are lessons that can be learned from taking what caregivers both say and do seriously and not just viewing them as noise that can get in the way of development; and anyway after all these years it's way too late for us to try to reassert control over the journey.

CONCLUSION

We have learned many lessons from our journey; about business, about the control of intellectual property, about working with physicians, nurses and informal caregivers. However, in the context of conducting research in non-traditional environments we have learned at least five valuable lessons.

- *Lesson (1) Get out of the lab.* We learned that testing a care provision technology in a lab makes as little sense as testing an airplane wing in a vacuum chamber. In order to assess technologies developed as tools for care provision it is necessary to assess them in the context of real world care provision, where real caregivers provide real care to real people;
- *Lesson (2) Place emphasis on people and care, not gadgets.* When developing and testing the ELMS and the HCIS we learned that there was no way for us to accurately measure and track those variables relating to the human *process* of care provision—how caregivers think and act in relation to information provided to them by the gadgets—without dealing with people. And, the more we dealt with people, and the more varied their roles, e.g., caregiver, supervisor, care recipient, the more we learned.
- *Lesson (3) Listen to what people say they want*. We learned over the last nine years that people say they want many things and once they have something they want it improved. In many ways, the easiest road to take is to regard these requests as noise and ignore them. However, this is a crucial mistake. The vital information gained from these questions, complaints and design suggestions is what moves the development process in the direction that actually results in something that can be used.
- *Lesson (4) Be prepared to give up control.* The real world is not a lab and the researcher is never in control. This was a painful but necessary lesson, the acceptance of which leads to an understanding that the people providing and receiving care are the ones who "own" the process of care provision, never the developer nor the researcher. Nothing a researcher can do will have significant impact on the culture of a care provision workplace—don't even try.
- *Lesson (5) Don't be surprised if you end up someplace unexpected.* Research in the real world is like the great American road trip: you know where you set out but cannot predict where you end up. This is because the interesting things and places you find along the highways and byways will ultimately influence where you wind up, which is guaranteed to be a different place than you thought you were going.

Taken together these five lessons reflect the fact that compared to the lab the real world is a noisy, messy, chaotic place. It is a place where the researcher encounters people who are not passive research subjects in a controlled setting, but real people going about their daily business of providing and receiving care. Indeed, the thoughts and actions of caregivers, as well as the behavior and attitudes of the people for whom they are caring, are indeed always "noisy" precisely because they are in real, as opposed to artificial, settings. While this makes life more complicated for the developer and the researcher, it opens the door to structured observation of the technology as it is actually used as a care provision application, something which is not possible in a laboratory.

In applying the spirit of these lessons, we advocate a shift in roles for the developer/researcher of care provision technologies. Rather than ignoring or filtering out the noise in hopes of approximating a controlled environment, we believe researchers should embrace the chaos of the real world and methodically record and analyze the care provision process in order to extract relevant information about the actual use of the technology as part of the care provision process. Instead of writing questionnaires and using well-worn replicable scales for things like caregiver burden, researchers should listen very carefully to the caregivers and care recipients and use them as key informants. In fact, researchers should go a step further and actively involve the caregivers and care recipients in the research and development process as *colleagues.* The caregivers, and when possible, the care recipients should participate in shaping research questions, tweaking technological tools, developing data collection instruments and helping in the interpretation of the results. There is a name for such an approach when applied in our disciplines of Anthropology and Sociology. It is called “participatory research”.

In conclusion, we encourage developers/researchers to leave the sanctity of the laboratory and step into the noise and sunlight of the real world and utilize non-traditional approaches such as participatory research. Certainly our long journey of taking the Everyday Living Monitoring System from mere idea to GEQuietCare®, developing the Trigger-Action-Outcome methodology, producing the HCIS informatics tool and implementing the EBETA evaluative framework would not have happened had we not first stepped out of the laboratory and embraced the noise.

REFERENCES

Alwan, M., Dalal, S., Mack, D., Kell, S., Turner, B., Leachtenauer, J., & Felder, R. (2006). Impact of monitoring technology in assisted living: outcome pilot. *IEEE Transactions on Information Technology in Biomedicine*, *10*(1), 192–198. doi:10.1109/TITB.2005.855552

Alwan, M., Sifferlin, E., Turner, B., Kell, S., Brower, P., Mack, D., Dalal, S. & Felder, R. (2007). Impact of passive health status monitoring to care providers and payers in assisted living. *Telemedicine and eHealth 13*(3), 279-285.

Biswas, J., Mokhtari, M., Dona, J. & Yap, P. (2010). Mild Dementia Care at Home – Integrating Activity Monitoring, User Interface Plasticity and Scenario Verification. *Lecture Notes in Computer Science, 6159/2010,* 160-170.

Blackburn, S., Brownsell, S. & Hawley, M. (2006). *Assistive technology for independence (AT4I).* Final Report of the Assistive Technology for Independence Study, Barnsley Hospital NHS Foundation Trust (BH). Obtained by email from Simon Brownsell simon.brownsell@nhs.net.

Celler, B., Lovell, N., & Brasilakis, J. (2003). Using information technology to improve the management of chronic diseases. *The Medical Journal of Australia*, *179*, 242–246.

Cleland, J., Louis, A., Rigby, A., Janssens, U., & Balk, A. (2005). Noninvasive home telemonitoring for patients with heart failure at high risk of recurrent admission and death. *Journal of the American College of Cardiology*, *45*(10), 1654–1664. doi:10.1016/j.jacc.2005.01.050

Glascock, A., & Kutzik, D. (2004). Moving telematics from the laboratory to a truly enabling technology within the community. In Zhang, D., & Mokhtari, M. (Eds.), *Toward a Human-Friendly Assistive ` Environment,Assistive Technology Research Series, 14* (pp. 145–154). Amsterdam: IOS Press.

Glascock, A., & Kutzik, D. (2006). The impact of behavioral monitoring technology on the provision of health care in the home. *The Journal of Universal Computer Sciences*, *12*(1), 59–80.

Glascock, A., & Kutzik, D. (2007a). An evidentiary study of the uses of automated behavioral monitoring. *Conference Proceedings of the 21st International Conference on Advanced Information Networking and Applications, Niagara Falls, Ontario, Canada, 2*(1), 858–862.

Glascock, A., & Kutzik, D. (2007b). From sensors to informatics: Creating communication protocols for caregiving. *Proceedings of the 3rd IET Conference on Intelligent Environments*, 325-332.

Glascock, A., & Kutzik, D. (2008). It's all about the information: The role of informatics in telecare. In William C. Mann (ed) *Aging Disability and Independence: Selected Papers from the 4th International Conference on Aging, Disability and Independence*, pp. 71-85.University of Florida.

Glascock, A. P., & Kutzik, D. (2009). A care informatics approach to telehomecare applications. In Dwivedi, A. (Ed.), *The Handbook of Research on IT Management and Clinical Data Administration in Healthcare* (pp. 368–382). Hershey, PA: IGI Publishing.

Helal, A., Cook, D., & Schmalz, M. (2009). Smart Home-Based Health Platform for Behavioral Monitoring and Alteration of Diabetes Patients. *Journal of Diabetes Science and Technology*, *3*(1), 141–148.

Chapter 8
Large Scale User Trials:
Research Challenges and Adaptive Evaluation

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ABSTRACT

The authors present a reflection on a series of studies of ubiquitous computing systems in which the process of evaluation evolved over time to account for the increasing difficulties inherent in assessing systems 'in the wild'. Ubiquitous systems are typically designed to be embedded in users' everyday lives; however, without knowing the ways in which people will appropriate the systems for use, it is often infeasible to identify a predetermined set of evaluation criteria that will capture the process of integration and appropriation. Based on the authors' experiences, which became successively more distributed in time and space, they suggest that evaluation should become adaptive in order to more effectively study the emergent uses of ubiquitous computing systems over time.

INTRODUCTION

When working with ubiquitous computing (Ubicomp) systems, challenges and rewards arise from moving from the relative safety of the usability lab into the uncontrolled environment of everyday life. For example, unpredicted contexts of use and environmental features such as intermittent network connectivity may challenge traditional evaluation methods, and yet we gain the mobility,

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contextuality and appropriation that let users take full advantage of new mobile devices. As Carter and Mankoff (2007) put it, "Ubicomp systems [are] more difficult to evaluate than desktop applications. This difficulty is due to issues like scale and a tendency to apply Ubicomp in ongoing, daily life settings unlike task and work oriented desktop systems." Many of these challenges have already been faced by researchers studying the *use* (rather than *usability*) of Ubicomp technologies in the wild. Observational techniques founded in ethnography may be well suited in principle but in practice are often hampered because of the difficulty of actually observing users' activities. Small devices such as mobile phones and PDAs can easily be occluded from view, and people's use may be intimately related to and influenced by the activity of others far away (Crabtree et al., 2006).

In this chapter, we reflect on our studies of four mobile multiplayer games: Treasure (Barkhuus et al., 2005), Feeding Yoshi (Bell et al., 2006), Ego and Hungry Yoshi (McMillan et al, 2010) and of two everyday awareness applications: Shakra (Maitland et al., 2006) and Connecto (Barkhuus et al., 2008). The development of these systems has spanned the last seven years, with user experience design and evaluation techniques evolving over this time. We show a progression from early trials lasting around a quarter of an hour and taking place within a specific confined area, to trials months or years in length (indeed, often without a specified end date) that explore users' integration of technology into their everyday lives. Studying system use over longer periods of time and in less constrained settings provides greater opportunity for witnessing unanticipated behaviour as users take ownership of the system, but can leave the evaluator more detached from the trial. Additionally, while many have studied the effects of uncertainty with regard to positioning accuracy and network connectivity on the user experience e.g.,(Crabtree et al. (2004)), the impact these factors have on evaluators is not usually explicitly acknowledged.

Here we discuss the strategies that we, as evaluators, employed to discover participants' reactions and experiences with regard to our five systems. The studies are presented chronologically, as the challenges faced in one study often influenced design and evaluation of subsequent systems. We suggest methods for keeping evaluators informed of activity during a trial that might take place over an extended period of time and over a wide geographical area, and suggest that such information is of crucial importance to adaptation of an ongoing evaluation based on evaluators' continual involvement with it or, in more extreme cases, immersion in it. Such adaptation may be done in order to inform and improve ongoing and post-hoc analysis. To conclude the paper we discuss the temporal and geographic scale of each study as contributing factors to the complexity of running such studies, and of gathering and interpreting evaluation data.

RELATED WORK

Researchers have examined how a particular design (along with external factors) can encourage adaptive behaviour, and how that behaviour can in turn inform the design process. Vougiazou et al. (2006) discuss a number of systems that feature evolving cooperation or the dynamic and ongoing creation of authored game rules. It is notable that the evaluation of each system, for the most part, was based on direct observation and was short-term in duration. While the authors identify the challenges of long-term studies, no strategies are offered to overcome them. Iterative participatory design practices for developing the usability of mobile devices offer to some extent more 'agile' evaluation techniques (de Sá et al., 2008), and there are some existing demonstrations of remote, in situ data collection systems (Carter et al., 2007; Consolvo & Walker, 2003; Froehlich et al., 2007). Froehlich et al. (2007) have explored context–dependent 'experience sampling' systems that prompt the user for explanatory input when a mobile device detects that it is in a context of interest. Carter et al. (2007) recently developed Momento, which supports experience sampling, diary studies, capture of photos and sounds, and messaging from evaluators to participants. It uses SMS and MMS to send data between a participant's mobile device and an evaluator's desktop client.

There is also a growing body of work examining performance and game-based systems that examines the often rapidly adapting practices of both participants in and authors of an experience. Researchers have noted, for example, how players may develop an "emerging etiquette" in mobile games that take place over relatively long periods of time (Grant et al., 2007). This appropriation and adaptation by participants may also be mirrored by those running a given game or performance. Systems involving more performative settings for player experiences have shown how those running—or 'orchestrating'—an experience, may sit in an evolving relationship with participants, such as in the SMS-based game Day of the Figurines (Crabtree et al., 2007) in which the game narrative came to be an ongoing negotiated production by orchestrators interacting with players. Other mobile city-scale experiences have focussed on the uncertainty inherent in using GPS and wifi systems, and how orchestrators' approaches to running the performance (i.e., their tactics and strategies) adapted over time, building up a working knowledge of how to manage that uncertainty (Crabtree et al., 2004). Such practices of orchestration also frequently involve distributed teams, and, of particular interest to this chapter, extensive monitoring of participants, leading to intervention when necessary.

By and large, however, this literature generally identifies and examines adaptation only within the bounds of users' practices and experiences, thus lacking any explicit consideration of adaptation of the practices of evaluators. For instance, existing frameworks for evaluation of Ubicomp, such as that proposed by Scholtz & Consolvo (2004), might provide a toolbox of techniques, metrics and guidelines for evaluators, making existing practices easier, but little is mentioned regarding new adaptive or emergent approaches to an evaluation.

Thus, our concern in this chapter is to address how adaptation within the experience may be complemented by evaluation techniques that are adapted and changed in response to user experience. It is not necessarily the case that adaptive evaluation is new in itself, but in this chapter we offer some examples of techniques we used and tools we developed to help take this relatively unacknowledged approach.

UBICOMP TRIAL WITHIN SEMI-CONTROLLED ENVIRONEMNTS

In this section we discuss the evaluation of Treasure, a mobile multi-player game (Barkhuus et al., 2005). Each game comprised two teams, each with two players, who competed in games lasting around a quarter of an hour within a fixed game 'arena' of ~7000m^2 on the edge of the University of Glasgow's grounds. Each player used a GPS and 802.11-enabled handheld PDA that showed a map of the game arena. The object of the game was to walk to the locations of 'coins' that players saw scattered around their maps, and to move in and out of areas of network coverage to upload their collected coins to a server in exchange for points.

Teams were asked to come back on several different days in order to play against different opponents. This enabled the players to discuss the game, and develop and refine tactics both in and between game sessions. In initial pilot studies, this was found to be very important; players would often spend their first game learning how to use the technology and hence how to play the game at a basic level, whereas in subsequent games they often developed more complex strategies that suited their style of play as well as the setting. Without these multiple plays, we suggest that much of the developing competence with and appropriation of the system we observed would not have come to the fore. Multiple plays or long-term use became imperative to a deeper understanding of system use, and we have tried to maintain this evaluation principle in all of the subsequent studies discussed in this chapter.

Errors in positioning technology and patchy network coverage are usually considered to detract from a user experience. Treasure was designed to exploit these factors, changing them from problems into resources for the game. However, these factors did still prove to be problematic when it came to collecting data for evaluation. Unlike lab-based experimentation, the log data gathered was often unreliable in the sense that the recorded position did not necessarily represent the actual location of the player when an entry in the log was recorded. Inaccurate positioning and intermittent connectivity meant that it was possible for there to be several versions of the game state at any one time—one for each player and one for the server. In order to make sense of all of these different streams of data, the information had to be synchronised. This is normally a very labour-intensive task (Crabtree et al., 2006), complicated by the need to explore circumstances of play and interaction by synchronising events captured by multiple data sources with multiple, sometimes conflicting, states of the system at any one time. Such challenges inspired the design of Replayer (Morrison et al., 2006), an analytic tool that integrates and synchronises log data from multiple sources to allow quantitative and qualitative forms of exploratory data analysis, an issue also explored by Greenhalgh et al. (2007). Like most evaluation, Treasure's analysis was conducted retrospectively—after each game or set of games. However, due to the limited space within which the game was played, evaluators were able to directly observe the play. This meant that they could use their observations to tailor the questions posed during the interviews that followed each game, enabling them to prompt participants to elaborate on areas of the trial that seemed significant.

EVALUATING A SYSTEM USED IN EVERYDAY LIFE

Feeding Yoshi was also designed to run on hand-held devices and exploit 802.11 (Bell et al., 2006). Rather than connecting to a single wifi access point (AP), it used the distribution of secure and unsecured APs as a resource for the game, with players collecting 'fruit' which grew in unsecured APs and 'feeding' it to Yoshis in the secure APs. Feeding Yoshi was designed to be played over a much wider area and over a much longer time period than Treasure, with the intention that users would have a chance to fit it into the contexts and routines of their everyday lives.

The trial participants consisted of two teams in Glasgow, one in Derby and one in Nottingham, with the study lasting a full week. Unlike Treasure, the evaluation put no constraints on where the game could be played—participants could play anywhere that wireless access points could be readily found, such as office blocks, cafes and suburban areas. As a result of this, and of our interest in discovering how players responded to the contingencies of the technology and of the everyday setting in which they were playing, the approach taken to evaluating Treasure was infeasible here. The game was not run within a semi-controlled environment, meaning that the main constraint put on game play was players' existing circumstances of work, leisure and home life. Therefore, evaluators were only occasionally able to observe players, as they were often spread out over different cities and there was no guarantee when or where they would play the game. Capturing video was similarly difficult; since a main research question was examining where and when users would choose to play, there was little point in arranging contrived meetings to video system use. In consideration of these challenges, the employed evaluation strategy focussed on system logs and post-trial interviews.

This greater detachment of the evaluator from the system use made the evaluation of Feeding Yoshi more challenging than that of Treasure. Although every participant was interviewed following the week's trial, the duration of the game was such that particular instances of play or players' motivations at specific times were often forgotten. Other aspects were deemed irrelevant by the players and therefore went unreported. As the evaluators were unable to directly follow the events of the trial, they were less able to focus questioning on specific topics that emerged from witnessed behaviour. Another issue arose when some players reported using other forms of communication technologies to discuss and encourage play with other team members. This had not been anticipated in advance and most of this information was inaccessible for post-trial analysis.

If unable to directly observe the participants, and not directly immersed in the game themselves, evaluators might find it difficult to establish how use of the system is developing. Opportunities to observe or log unanticipated activity can be lost, and without such behaviour being mentioned by chance during interviews, its occurrence might go completely undetected. We subsequently tried to address these problems in the evaluation of later systems.

DYNAMIC QUESTIONING: FLEXIFILL

The previous sections have shown that the evaluation of Feeding Yoshi was performed reflectively without any direct observation of the play. In subsequent systems such as Shakra (Maitland et al., 2006) and Connecto (Barkhuus et al., 2008), we tried to overcome this problem by introducing new techniques that enabled more informed reflective evaluation. The goal was to find a technological means of providing evaluators with a greater degree of insight into user activity during a trial and to allow them to embark on interviews with a better understanding of events in order to tailor questioning to each individual participant's experience.

Shakra was a mobile phone-based application that analysed patterns of fluctuation in GSM cell signal strength to provide summaries of the amount of time a user spends walking. Users could view their daily activity levels in comparison with the accumulated activity totals of their friends, with the intention of making people more aware of their activity levels and thereby hopefully encouraging them to achieve the recommended 30 minutes per day. In the evaluation of Shakra users were given a usage diary—a printed form that they were asked to fill in and return at the end of the trial. Shakra was piloted with three groups of friends over the course of one week, the aim being to examine the impact the activity tracking and sharing of activity levels had on users' self-awareness and to discover whether this motivated any change in attitude towards physical activity.

The evaluation of Shakra attempted to address some of the problems experienced in evaluating Feeding Yoshi. The usage diaries were an attempt to overcome the issues of delayed reflection, with participants encouraged to document any significant happenings that occurred each day. The diary had 19 questions and was returned after the trial but before the participant was interviewed, so that evaluators could familiarise themselves with the individual's experience and tailor specific questions to draw out particular events. However, it became apparent during interviews after the trial that the players would spend less time on the (static) diaries on each successive day, stating that they felt they were repeating the same things day in and day out. Additionally, our evaluations were focussed on how user behaviour changes over time, and a static diary is not a tool adept at uncovering such information. While the diary could capture some very common issues that arise in such experiences, getting at the nuanced behaviour in a particular experience was much harder using this technique. The evaluation of a second awareness application called Connecto attempted to address these difficulties through the creation of a more dynamic diary tool.

Connecto was a mobile phone application that displayed contextual information about friends and contacts. Building on from the previous usage diaries, a new tool called FlexiFill was designed to make daily enquires about system use via a more dynamic web-based interface. Within this diary-style interface, information logged during the trial was shown to the participant, as a reminder of who they had communicated with. This helped to prevent users forgetting interesting events, and acted as a prompt for them to recall their motivation and actions around the communication. In each day's entry, users were asked about a single, randomly selected phone call and text message sent that day. Since all information about location and communication was logged and sent to a central server via GPRS, it was simple to use this information in the questions. From previous experiences, we were aware that participants are reluctant to write thorough diaries by hand, especially if they have to do it daily and the questions are repetitive. The diary was therefore designed to be flexible; participants could fill it in at a time and place that suited them. In order to help give incentives for answering questions posed in the diary, players were presented with the FlexiFill interface before they could gain access to the game's website. Since the trial of Connecto lasted two weeks, we also conducted interviews both at the midway point and end of the trial. In preparation for these interviews we were able to use the participants' FlexiFill answers in order to tailor the interview questions to that particular participant.

AWARENESS, ORCHESTRATION AND EVALUTATION

Ego was a system that made use of both mobile and online play. During mobile play, the system captured aspects of the player's everyday life that could be used to present a profile tailored to the interest of the audience viewing the profile. The aim of the game is to boost one's 'ego' by being seen as the most 'popular', 'well-travelled' and 'coolest' person. To achieve this, players could gain points in three different ways: (1) when the players' phones detected proximal Bluetooth devices they earned 'popularity' points; (2) when the phones detected wireless access points players gained 'well-travelled' points; (3) each day players were asked to vote for co-players who had done the most interesting things the previous day, gaining the three most voted–for players more 'coolness' points. This logged information was then streamed to the server via GPRS, slowly developing the profiles of the players.

The game was trialled over a month with two groups of five, where each player knew everyone else in his or her group. During play, relationships evolved between individuals belonging to different groups as well as between those in the same group. An example of this involved a conflict between two players who fell out over comments made to a mutual friend (one of the group's lecturers, with whom the group were friendly and socialised with, but who was not part of the game). When one player criticised this lecturer, another player was offended, and supported the lecturer. The offended player then used Ego to express this feeling, through continuously taking points from the other player. This type of retribution is seen in the "he said she said" encounters discussed in (Goodwin, 1980).

During the trial each player was interviewed halfway through the game and then again at the end of the month. However, the design of the Ego system also enabled the evaluators to unobtrusively examine player profiles on the website throughout the month and thereby observe what was happening in the game. This continual and ongoing awareness enabled the evaluators to identify when players were having technical problems or when interesting interactions took place, with both activities then shaping and informing subsequent as well as ongoing analysis. A feature of this continual connection is that it enables data to be gathered in a less intrusive way than direct observation or shadowing. Such direct techniques are often impractical in experiences that span a large area over a long duration. In Ego, the evaluators were able to passively involve themselves in players' experiences without heavily impacting them, and yet gain understanding about interactions between players.

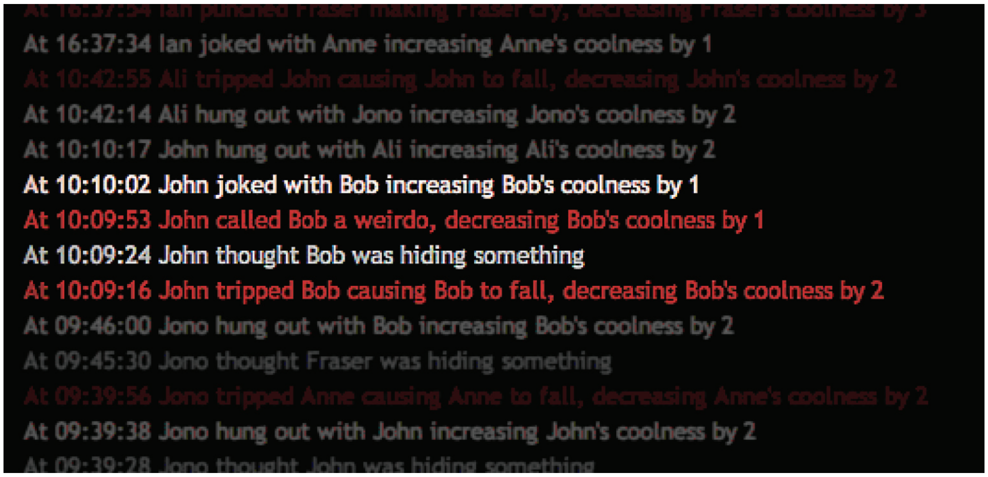
However, on some occasions, the evaluators were moved to make more active interventions during the trial. For example, the users would sometimes encounter technical difficulties, which is to be expected with a system running over such a large period of time and geographical distribution. In past trials it had been difficult for users to understand when the system was not working correctly, typically resulting in frustration and disengagement from the experience. However, through evaluators' continual awareness, the identification of such problems was no longer the sole responsibility of the user. In Ego, by being able to observe the system and immerse themselves in the game as if they were playing, evaluators could remotely identify occasions when patterns of activity were potentially unusual and intervene accordingly. For example, one participant who had been an extremely active player had only managed a very low score one day, which did not fit with his usual pattern of play. He had not contacted the evaluators since he was in the final few days of the trial and he assumed he had done something to break the device. Through their continued awareness of the system and individuals' play, evaluators were able to identify and fix this problem. In this case the database on the mobile client had been corrupted, but it was then possible to fix this within an hour of the problem being identified. This prevented this user's experience from being cut short prematurely and therefore generated more data for analysis.

It is worth noting that one possible side-effect of the continual attention paid to user problems by evaluators is an increased engagement in the trial by those users, therefore opening up findings to the potential criticism of an increased likelihood of the Hawthorne effect. "Proponents of the Hawthorne effect say that people who are singled out for a study of any kind may improve their performance or behavior not because of any specific condition being tested, but simply because of all the attention they receive." (Rice, 1982). Such a view seems to indicate that the degree of attention paid to those participating in a study is positively correlated with any subsequent Hawthorne effect—a commonly held assumption being that the no human-centred study is completely free from the Hawthorne effect (Macefield, 2007). However, the generalisability of the Hawthorne effect has recently been called into question (Rice, 1982; Macefield, 2007). Macefield (2007) presents a full discussion on the limitations of such a generalisation with respect to usability evaluations. Similarly, Crabtree & Rodden (2004) propose that the Hawthorne effect is often overestimated when considering ethnographic studies in the workplace and home, simply because when in these environments people "have better things to do than impress or worry about the ethnographer".

The Ego evaluation also featured a new version of the FlexiFill tool. Rather than relying on a relatively broad sampling of user activity over the course of the trial as the focus of questions, evaluators used the improved FlexiFill which permitted the addition and tailoring of questions in order to make specific enquiries at any point, once again moving a further step away from post-hoc static diaries and questionnaires. Any observed actions that seemed interesting or puzzling could be put to the user the next time they logged in, without waiting for a post-trial interview, reducing the risk of player accounts becoming skewed over time or, worse, forgotten.

One subtle example of this revealed a complex, but somewhat misguided tactic employed by a

Figure 1. An extract from the events page of the Ego game's online component (events relevant to this chapter are indicated by the dashed box). Players' actions during the game were made public to everyone else.



player to hide his activity from those in his team. Throughout the game, players had the ability to hide or reveal certain aspects of their profile to others, and either give or take points to or from other players. Players' use of these abilities was displayed on an events page accessible to other players, making them accountable for their actions. Figure 1 shows an extract from the events page below.

Figure 1 shows John being 'unfriendly' to Bob before he is then 'friendly' to him. Through their continued awareness of the game the evaluators noticed this pattern and felt it to be unusual. At first it was thought that the player did not fully understand the game mechanics. However, during the trial a question was added to FlexiFill specifically for this player, asking about this event. Explaining his actions in an interview, the player stated:

Where it shows you on the side of what happens it goes in chronological order so the first thing [John] would have seen was that I joked with him and then he wouldn't have bothered to check the fact that I have went absolutely after him.

Although this reasoning was flawed, it reveals not only a tactic the player developed, but also how he viewed the events page: namely that it offered the potential to present a certain (in this case, incorrect) impression to others. Taken in the larger context of the game, this conduct led the evaluators to question the relationship between these two players who were, at face value, friends, which in turn led to insight into the dynamic behind the whole cohort of players as a social group. It is extremely difficult to say whether or not subtle events like this would have been uncovered and understood through the use of static diaries, post-trial interviews and reflective analysis. However, it is possible to say that with their continual awareness of the happenings within the game, evaluators were more attuned to the in-game events and therefore more likely to investigate what were at times quite nuanced interactions.

MASS PARTICIPATION

In the years since these trials, the smartphone market has increased enormously, with many more people now regularly carrying mobile computing devices with them. Allied to this has been the creation of a number of 'app stores' on various platforms for distributing applications to these mobile devices. Such distribution mechanisms offer great potential to researchers in recruiting far larger numbers of users than is currently typical for ubicomp trials. To study this method of recruitment and assess its implications for conducting research, we ported Feeding Yoshi to the iPhone, calling it Hungry Yoshi (McMillan et al, 2010). By releasing the app as a free download via a public software repository we aimed to attract large numbers of users from all over the world. Users could install the app through a mechanism that they were already comfortable with and we hoped that having the application on their own devices would lead to more naturalistic interactions.

In pioneering this form of distribution for large–scale ubicomp system trials, we were able to further explore the boundaries of time and space in ubicomp applications and examine the use of existing evaluation techniques. The Hungry Yoshi trial began in September 2009 and is still ongoing (At the time of writing the trial has been running for a year.) The trial has included qualitative and quantitative data analysis and engaging users worldwide in the iterative design and adaptation of the game.

Like Ego and the earlier version of Feeding Yoshi, interacting with participants was the greatest challenge in Hungry Yoshi. Our first dialogue with users was to explain the nature of the trial and gain consent that any data generated from the user could be used for the purposes of our research. As such, a terms and conditions screen is shown on first launch, explaining the trial, who the researchers are, the information we record through use of the application, ways of contacting us and ways to opt out of the trial. Since the application is submitted to a global audience, these terms are provided in four different languages. These terms had to be agreed to before the user could begin to use the application.

Although users were informed of the nature of the trial on first launch, the majority did not physically meet with researchers and as such evaluator contact with participants had to be approached in a different manner. The users had not come to us explicitly as 'trial participants', but were simply smartphone owners wishing to download and play a new game that had become available on the store. As this was a new scenario for us as evaluators, we saw the need to introduce two new mechanisms into the evaluation to remain in contact with participants: tools for communication within Hungry Yoshi, and communication via a social networking web site.

Following on from the use of FlexFill to elicit responses to evaluator-posed questions during a trial, Hungry Yoshi included communication with researchers built into the app as a game feature. Within the game itself we built a mechanism that enabled users to earn 'tokens' to help them in the game by performing tasks that were set by researchers throughout the course of the trial. In this way, we could relay messages to participants, ask specific questions and receive feedback as appropriate.

In addition to the task system, FlexiFill was extended to make use of Facebook, a popular online social networking application. Facebook was used as a means of facilitating more in-depth dialogues and to support communication between participants themselves. Users could optionally log into the application using Facebook Connect, a service with an iPhone API that allows users to verify themselves and log in to third party sites and applications using their Facebook accounts. In establishing links via Facebook, it was also possible to contact participants to set up interviews via telephone or Skype, so that more qualitative means of evaluation could be performed. In running the trial of Hungry Yoshi with a set of participants we never physically met, we as researchers were further detached from interviewees again, as had been the case when moving from Treasure to the original version of Feeding Yoshi. However, by streaming back data from apps, we were better placed to focus interview questions on observed behaviour. For example, one interviewee was observed to have scored negative points on his first few days of use and on questioning him on this fact it was revealed that he had misunderstood the game rules at first. This mechanism also allowed us to select interviewees based on interesting patterns of behaviour. For example, one player's location data appeared to suggest that she played the game while travelling, and on speaking to her she confirmed that she regularly played it on her daily commute to work.

Given the flexibility of the tools for interacting with users and studying log data, we were able to use the evaluation tools to ease the task of redesign. This reflects one of our research goals, which is developing means to quickly and appropriately adapt software to suit the changing contexts and interests of users. For example, as an answer to the task "What could be improved about Yoshi?", one user (anonymised here as Helen) commented that plantations were often too full. Helen was invited for interview, and the interviewer then raised this point to obtain further detail. Helen explained that, as plantations auto-generate fruit at a rate of one per hour, they would often be full, which she felt was to the detriment of the game. In particular, Helen described a situation where she would empty a plantation before leaving for work in the morning, and wanted to collect a seed from work to plant when she got home. However, by this time the previously empty plantation would have around 10 pieces of fruit in it again, which would have to be picked first and fed to unwilling yoshis, leading to a points penalty.

Following this interview, the game designers agreed that this was a valid criticism that should be addressed if it reflected a common concern or problem among users. We again used the task mechanism to consult our user-base at large. A question was added as a task in the game, in the form of a vote as to whether to introduce this feature, and exactly what form it should take. We presented three options: (A) leaving the game unchanged, (B) players could burn empty plantations to stop them re-growing (as suggested by our interviewee) and (C) even full plantations could be burned, which would also destroy all the fruit that had grown. 17% voted in favour of leaving the game as it was, while 29% were keen to see option B and 54% selected option C. The chosen feature was therefore implemented and distributed in a new Yoshi version, thus beginning another iteration in our design process.

On detecting that Helen had installed the new version, we contacted her again to gauge her reaction towards the new feature and she replied positively, agreeing that the version implemented, although not the design she had suggested, was the better of the new options. Around the same time, we included another vote on the new feature, consulting the opinion of the user-base at large after they had had a chance to use it. Users responded with approval, with 94% agreeing that they liked the new feature. This demonstrated to us a significant benefit in this iterative approach of conducting design by engaging with users at both a micro and macro-scale, and letting the results of one feed into the other.

DISSCUSSION

As systems like Ego and subsequently Hungry Yoshi push further into the wild, away from controlled and constrained settings, the spatial distribution and temporal duration of users' experiences grows. Space and time play key parts in understanding the increased levels of uncertainty introduced by the evaluation of Ubicomp systems used in this way. Responding to this changing perspective directed us to exploit more agile evaluative techniques to tackle the rising uncertainty—i.e., the seemingly uncontrollable aspects of an experience—that naturally go hand-in-hand with embedding interactive systems into users' lives. It is only through increased awareness

Table 1. Summary of the evaluations of the discussed systems

System	Space	Time	Number of users	Evaluator awareness and involvement	Data Collected
Treasure	Small (Constrained)	Very short (minutes)	20	Direct observation of users' actions	Direct observation, interviews, video, system logs
Feeding Yoshi	Large (Unconstrained)	Short (days)	16	Indirect post-event / reflective methods	Interviews, system logs
Shakra	Large (Unconstrained)	Short (days)	16	Indirect / reflective	Interviews, usage diaries, system logs
Connecto	Large (Unconstrained)	Medium (weeks)	12	Indirect / reflective / adaptive	Interviews, semi-adaptive usage diaries, GPRS, system logs
Ego	Large (Unconstrained)	Long (Month)	20	Semi-direct / indirect / adaptive	Interviews, ongoing observation through GPRS uploading, system logs
Hungry Yoshi	Large (Unconstrained)	Long (Year)	5000 (play > 5 days)	Semi-direct / indirect / reflective / adaptive	Interviews, ongoing observation through GPRS uploading, system logs, task mechanism to ask questions directly

that we may manage and control uncertainty in evaluation procedures. Using time and space as a basis to characterise evaluated user experiences, we can distinguish between four rough categories and draw out distinctions between the kinds of evaluative techniques we found necessary for each. The table below summarises much of the prior discussion of our five systems, and serves to help with the subsequent discussion.

Treasure is an example of a system in which interaction is relatively *constrained with regard to both duration and space*. Although there were some difficulties in collecting data for evaluation, and tight experimental control was limited to some extent through the trial's openness to interruption by people outside the trial (such as car drivers passing through the area), Treasure's limited spatial and temporal extents permitted close and relatively comprehensive direct observation. On the other hand, broader issues of how Ubicomp technologies may be woven into everyday life are not addressed easily when time and space are so constrained.

User experiences of *longer duration but constrained space* tend towards more 'traditional' Ubicomp systems such as the Active Badge Location System (Want et al., 1992) and smart home environments (Demiris et al., 2007). Evaluations here have necessitated ongoing commitment to a static setting like a home or an office building. To a varying degree, the challenge for evaluators in studying these scenarios is in maintaining this continual involvement in the systems—rather than an intense, spatially distributed involvement (see below). Thus the problem becomes one of determining when interesting interactions take place rather than where.

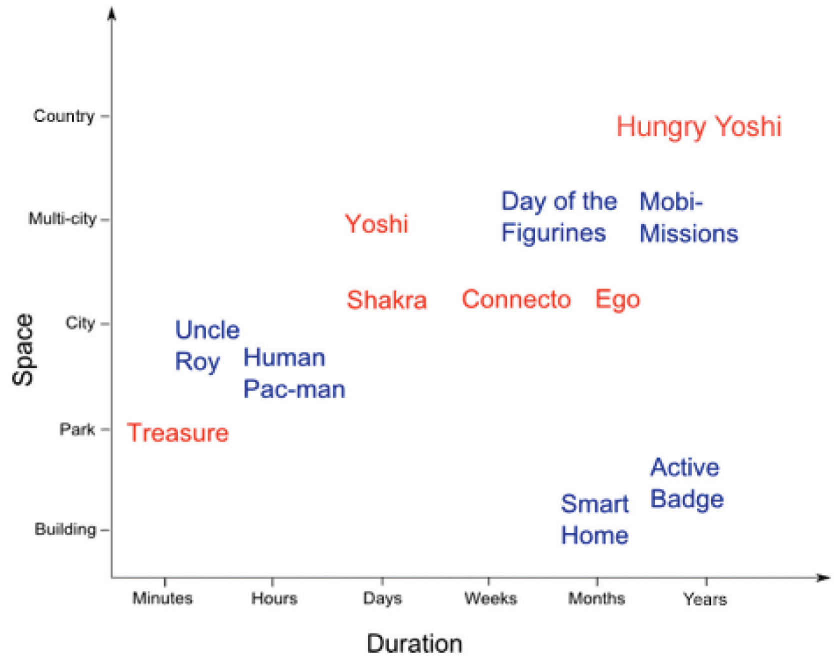
A *shorter duration but a less constrained space* suggests participants may move in a far less restricted way—with no set boundary. City-scale experiences such as Human Pac-Man (Cheok et al., 2003) and Uncle Roy All Around You (Benford et al., 2004) involved evaluating games that took place over a large yet flexible area, with player experiences lasting at most a few hours each. Direct observation was still possible due to the temporally focussed nature of player interactions. Although problems collecting this observational data are typically mitigated by the limited duration, such evaluation activity is often quite intensive due to monitoring or shadowing participants over such a large physical space.

Experiences involving fully *unconstrained spaces and long durations* perhaps present the greatest challenge analytically, even though systems like these have become increasingly common for researchers concerned with a key characteristic of Ubicomp—the appropriation of technology in everyday life. The player experience in games like MobiMissions (Grant et al., 2007) and Day of the Figurines (Crabtree et al., 2007) lasted a month or more, during which time players could roam wherever they pleased. Such systems are usually assessed without direct observation, instead exploiting mixed methods of interviews, questionnaires, usage diaries and so on. We note that such conventional, static evaluation techniques were employed in our earlier systems like Feeding Yoshi. Connecto and Ego followed a modified version of this approach due to the trial lengths and unconstrained spatial distributions of users, but, importantly, data streamed via GPRS enabled evaluators to view the moment-by-moment actions of the users and adapt both the systems' orchestration and their ongoing evaluations accordingly.

Figure 2 attempts to summarise the systems mentioned above in terms of time and space. Difficulty in exercising experimental control increases as both geographic distribution ('space' in Figure 2) and temporal duration increase. For Treasure, it tended to be easier to mitigate uncertainty about where and when interactions might occur due to 'park-sized' interactions occurring over minutes that could be covered by saturating the space with evaluators. Shakra and Yoshi introduced uncertainty over *where* interactions might happen due to 'city- or multi-city sized' interactions as well as extending data collection times from minutes into days. Connecto and Ego stretch the boundaries of evaluation to a greater degree by involving 'city-sized' interactions for weeks or perhaps months. Finally Hungry Yoshi pushed even further by extending the user trial to a global audience, magnifying the uncertainties over where and when interaction may occur. Hungry Yoshi also pushed our adaptive evaluation techniques by introducing the idea of mass participation. As applications run on users' own devices, trials do not require a specified end date when equipment is retrieved, so trials can run for as long as researchers are willing to gather and study data, and interact with users.

As we increase the temporal and geographic scale of user experiences, we gain a greater opportunity to see how ubiquitous computing may become embedded into everyday life, subject both to mundane routines of work and home, and to possibilities for serendipitous and opportunistic interaction. Through this we might explore more fully how competence, system appropriation and mastery, as well as strategies and tactics (particularly in the case of Ubicomp games) develop in use. As we have seen, however, this interest is in tension with our ability to evaluate such uses and environments. For summative methods, which as we note may be more practical in longer term trials of a greater spatial distribution, evaluators must assess much data collected in a post-hoc way, gleaning information from users during interviews and system logs. In contrast, ethnographic studies favour observation and rich description as a way of understanding system use. By engaging and immersing oneself in the experience, evaluators may be able to observe many of the more subtle interactions that take place. Such techniques have been key to understanding the nature of interaction either over a lengthy duration *or* wide physical space. We faced difficulties in adopting such ethnographic techniques on interaction both unconstrained in space and happening over a long time, and so we attempted to produce a synthesis of both forms of technique. As such, in the evaluation of Ego we attempted to claw back some of the properties of ethnogra-

Figure 2. Categorisation of Ubicomp system evaluations by time and space



phy—such as ongoing observation—which were lost by adopting more summative methods. This resulted in evaluators continually observing participants' activities online in order to inform later face-to-face interviews or questionnaires, as well as carrying out a form of orchestration, intervening as and when required in order to fix technical glitches and keep the system running smoothly.

Adaptive evaluation can thus come to employ existing orchestration techniques applied to other systems, as described earlier in this chapter. We note that in these more performance-based systems (such as Uncle Roy All Around You or Day of the Figurines), orchestration is geared towards maintaining the performance as well as ensuring the smooth running of technology. An adaptive perspective on evaluation then couples these two facets of orchestration, using the idea that the continual involvement with a system's execution—part and parcel of general orchestration duties—can then also be used to inform ongoing evaluation.

In summary, this chapter argues against a narrow restriction to any one particular evaluation perspective. Instead, we see different approaches as being tools to use or combine, as appropriate to the evaluation context. There are times when either quantitative or qualitative approaches are most useful, and different regions of the figure favour different evaluation techniques. For systems that involve smaller, room- or building-sized spaces and shorter durations from minutes to hours, we would recommend constructing a video record from multiple angles, perhaps also embedding sensors within the environment and also potentially conducting more formal experimental setups. Evaluator involvement within these spaces can or should be high. Within such evaluations, logging is important, although remote monitoring is less vital than for other regions. Remote monitoring is likely to be unnecessary given the increased evaluator access. For systems run in much larger (e.g., city-sized or global) spaces but over similar time periods, logging comes into its own as a vital tool, as does remote monitoring, however equally important is the use of mobile camera operators recording video when and where possible. These fragments are, currently, more feasibly pieced together after the event although we note that advances in wireless networking should make real-time collation feasible very soon. Systems in smaller spaces but over longer durations in turn preclude more exhaustive video recordings, again favouring remote monitoring and logging as useful ways to enrich a video record consisting of short samples across the duration of the system's run. Finally, for systems in the more problematic larger space, longer duration region, we recommend our adaptive evaluation techniques.

THE CHALLENGES OF USING ADAPTIVE EVALUATION

There are three overarching and inter-related challenges to consider in the design of adaptive evaluations: firstly, the appropriate triangulation of both evaluation methods and of evaluation data; secondly, capturing adequate amounts and types of data while avoiding data overload; and thirdly, maintaining scientific rigour. Although the triangulation of data from multiple sources and of mixed methods is an approach (Denzin, 1978; Mackay & Fayard, 1997; Wilson, 2006) rather than a problem, a challenge lies in the appropriate selection of methods and/or data to be logged in order to avoid data overload when attempting to formulate reliable findings which help answer the research questions of concern. Data overload may occur due to the sheer volume of data being captured, as could potentially be the case in any long-term or large-scale evaluation. It is exacerbated somewhat during adaptive evaluations when ongoing analysis of data is required in order to maintain an awareness of what is happening in the field. While the question of scientific rigour should be of concern to any researcher, when employing adaptive evaluation methods, researchers must strive to ensure that if an evaluation is adapted for a particular user or subset of users, the subsequent findings remain comparable with user group as a whole and that the nature of the adaptation over time is well-documented.

As part of our ongoing work, we are creating FlexKit, a platform for creating component-based smartphone applications and for adapting the software used in their evaluation. FlexKit is an adaptive middleware infrastructure for creating component-based systems with additional support for recommendations, reviewing and user feedback and sharing of software components. The infrastructure itself supports users, developers and evaluators at different levels. FlexKit is a step on from FlexiFill: where FlexiFill enabled evaluators to edit the questions put to users, FlexKit enables evaluators to provide new modules to users so as to alter their applications. FlexKit also offers the ability to update logging code, so as to capture data that was either missed or deemed unnecessary based on earlier premises in the user trial. In this section we are going to focus on its use for evaluation.

FlexKit makes use of the Domino (Bell et al., 2006), component architecture to support the integration of software modules at runtime. The current version of FlexKit is available for iOS and it is currently being alpha tested in two systems, World Paint and FlexBook. World Paint is a collaborative painting game that allows users to 'paint' the world by tracking their movement and displaying paint blobs over a map of the world. While FlexBook is an application for customising and building Facebook posts. Within FlexKit, modules are installed explicitly though user interaction or implicitly though system updates. Modules can be obtained in two ways: passed from peer-to-peer over ad hoc data connections, or they can be obtained from the shared module repository available via the FlexKit module store. Once a module exists on the local device, Domino can be instructed to integrate the module. The module is then available within the launched application and a user can include it in the active configuration.

The significance of FlexKit for large-scale trials can best be seen when evaluators work with developers to adapt the system to capture previously un-captured data, and so enable the exploration of new ideas or research questions raised during a system deployment. FlexKit has its own logging layer, so when an evaluator wishes to augment or change the logged information it is possible for the developer to update a particular module with the new data capturing facility. Through the FlexKit update mechanism, this module can then be silently integrated into the running application. The main advantage of this approach is that it makes the evaluation of mass participation systems much easier and does not require evaluators to be in contact with participants in order for updates to happen.

CONCLUSION

While we would not necessarily claim that what evaluators did on Ego and in Hungry Yoshi—i.e., orchestrating the experience and modifying the research questions on-the-fly—is radically new, we suggest that the way they did it contributes toward the argument that more strongly adaptive evaluation is an appropriate strategy for overcoming the kinds of control problems faced when evaluating user experiences of large geographic and temporal scale.

A variety of methods have been discussed that enable the evaluator to maintain some degree of control and connection. Adaptive journals such as FlexiFill, like experience sampling, aim to capture elements of the evaluation that may be neglected if reflection is attempted only at a later date. Logged data can be visualised post-hoc (Greenhalgh et al., 2007; Morrison et al., 2006) or alternatively can be streamed in real-time, thus providing a continuous awareness mechanism for the otherwise isolated evaluator. Orchestration techniques commonly employed in performance-based systems and games (Crabtree et al., 2004; Vogiazou et al., 2006) allow evaluators to direct the course of the evaluation as their research questions change in the light of ongoing observations. We suggest that when combined, such a collection of techniques afford the *adaptive evaluation* of Ubicomp systems in the wild, and open up new directions for future work on novel tools and methods for evaluation. And, although many of the systems we have reviewed in chapter (whether our own or others') are games-based, we would also argue for the relevance of adaptive evaluation techniques to a broad range of Ubicomp domains.

More generally, we see strong benefits for evaluators in taking advantage of the same design principles and technologies that we are developing for users, in terms of using wireless networks and distributed sensors and cameras as tools for maintaining awareness, and of building up models of context and information with use (and perhaps even with users). We see the potential to make evaluation more of a synchronous engaged experience despite the vagaries of geographic and temporal scale, shifting context, and the work of fitting Ubicomp evaluation into the routine of our own everyday lives.

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REFERENCES

Barkhuus, L., Brown, B., Bell, M., Sherwood, S., Hall, M., & Chalmers, M. (2008). From Awareness to Repartee: Sharing Location within Social Groups. In Czerwinski, M., Lund A., M. & Tan, D., S. (Eds.) *CHI*, (pp. 497-506), Florence: ACM.

Barkhuus, L., Chalmers, M., Tennent, P., Hall, M., Bell, M., Sherwood, S., & Brown, B. (2005). Picking Pockets on the Lawn: The Development of Tactics and Strategies in a Mobile Game. In Beigl, M., Intille, S., Rekimoto, J., & Tokuda, H. (Eds.), *Ubicomp* (pp. 358–374). Tokyo: Springer. doi:10.1007/11551201_21

Bell, M. Hall. M., Chalmers, M., Gray, P., Brown, B. (2006). *Domino: Exploring Mobile Collaborative Software Adaptation Proc. Pervasive 200*6. Dublin, pp. 153-168.

Bell, M., Chalmers, M., Barkhuus, L., Hall, M., Sherwood, S., Tennent, P., et al. (2006) Interweaving Mobile Games with Everyday Life. In Olson, G., M. & Jeffries, R. (Eds.) *CHI*, (pp. 417-426), Montreal: ACM Press.

Benford, S., Rowland, D., Flintham, M., Drozd, A., Hull, R., Reid, J., et al. (2005) Life on the edge: supporting collaboration in location-based experiences. In van der Veer, G., C. & Gale, C. (Eds.) *CHI* (pp. 721-730), Portland, OR: ACM.

Benford, S., Seager, W., Flintham, M., Anastasi, R., Rowland, D., & Humble, J. (2004). The error of our ways: The experience of self-reported position in a location-based game. In Davies, N., Mynatt, E., & Siio, I. (Eds.), *Ubicomp* (pp. 70–87). Nottingham, UK: Springer.

Carter, S., & Mankoff, J. (2005). Prototypes in the Wild: Lessons Learned from Evaluating Three Ubicomp Systems. *Pervasive*, *4*(4), 51–57. doi:10.1109/MPRV.2005.84

Carter, S., Mankoff, J., & Heer, J. (2007) Momento: Support for Situated Ubicomp Experimentation. In Rosson, M., B. & Gilmore, D., J. (Eds.) *CHI*, (pp. 125-134), San Jose, CA: ACM Press.

Cheok, A. D., Fong, S. W., Goh, K. H., Yang, X., Liu, W., & Farzbiz, F. (2003). Human Pacman: a sensing-based mobile entertainment system with ubiquitous computing and tangible interaction. In Jamin., S. (Ed.) *NetGames* (pp. 106-117), Redwood City, CA: ACM Press.

Consolvo, S., & Walker, M. (2003). Using the Experience Sampling Method to Evaluate Ubicomp Applications. *Pervasive Computing*, *2*(2), 24–31. doi:10.1109/MPRV.2003.1203750

Crabtree, A., Benford, S., Capra, M., Flintham, M., Drozd, A., & Tandavanitj, N. (2007). The Cooperative Work of Gaming: Orchestrating a Mobile SMS Game. *CSCW*, *16*(1-2), 167–198.

Crabtree, A., Benford, S., Greenhalgh, C., Tennent, P., Chalmers, M., & Brown, B. (2006) Supporting Ethnographic Studies of Ubiquitous Computing in the Wild. In Carroll, J., M. (Ed.) *DIS* (pp. 60-69) New York: ACM.

Crabtree, A., Benford, S., Rodden, T., Greenhalgh, C., Flintham, M., & Anastasi, R. (2004). Orchestrating a mixed reality game ‘on the ground. In Dykstra-Erickson, E., & Tscheligi, M. (Eds.), *CHI* (pp. 391–398). Vienna: ACM.

Crabtree, A., & Rodden, T. (2004). Domestic Routines and Design for the Home. *CSCW*, *13*(2), 191–220.

de Sá, M., Carriço, L., Duarte, L., & Reis, T. (2008) A framework for mobile evaluation. In In Czerwinski, M., Lund A., M. & Tan, D., S. (Eds.) *Ext. Abs. CHI* (pp. 2673-2678), Florence: ACM.

Demiris, G., Oliver, D., Dickey, G., Skubic, M., & Rantz, M. (2007). Findings from a participatory evaluation of a smart home application for older adults. *Technology and Health Care*, *16*, 111–118.

Denzin, N. (1978). *Sociological Methods: A Sourcebook* (2nd ed.). New York: McGraw Hill.

Dourish, P. (2004). What We Talk About When We Talk About Context. *Personal and Ubiquitous Computing*, *8*(1), 19–30. doi:10.1007/s00779-003-0253-8

Froehlich, J., Chen, M. Y., Consolvo, S., Harrison, B., & Landay, J. A. (2007) MyExperience: a system for in situ tracing and capturing of user feedback on mobile phones. In Knightly, E., W., Borriello, G. & Carceres, R. (Eds.) *MobiSys* (pp. 57-70), San Juan, CA: ACM.

Goodwin, M. H. (1980). He-Said-She-Said: Formal cultural Procedures for the Construction of a Gossip Dispute Activity. *American Ethnologist*, *7*(4), 674–695. doi:10.1525/ae.1980.7.4.02a00050

Grant, L., Daanen, H., Benford, S., Hampshire, A., Drozd, A., & Greenhalgh, C. (2007). MobiMissions: the game of missions for mobile phones. In Swanson, J. (Ed.), *SIGGRAPH 2007 Educators Program*. San Diego: ACM.

Greenhalgh, C., French, A., Tennant, P., Humble, J., & Crabtree, A. (2007). From replay tool to digital replay system. In Online Proceedings of *E-Social Science*, Ann Arbor, MI: ESRC/NSF.

Macefield, R. (2007). Usability Studies and the Hawthorne Effect. *Journal of Usability Studies*, *2*(3), 145–154.

Mackay, W. E., & Fayard, A.-L. (1997) HCI, Natural Science and Design: A Framework for Triangulation Across Disciplines. In (Editors Names) *Designing Interactive Systems*. (pp. 223-234), Amsterdam: ACM.

MacMillan, D., Morrison, A., Brown, O., Hall, M., & Chalmers, M. (2010) Further into the Wild: Running Worldwide Trials of Mobile Systems. Proc. Pervasive 2010, 210-17, http://dx.doi.org/10.1007/978-3-642-12654-3_13

Maitland, J., Sherwood, S., Barkhuus, L., Anderson, I., Hall, M., Brown, B., et al. (2006) Increasing the Awareness of Daily Activity Levels with Pervasive Computing. In Bardram, J., E., Chachques, J., C. & Varshney, U. (Eds.) *Pervasive Computing Technologies for Healthcare* (pp.1-9) Innsruck: IEEE.

Morrison, A., Reeves, S., McMillan, D., & Chalmers, M. (2010). Experiences of Mass Participation in Ubicomp Research. [Copenhagen, Denmark.]. *UbiComp*, *2010*(Sept), 26.

Morrison, A., Tennent, P., & Chalmers, M. (2006) Coordinated Visualisation of Video and System Log Data. In Andrienko, G., Roberts, J., C. & Weaver, C. (Eds.) *Coordinated and Multiple Views in Exploratory Visualization* (pp. 91-102), Zurich: IEEE.

Rice, B. (1982). The Hawthorne defect: Persistence of a flawed theory. *Psychology Today*, *16*(2), 70–74.

Scholtz, J., & Consolvo, S. (2004). Toward a Framework for Evaluating Ubiquitous Computing Applications. *Pervasive Computing*, *3*(2), 82–88. doi:10.1109/MPRV.2004.1316826

Vogiazou, Y., Reid, J., Raijmakers, B., & Eisenstadt, M. (2006). A research process for designing ubiquitous social experiences. In Mørch, A., Morgan, K., Bratteteig, T., Ghosh, G., & Svanaes, D. (Eds.), *NordiCHI* (pp. 86–95). Oslo: ACM Press. doi:10.1145/1182475.1182485

Want, R., Hopper, A., Falcao, V., & Gibbons, J. (1992). The active badge location system. *Transactions on Information Systems*, *10*(1), 91–102. doi:10.1145/128756.128759

Wilson, C. E. (2006). Triangulation: the explicit use of multiple methods, measures, and approaches for determining core issues in product development. [-ff]. *Interaction*, *13*(6), 46. doi:10.1145/1167948.1167980

Chapter 9
Experimental Setups for User Evaluation of Mobile Devices and Ubiquitous Systems

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ABSTRACT

Nowadays, mobile devices features are often linked up to the context of usage. As a consequence, researchers must consider not only the user and the device, but also the surrounding environment when designing effective user study evaluations. Two opposite experimental setups are possible: in-situ and in the laboratory. There is no consensus on their respective benefits, for instance with regard to the number of usability issues detected. In this chapter, the author isolates independent variables that could contribute to evaluation biases by proposing a taxonomy that splits the in-situ and laboratory experimental setups into two new setups. The author describes the concept of the "Uncertainty Principle" to emphasize the dilemma between precise observation and bias minimization and introduce the "Trojan Horse" technique to partially overcome the consequences of the uncertainty principle. As a conclusion, a methodology using the four experimental setups in a complementary way is proposed.

INTRODUCTION

In the last decade, mobile devices have reached the threshold of technical maturity to be widely used in both professional and leisure contexts. For instance, GPS-based automotive navigation systems or network capable smartphones are nowadays considered common objects. Moreover, as mobile devices continue to evolve, researchers have transitioned evaluating ubiquitous environments and pervasive systems from laboratory prototypes to real-world implementations.

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The features of these categories of systems make the mobility of the user possible, either together with the system (for mobile devices), or inside it (for ubiquitous systems). Moreover, to work properly, these systems must be aware of their surrounding environment. For instance, an automotive GPS moves with the car (and so with its driver) and is aware of traffic jams. An augmented museum detects the presence of visitors as they move through the halls.

These two characteristics –mobility and context-awareness– of mobile devices and ubiquitous systems raise new methodological issues for system evaluation during user studies. It is thus not only an "interactive system" we must evaluate, but more generally an "interactive environment." In other words, the evaluation cannot only focus on the device, but must also take into account the context of use, and its variations while the user is moving.

Traditional user evaluation methods. If we had to define a canonical description of user evaluation, we would say that, traditionally, user evaluation takes place in a usability laboratory, that is to say a closed room where the environment can be easily controlled. The user is requested to perform the tasks that have been chosen by the evaluators. The evaluation methods are based on the observation of users either directly, or through one-way mirrors, or via audio/video recording systems. Frequently, the user is encouraged to think aloud in order to facilitate the interpretation of his/her activity. A facilitator may be present throughout the experimentation or only at the beginning and the end. His/her role is to give instructions to the user, to answer any questions the user may have, and to observe. To sum up, the two key elements of user evaluation are observation and control of the experiment variables.

Unfortunately, traditional user evaluations methods cannot easily deal with the two characteristics –mobility and context-awareness– of mobile devices and ubiquitous systems. For instance, the user evaluation of a smartphone for skiers requires users to move –to ski down the mountain– with the device in a complex context –a ski resort– that could not be mimic in a traditional usability laboratory.

Motivations: user evaluation of interactive environments. As we have said previously, mobile devices characteristics –mobility and context-awareness– raise new methodological issues. The main issue is to set up a realistic interactive environment while keeping enough control to analyze the interactions between the users and the interactive system.

So, the question is: what is the degree of realism necessary to ensure the validity of user evaluations? In practice, we have to determine how to place the user in interrelationship with these elements, either by simulating them in a usability laboratory, or by using the elements of the real-world in-situ. A priori, in-situ experiments should always be best. But this type of experiment is known to be complex to set up (Kjeldskov, Skov, Als, & Høegh, 2004). Our aim is to determine if the higher cost of in-situ experiments is justified by better results. In other words, we wonder if in-situ experiments are worth the hassle.

The article is structured as follows. First, we detail related work. After reviewing the state-of-the-art, our thesis is presented and our research roadmap is explained. Then, the three experiments of our roadmap are detailed. Finally, the article presents a generalization of our results and proposes a methodology for user evaluation of interactive environments.

METHODS: LABORATORY OR IN-SITU?

First, it is necessary to determine what are the relevant elements of the interactive environment that must be set up for the experiment. We propose to structure this set of elements into four categories: the user (or users if a collaborative environment is under evaluation); the devices in direct interaction with the user; the tasks directly related to the evaluated devices; and the context, which is defined as a complementary set of the three preceding elements, i.e., other users, other devices, and tasks with no direct link with the evaluation.

Usually, it is straightforward to determine the elements of the first three categories because they are in direct relation with the objectives of the evaluation. On the contrary, for the last category, making the distinction between relevant and non-relevant elements of the context can be difficult. Indeed, by definition, mobile devices and ubiquitous systems form a unit with their environment. Elements of the context have a direct influence on the interaction, whereas the others contribute to create a general atmosphere. For instance, bad weather conditions in a ski resort or a crowded museum can have a significant impact on interaction, and so, are relevant. On the contrary, traffic jams at a ski resort entrance or bad weather condition around a museum building have little impact on the interaction.

The literature distinguishes two main approaches to set up a realistic interactive environment (Hagen, Robertson, Kan, & Sadler, 2005). A first approach –usability laboratory– simulates the aspects of the environment with varying degrees of realism. A second approach –in-situ– places users in the real world, where all the aspects of the environment are naturally present. Overall, it may seem "obvious" that the in-situ approach have greater validity than the laboratory approach, because all the expected aspects of the environment must be present. We will see that the literature is not unanimous on this point.

Laboratory. A first approach consists in simulating the elements of the interactive environment, with more or less realism, in a usability laboratory. This traditional approach is based on well-known methodologies.

The user mobility is the crucial element that researchers seek to simulate. Various simulation techniques were used: the user could walk around buildings (Brewster & Walker, 2000), inside corridors (Pirhonen, Brewster, & Holguin, 2002) or on a course in the usability laboratory (Kjeldskov & Stage, 2004). Mini-steppers (Pirhonen, et al., 2002) or treadmills (Kjeldskov & Stage, 2004) could also be used to simulate the walk. In addition, others researchers tried to recreate the "general atmosphere" of the environment with real furniture in a usability laboratory divided into several rooms, for instance to simulate hospital rooms (Kjeldskov, et al., 2004).

These simulation techniques are well adjusted for the simulation of short-duration experiments for small-size environments (for instance: offices, shops, apartments). However they usually require a large usability laboratory and can be quite expensive. They are not well adapted to simulations of long-duration experiments in large-size environments (for instance: ski resorts, museums). And, more generally speaking, a high level of simulation fidelity is difficult to achieve if the system under test is designed for large or complex environments. Moreover, even if the simulation is very realistic, the user always perceives it as a simulation, and should not behave as usual. Furthermore, a lot of real-world elements, for instance adverse weather conditions, are missing. As a consequence, some usability issues, for instance a non-waterproof touch-screen, are hidden.

In-situ. In contrast, a second approach consists of replacing simulated elements by real world elements (i.e., experimenting in-situ). A priori, more reliable results must be obtained, since the experimental setup is supposed to be as close to the future usage environment as it can be. Regrettably, in-situ experiments are known to be complex to set-up, and suffer from important variability of the experimental conditions due to the natural variability of the real world (Kellar, et al., 2005). Maybe as a consequence of it, they are used very infrequently in the field of mobile usability research (Kjeldskov & Graham, 2003).

The literature uses several different terms to name in-situ experiments. The non-exhaustive list of references and used terms includes: "field experiments" (Hertzum, 1999), "field trails" (Jensen & Larsen, 2007), "experimentations in the wild" (Waterson, Landay, & Matthews, 2002), "reality testing" (Bennett, Lindgaard, Tsuji, Connelly, & Siek, 2006), and "quasi-experimentation" (Roto, Oulasvirta, Haikarainen, Lehmuskallio, & Nyyssönen, 2004). In our knowledge, there is no attempt of classification of these terms. To standardize the vocabulary, we use the generic term "in-situ" throughout this article even if the authors of cited papers use another term.

Laboratory versus in-situ. In the literature, numerous publications compare laboratory versus in-situ experiments (Fields, Amaldi, Wong, & Gill, 2007). These comparisons between the experimental protocols are mainly based on two criteria: the number of problems detected and their severity, generally as defined by Molich (Molich, 2000). In our knowledge, there is no attempt to use the Hartson et al. criteria for the evaluation of usability inspection methods (Hartson, Andre, & Williges, 2003). The results published in the literature vary: several publications claim that there is no difference between the experimental setups, while others argue the opposite.

If we study the publications, we first note that most of them detect no or few differences between laboratory and in-situ experiments. Beck et al. (Beck, Christiansen, Kjeldskov, Kolve, & Stage, 2003), Kjeldskov et al. (Kjeldskov, et al., 2004), (Kjeldskov, et al., 2005), Betiol and Cybis (Betiol & Cybis, 2005) as well as Kaikkonen et al. (Kaikkonen, Kekäläinen, Cankar, Kallio, & Kankainen, 2005) conclude that the differences are not significant. However, while Betiol and Cybis detect problems of greater severity in the laboratory, Kaikkonen et al., indicate that problems detected in the field are slightly more severe. The Kjeldskov et al. publication (Kjeldskov, et al., 2005) gives complementary results: the intersections between the issues detected by four methods (including laboratory and in-situ) were important for the critical problems, partial for the serious ones, and weak for the cosmetic ones.

On the contrary, another evaluation, concerning six methods tended to prove that the static evaluation –the test user is sitting at a table– could detect more usability issues than all the others, in particular the in-situ evaluation (Kjeldskov & Stage, 2004). These results are consistent with the Baillie and Schatz conclusions (Baillie & Schatz, 2005). As the in-situ experiments are more complex to set up than laboratory ones, it seems preferable to only use this technique. More recently, Duh et al. called the Kjeldskov al. results into question since they detected more usability issues in-situ than in the laboratory (Duh, Tan, & Chen, 2006). The Duh et al. experiments could be easily compared to Kjeldskov et al. ones since they used the same classification of ergonomic problems severity: the one defined by Molich (Molich, 2000). Moreover, the Duh et al. experiment protocol was very similar to the Kaikkonen et al. one who concluded, on the contrary, that the differences were tiny (Kaikkonen, et al., 2005). These results are consistent with the Po et al. conclusions about heuristic evaluations: they suggest that heuristic evaluations detect more usability issues in-situ than in the laboratory (Po, Howard, Vetere, & Skov, 2004).

Discussion about possible biases. These results lead to the conclusion that not only is there no consensus concerning the added value of in-situ experiments, but also, that the comparisons between laboratory and in-situ experiments are not easily reproducible. A closer look on the experimental setups gives interesting indications about possible biases.

In all the experiments, at least one person – usually a facilitator– is present close to the user. In the majority of the experiments, a gooseneck camera is used to record the user interaction with the mobile device. To capture the context in the laboratory, ceiling cameras or cameras on tripods are used. In-situ, cameras are fixed on the user's shoulder or cameramen are in charge of this task.

Moreover, the same tasks are prescribed to the users both in the laboratory and in-situ. In summary, most of the experimental setups are identical or very similar in the laboratory and in-situ. This methodological approach is interesting because the experimental setups can be removed from the set of independent variables. As a consequence, the results of the experiments can be compared according to the context –the unique independent variable.

However, this in-situ approach has important consequences because the social activities of the user are constrained by the experiment. For instance, Kjeldskov et al. observed that the set {user, facilitator and cameraman} could create a "group effect": the people of the user's entourage deviated from the group track and did not try to interrupt the activity of the user (Kjeldskov, et al., 2005). We detected a similar effect (Jambon, Golanski, & Pommier, 2007). So, in our point of view, this approach makes the user walk in a "protection bubble" that isolates him/her from the natural context.

Baillie and Schatz found that users performed their tasks faster and made fewer mistakes in-situ. They suggested that users might feel more "relaxed" outside of the laboratory (Baillie & Schatz, 2005). Similarly, Schulte-Mecklenbeck et al. pointed out that, for a task of information retrieval on the web, users did not finish all their tasks less frequently and retrieved more information in the laboratory than in-situ. The authors speculated that a "psychological pressure", due to the presence of the observer, is the main reason (Schulte-Mecklenbeck & Huber, 2003).

On the contrary, when users are left alone, Isomursu et al. observed significant improvements in the quality of the self-reported usability problems (Isomursu, Kuutti, & Väinämö, 2004). The authors used the "experience clip technique" that consisted in charging one of the users to play the role of the cameraman. In this experiment, with couples of users, one of the users was in charge of recording a video-clip (with a camera phone) of the other user (interacting with the mobile device) whenever a usability or usage problem occurred. Isomursu et al. detected that when the users did not know each other (in this case, the video-shooter was a researcher), the quality and pertinence of the video-clips illustrating the usability or usage problems reported in the field dropped significantly. Surprisingly, when asked, the users "explained that the presence of the researcher did not have any effect on the usage situation" (Isomursu, et al., 2004). Moreover, in this latter situation, the user did not try to correct the device related problems, but instead usually asked the researcher for help.

We argue that from a methodological point of view, the in-situ experiments described here can be viewed as laboratory experiments that are "relocated" in the field. As a consequence, the supposed added value of the real context may be partially lost due to the "protection bubble" effect. In these articles, no formal distinction is made between laboratory and in-situ experimental setups. The in-situ experimental setups are usually defined as the opposite of the laboratory experimental setups. There is a tacit consensus to consider in-situ experimental setups as placing the user in a "natural" context or in an "ecological" situation. As a consequence, authors make only one distinction between laboratory and in-situ experimental setups. In our opinion, there are two kinds of in-situ experimental setups.

RESEARCH AGENDA

Hypothesis. The latter remarks and anecdotes led us to study more precisely the experimental protocols used in laboratory and in-situ. For all these experiments, the protocols are almost identical in laboratory and in-situ. The tasks performed by the users are prescribed. Usually, a facilitator stays in the immediate vicinity of the user. In addition, cameramen and/or observers may be required to facilitate the data collection. The instrumentation of the experiments is usually composed of a camcorder, and sometimes, a gooseneck camera, fastened to the device, is also used to capture the interactions between the user and the device.

From a methodological perspective, the in-situ experimental setup is similar to the laboratory one. The in-situ protocol can be seen as a variation of the laboratory protocol, because the user, the device, the facilitator, the observers and the instrumentation are simply "moved" from the artificial context of the laboratory, to the real context in the field. In other words, the stage changed, but the actors, the decors and the script are identical. So users acts in a context that is far from reality. Moreover, he/she may suffer, even without realizing it, from some influence of the presence of the observers.

Finally, we hypothesize that, in-situ, the user acts in a "bubble" where his/her tasks, general activity, social relationships, etc. are constrained by the experimental protocol. We assume that the expected benefits of the in-situ are partly annihilated by these constraints, and therefore, the detected differences between the two configurations are partly artifacts. In other words, we hypothesize that the location of the experiment for the mobile/ubiquitous system is not the key element that makes the difference between laboratory and in-situ experimental setups. We assume that the people (e.g., facilitator, cameraman) as well as the instrumentation devices (e.g., gooseneck camera, wireless microphone) have an important effect on the user behavior because they alter the realism of the environment. Moreover, the level of the instructions given to the user –tasks prescribed or not– change significantly the experimental setups. Our assumptions are consistent with Thomas and Kelloggs ones about the minimization of the "ecological gap" [Thomas, 1989 #120]. At last, we hypothesize that there are more than one in-situ experimental setup.

In-situ with or without ecological context. We propose to split the in-situ experimental setups into two opposite setups. The first setup is similar to laboratory experiment. The only significant difference is the location: the laboratory is replaced by the real world, but the people and the instrumentation are still present. The second one tends to place the user as close as possible to reality, in other words in an ecological context. This experimental setup is characterized by the absence of visible elements related to the observation –people and instrumentation– in order to preserve the self-determinism of the user.

More formally, compared to the laboratory experimental setup, the realistic ecological context experiment takes place in-situ if (1) the context is real and (2) the device and the data are perceived as real by the user (however the Wizard of Oz technique could be used). The ecological context is preserved if, moreover, (3) the user is free to do what he/she wishes –no prescribed tasks– and (4) all observation elements –people and instrumentation– are invisible. We now name this latter experimental setup "in-vivo".

Very few in-vivo experiments are reported in the literature. The Demumieux and Losquin publication that focuses on usage statistics of mobile phones (Demumieux & Losquin, 2005) or the more recent work of Jensen and Larsen (Jensen & Larsen, 2007) are the rare exceptions. This quasi-absence of in-vivo experiments can be explained by the technical difficulties that must be overcome to set up these experiments. For instance, the observation is difficult because video-recording systems cannot easily be placed in the context. Moreover, the added value of these experiments is difficult to estimate, even if instinctively one could think that the ecological context must increase the validity of the results.

Uncertainty Principle. In-vivo experiments face another critical issue. It is quite impossible to know whether users act in a different way in ecological context or not, because classic observation techniques, for instance the video recording technique, alter the ecological context. Alternatives to the video recording technique, for instance diaries or critical incidents technique, cannot be used because they distract the user for his/her task. Questionnaires can be used at the end of the experiments, but they are not well adapted to the evaluation of precise usability problems: users forget them. In practice, the observation of the interactions between the user and the device can only be performed via computer logs. In summary, experiments can be set up in-situ (1) without ecological context but with plenty of data available or (2) with ecological context but not with enough data to interpret the user interaction with the device.

We name this constraint the "Uncertainty Principle" because of its semantic proximity with the principle stated by Heisenberg concerning the quantum physics. In our context, this principle can be stated as follows: "it is not possible, at the same time, to precisely observe a situation of man-machine interaction without, by side-effects, disturbing it." Although it is known that the observer affects the observed (Schulte-Mecklenbeck & Huber, 2003), in our knowledge, a similar principle has never been formalized for mobile usability testing. The experimenters have a difficult dilemma: either they choose to observe with precision and accept biases, or they choose to minimize biases, and in consequence accept to have limited observations that minimize the interest of the experiment.

Trojan Horse technique. Even if it is not a priori possible to transgress the Uncertainly Principle, we defined a technique that minimizes the biases introduced by observation while guaranteeing enough information collection to analyze the interactions. Users cannot ignore that they are being observed, but researchers can introduce a recording device that has both visible and hidden recording features. We first used this easy way in the E-skiing experience. For this experiment, it was not possible to use a shoulder camera hold by a cameraman or a gooseneck camera above the smartphone because of the ecological context. So, we fastened a mini-camera on the skiers' helmets. The video replay feature of the smartphones justified the presence of the camera. Actually, the main feature of the camera was to record the user interaction with the smartphone, witch is supposed to be in the camera's field of view. This easy way was generalized in the Museum experiment. In that experiment, we used a postcard as a guide for the exhibition, but the postcard was also a RFID based tracking system.

The Trojan Horse technique, as we named it, takes as a starting point the Wizard of Oz idea of masking to the user some aspects of the experimental setup. The Trojan Horse technique is based on the double usage of a recording device. The first usage is clearly visible and has a believable utility. The second usage is masked and aims at recording useful information for the observation. The basic principle is to make the user accept a recording device for a personal usage –the horse– in the ecological context –the town of Trojan– in order to put silently in that context a recording device useful for observation –the Greek soldiers. In practice, the Trojan Horse technique may be used in many situations. Two approaches are possible:

- If the mobile device or the ubiquitous environment already has a device that could capture the needed information, it is possible to add new features to the device, for instance a recording system.
- If the mobile device or the ubiquitous environment does not have such a device, it must be added. To do so, a believable usage must be found to it, in order to justify its presence. This first usage does not need to be useful for the experiment, it must just be believable.

For instance, to study the geo-localized use of SMS on mobile phones, the phones could be equipped with a GPS. The GPS may be presented to the test users as one of the tested features of the phones, but in fact, it is used to detect the user position when sending SMS. Nevertheless, the Trojan Horse technique could not always be implemented. In general, it is not possible to provide a believable justification for the recording device in situations where the device may seem incongruous. For instance, it is be difficult to justify a camera in hospital rooms.

Moreover, researchers must balance between the ethical and the efficiency aspects of the Trojan Horse technique. It is imperative to inform users of what is recorded, even if, this technique requires to partly hide the real use of the data at the beginning of the experiment. In all cases, the users must be informed at the end of the experiment about the Trojan Horse and how data was collected and used.

Roadmap. We must continue to explore if in-situ experiments are worth the cost. More formally, our objective is to determine the added value, in terms of correctness and completeness, of in-situ experiments compared to laboratory experiments. Articles dealing with comparisons between experiments in laboratory and in-situ without ecological context already exits in the literature (see paragraphs about methods). Our roadmap is to complement these results with the analysis of experiments in-vivo.

In ecological contexts, the video-observation of users is not always possible, so the computer logs collected by the devices are the primary source of information. These logs are related with interactions between user and device –user actions and interface feedbacks– and also with the more general user activities –geo-localization, network logs, etc.

We first created a meta-evaluation (MapMobile experiment) in a quasi-realistic context in order to compare findings obtained with two different sets of observation data: video records versus computer logs. The objective of the meta-evaluation was to determine to what extent the analysis of computer logs could replace the analysis of video records. In other words, this experiment was necessary to "calibrate" the observation technique we have been using until now in ecological context.

Then, we tested the Trojan Horse technique with two experiments in-situ with ecological context. The first test was the user evaluation of a mobile service for skiers in a ski resort (E-skiing experiment). The second one was the user evaluation of a ubiquitous environment that was set up for a temporary museum exhibition (Museum experiment).

EXPERIMENTS

MapMobile experiment. This experiment was a meta-evaluation, so it had two objectives: a basic objective, the device usability evaluation, and a meta-objective, the observation techniques comparison.

The basic objective was to evaluate the usability of context-aware personal digital assistant that also gave geo-localized information to the user. The scenario simulated the indoor guiding of an executive in a professional context. The experiments took place in a real professional building during work hours. Twelve users participated to the experiments. Due to technical failures or organizational mistakes, the records of two users were to be removed from the data set. Each experiment lasted about thirty minutes. A facilitator and cameraman accompanied the user, as shown in Figure 1. The facilitator was in charge of giving instructions and asking specific questions during the scenario execution.

The meta-objective was to compare two different observation techniques. The first technique was representative of experiments in-situ (without ecological context). We recorded the video of the context (camcorder held by a cameraman), the comments of the user (wireless microphone) and the PDA screen film (screen grabber tool). The second technique mimicked observations that could take place in-vivo (with ecological context). We recorded the user actions, the interface feedbacks and the geo-localization of the device. Both sets of data were record at the same time for all

Figure 1. MapMobile device (on the left), and the user with the facilitator and the cameraman in one of the building corridors (on the right)

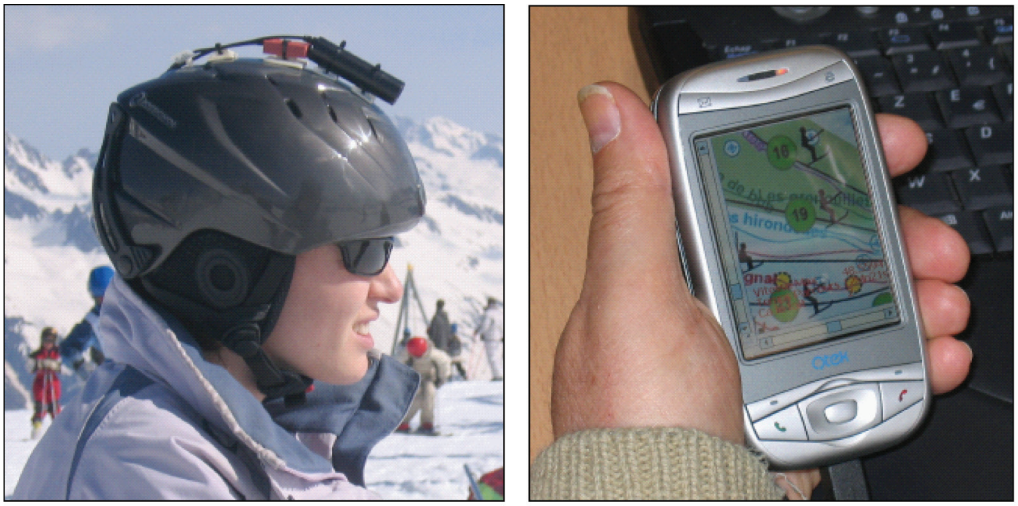
the users. Our hypothesis was that the two observations techniques had a similar power of detection of usability problems. The comparison used a blind test. The analyses of the two kinds of recorded data were performed separately. No communications were allowed between the evaluators. Once both finished analysis, another evaluator crosschecked and compared the two sets of results, and in case of mismatch, verified the exactness of the usability problems detected thanks to the video records.

In summary, the meta-evaluation concluded that usability problems detected via classic observations techniques (without ecological context) were more numerous. The second observation technique (with ecological context) could only detect usability problems that alter –deviate or delay– a reference sequence of user interactions and interface feedbacks. However, the main critical usability problems were detected via the two observation techniques (Jambon, Golanski, et al., 2007).

E-skiing experiment. The objective of the E-skiing experiment was to test the Trojan Horse technique in-vivo. The device under test implemented a proactive service that aimed at improving the skier's experience. The system carried by the skiers (Figure 2) was composed of a set of sensors (video, acceleration, and geo-localization) associated with recorders and a user interface (smartphone). During the skiing day, the data from the sensors were recorded and analyzed after each ski run. The skiers were informed proactively, via SMS, that new information on their preceding ski runs was available. Thanks to the hyperlink provided in the SMS, the skiers could consult via the smartphone their performances: the course, the distance crossed, the run duration, the maximum speed, the acceleration, and the video of the run. Since it was only a technical test, only one group of four skiers used the system. As a consequence we did not try to conclude about the usability of the system.

The hypothesis was that the Trojan Horse technique could be used in an ecological context and that the observation of user interactions was possible. This experiment was preceded by many technical tests, in laboratory, outside, and in the ski resort. In spite of these tests, the video records were almost not exploitable for the usability analysis: the weak visual angle of the mini-cameras and displacements of the helmets during the runs resulted in bad framing. Moreover, because of accelerations during jumps, three of the

Figure 2. Helmet equipped with a mini-camera and an accelerometer (on the left) and service application on the smartphone (on the right)



four camera focus systems jammed during the experiment. These technical problems could probably be overcome in the future thanks to more robust hardware.

Nevertheless, we obtained very interesting information about the system usage. The activities of the skiers were rebuilt thanks to the SMS bill, information server logs, and GPS tracking records. We could determine the moments when and where the skiers were proactively informed of the availability of new data, and, when and where they accessed the data. We were surprised to discover that, actually, they exclusively used the device, not on the trials but at the bar during breaks! Users confirmed this in post-experiment informal interviews. We concluded that the Trojan Horse technique is not easy to implement in the wild, but that user activity could be reconstructed with partial information from computer logs. The results could be consulted in French in (Jambon, 2006).

Museum experiment. We then set up a new experiment to test the Trojan Horse technique in-vivo with ubiquitous environments. The system under test was a ubiquitous environment associated with a temporary exhibition about camouflage and private life at the Rhône Natural History Museum in Lyon (France). The museum was equipped in order to detect and identify visitor’s movements between halls and interactive information kiosks could react to the visitors’ presence. The objective was to analyze the visitor’s paths in the exhibition and their usage of the information kiosks.

This experiment was also the opportunity for us to test the scalability of in-vivo experiments. We thus increased the duration of the experiment: a few weeks instead of one day for E-skiing. We also increased the number of users: several hundreds of visitors instead of one group of four skiers. The operation of this ubiquitous environment was based on radio frequency identification tags (RFID). A tag, that looking like a postcard, was given to the visitors with their entry tickets (Figure 3). The visitor’s tracks in the exhibition were detected via a set of antennas.

The data were first cleaned up from incoherent records because of technical failures or human errors in the management of the postcards. Then, a first level of analysis determined that about five hundred visitors tracks were analyzed. A second level of analysis determined the visits durations (about one hour) and the types of tracks followed

Figure 3. Postcard with a hidden RFID tag (on the left) and one pair of antennas of the RFID based tracking system (on the right)

by the visitors. We determined that about half of the visitors carried out a complete visit (they use both information kiosks) as it were envisaged by the scenario writer. The lack of video records made the interpretation of abnormal visitors tracks difficult. In most cases, the comments of staff, in particular the guards, allowed us to discover the reasons of the abnormal behaviors detected. This problem seems to be generic with experiment in-situ in ecological context. The results could be consulted in French in (Jambon, Mandran, & Perrot, 2007).

Synthesis. From a technical standpoint, the experiments in the field are more difficult to set up than laboratory experiments. Experimenters must be aware that "out of the lab," the expression "it's the jungle out there" (Kellar, et al., 2005) is right. The situation is worse in ecological contexts because there is no facilitator to solve minor prototype bugs, thus the device must be reliable. In our opinion, there is no major difference between laboratory experiments and in-situ experiments, because the "protection bubble" isolates the user from a part of the variability of the real world. However, these experiments are interesting if the context is difficult to simulate.

From a methodological standpoint, we make a strong distinction between in-situ and in-vivo experiments. The difference is not only a consequence of the absence of observers and instrumentation, but also a consequence of the absence of instructions. Without prescribed task, test users use available systems functions as they wish. Because they use only a limited set of functions, it is coherent to detect less usability problems in ecological context. However, the usability problems detected must be more relevant because they appear in the real usage context of the system. In addition, in-vivo experiments are well adapted to the evaluation of usage. For instance, in the E-skiing experiment, the most important result was about the real usage of the system. In the Museum experiment, reliable statistics about kiosks usage could be collected.

GENERALIZATION

Taking as starting point the distinction between laboratory and in-situ experimental setups in the literature, we proposed the concept of in-vivo as a specialization of the in-situ configuration. However, the search for a classification system of these configurations, as well as recent literature results (Kjeldskov & Skov, 2007), led us to define another configuration, the “realistic simulation”. In addition, we standardize the names of these configurations, based on a terminology inspired by biology, which is consistent with the terminology proposed by Kjeldskov et al. (Kjeldskov & Skov, 2007).

The laboratory (in-vitro). The usability laboratory is the reference configuration. It is characterized by an artificial context. The usability problems detected are directly dependent on the tasks performed by the user, specified in the scenarios. This configuration is suitable for the study of usability issues. It is therefore unlikely that usage issues or patterns could be indentified with this configuration. We now mane this configuration “in-vitro” to be consistent with the terminology proposed by Kjeldskov et al. (Kjeldskov & Skov, 2007).

The field (in-situ). Compared to the in-vitro configuration, the main interest of the in-situ configuration is to have more realistic contextual elements. The experimental setup is only slightly different from the in-situ configuration. Notably, user tasks are also prescribed. So, it is not surprising that usability issues detected are similar in type and number in these two configurations. Moreover, the presence of a facilitator and observers is a known bias.

If the environment is somewhat constrained, even if the users are often isolated from the real world by a “bubble”, unplanned events from the environment can make the evaluation more relevant. The usability issues detected are “localized” in the real context. For instance, if a smartphone screen is not readable in the direct sunlight brightness, this usability issue will not be detected in-vitro, but will be detected in-situ, providing it shine... This is a limitation of this configuration. The elements of the environment are inherently unpredictable. So, there is no guarantee that they will occur.

We name this configuration “in-situ”, which is consistent with the terminology proposed by Kjeldskov et al. (Kjeldskov & Skov, 2007).

The real world (in-vivo). The experimental setup changes radically. The facilitator and observers are absent and so do not influence the user, who can use the system under test as he/she whishes. Two types of results are obtained: (1) usage statistics of the device, i.e. the tasks that the user perform naturally; and (2) usability issues “filtered by the real usage”, i.e. usability issues related to the user activity in the real life. By definition, these tasks are only a subset of the possible tasks that can be performed with the device. So, it is consistent that the number of usability issues detected in-vivo is much less than in-vitro or in-situ. However, ergonomic problems detected would gain in relevance, as they are triggered by the actual use of the device.

However, the results obtained with this configuration should be taken with caution since the tasks performed by the subjects and events from the context do not occur in a deterministic manner, and can be viewed as hidden independent variables. To minimize this risk, it can be interesting –if feasible– to significantly increase the number of subjects and the experiment duration to statistically increase the probability of occurrence of the events. Moreover, the fact that the user is aware of being part of an experiment provides a bias, known as the “Hawthorne effect” (Macefield, 2007). Although controversial, this effect suggests that the user performance may improve by the only fact that the user is aware of being part of an experiment.

We name this configuration “in-vivo”, which is consistent with our terminology. Note that Kjeldskov et al. did not mention this configuration in their article (Kjeldskov & Skov, 2007).

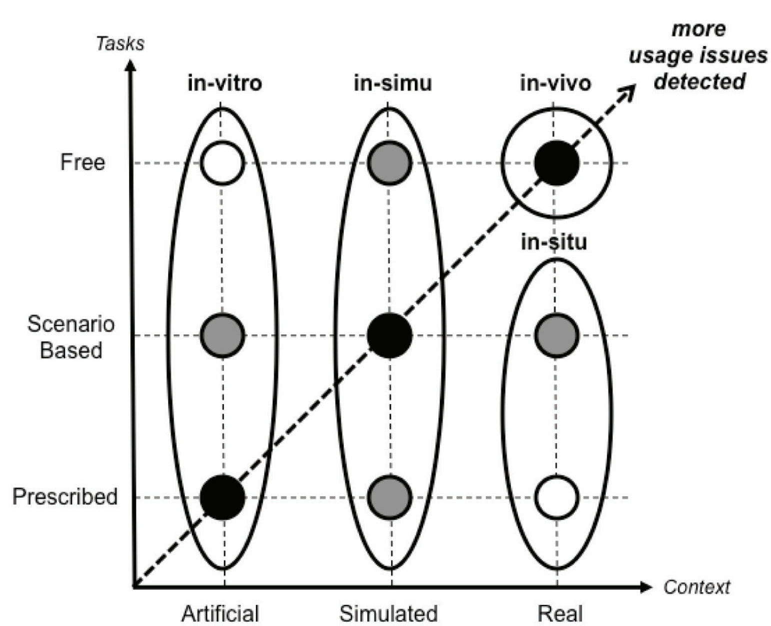
The realistic simulation (in-sim). There is an intermediate situation between artificial and ecological environment: the simulation. This configuration can only be used when it is possible to create a credible simulation of the context. The users tasks can be free, prescribed, or based on realistic scenarios, but the duration of theses tasks must be compatible with the use of a simulator. This configuration can be vew as a resctriction of the in-vivo configuration where the environment is partially controlled. This configuration was explored in two papers under different names. Kjeldskov et al. name it "in-sitro" (Kjeldskov & Skov, 2007) and Hertzum names it "workshop" (Hertzum, 1999).

We name this configuration "in-simu", which is consistent with our terminology. Note that Kjeldskov et al. consider it as an intermediary configuration between in-vitro and in-situ. As a consequence, they name it "in-sitro" (Kjeldskov & Skov, 2007). We think that this denomination is not explicit. Moreover, our classification is different. That is why we chose the term "in-simu".

CLASSIFICATION AND APPROACHES

Classification. Considering the four configurations, the task (prescribed, scenario based or free) and the context (artificial, simulated or real) emerge as the two main orthogonal dimensions of the classification. To our point of view, the realism of the device, and the presence of observers and observation devices are secondary dimensions. Indeed, the realism of the device is a significant element only when coupled with the realism of the context. In the same way, the presence of observers is not desirable when the context is real, or when the users can perform tasks without constraints. We thus deduce theoretically nine possible situations (figure 4). We group them according to the four previously defined configurations: in-vitro, in-simu, in-situ and in-vivo. Overall, the realism of the context determines the configuration. If the context is real, the in-vivo configuration differs from configuration in-situ by the constraints on tasks.

Figure 4. Classification of configurations according to the tasks and context



Within each configuration, all situations are theoretically possible. However, we make the distinction between the situations that we found most relevant (black circles), intermediate ones (gray circles) and those that seemed less attractive (white circles). The least interesting situations are extreme situations when the experimental protocol seemed impractical. Indeed, free tasks in an artificial context seemed irrelevant because it must be difficult for a user to act "naturally" in the context of a usability laboratory. Similarly, requesting users to carefully execute prescribed tasks in a real context seemed unrealistic, because interruptions are common in the real world.

In contrast, we believe the most interesting situations are situations that present a good match between the prescription of tasks and realism of the context. Indeed, the artificial environment of a usability laboratory is well suited to prescribed tasks, the simulated environment allows users to execute realistic scenarios, while free task are well suited in a real context. Intermediate situations are compromises between the two previous ones. Note that the configuration in-situ does not include one of the most interesting situations. Indeed, we believe that this configuration is only a good compromise when the configurations in-vivo or in-simu cannot be implemented.

Possible approaches. From our point of view, the four configurations defined above are more complementary than competitive. The configuration in-vitro is the reference tool to search for usability issues. The configuration in-simu can detect the features that make sense for the user as well as some usability problems, but in a controlled environment. Finally, the configuration in-vivo can finalize the study with emphasis on usage patterns. The configuration in-situ is a special case that can substitute for in-simu or in-vivo configurations if, respectively, the context is difficult to simulate or letting the user perform free tasks does not make sense. The choice of a particular configuration can also be determined by the objectives of the evaluation or by the technical limitations of the system under test. For instance, in-vitro, it is possible to use mock-ups via the Wizard of Oz technique, which is quite impossible in-vivo, with the notable exception of the work of Consolvo et al. (Consolvo, et al., 2007).

For a given device, the "natural" order is to perform the three types of evaluation in the sequence (in-vitro → in-simu → in-vivo) in order to gradually identify usability issues and then usages ones. The in-simu step is optional. This approach however has a flaw: if some features do not correspond to real usages, they have been nevertheless developed, at great expense, during the previous two steps. It is also possible to invert this "natural" order and follow a reverse sequence: (in-vivo → in-simu → in-vitro). The idea is to identify usages patterns before focusing only on the usability of the used features. The drawback of this approach is that a critical usability issue can mask an interesting feature, not used by users only because of its poor usability.

CONCLUSION

In conclusion, we suggest that there are not only two –laboratory and field– but at least four –laboratory, simulator, field and real world– possible configurations for the user evaluation of mobile systems and ubiquitous environments. These configurations are not competitive but complementary because they have varying abilities to detect usability and usage issues.

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REFERENCES

Baillie, L., & Schatz, R. (2005). *Exploring multimodality in the laboratory and the field.* Paper presented at the Proceedings of the 7th International Conference on Multimodal Interfaces, Torento, Italy.

Beck, E., Christiansen, M., Kjeldskov, J., Kolve, N., & Stage, J. (2003). *Experimental Evaluation of Techniques for Usability Testing of Mobile Systems in a Laboratory Setting.* Paper presented at the OzCHI'2003, Brisbane, Australia.

Bennett, G., Lindgaard, G., Tsuji, B., Connelly, K. H., & Siek, K. A. (2006). *Reality testing: HCI challenges in non-traditional environments.* Paper presented at the CHI'06 extended abstracts on Human Factors in Computing Systems, Montréal, Québec, Canada.

Betiol, A. H., & Cybis, W. A. (2005, 12-16 September). *Usability Testing of Mobile Devices: A Comparison of Three Approaches.* Paper presented at the IFIP TC13 International Conference on Human-Computer Interaction - Interact'2005, Rome, Italy.

Brewster, S., & Walker, A. (2000). *Non-Visual Interfaces for Wearable Computers.* Paper presented at the IEE workshop on Wearable Computing (IEE, 00/145), London.

Consolvo, S., Harrison, B., Smith, I., Chen, M. Y., Everitt, K., & Froehlich, J. (2007). Conducting In Situ Evaluations for and With Ubiquitous Computing Technologies. *International Journal of Human-Computer Interaction*, *22*(1), 103–118. doi:10.1207/s15327590ijhc2201-02_6

Demumieux, R., & Losquin, P. (2005, 19-22 September). *Gather customer's real usage on mobile phones.* Paper presented at the 7th International Conference on Human Computer Interaction with Mobile Devices and Services (MobileHCI'05), Salzburg, Austria.

Duh, H. B.-L., Tan, G. C. B., & Chen, V. H.-H. (2006). *Usability evaluation for mobile device: a comparison of laboratory and field tests.* Paper presented at the Proceedings of the 8th conference on human-computer interaction with mobile devices and services, Helsinki, Finland.

Fields, B., Amaldi, P., Wong, W., & Gill, S. (2007). In Use, In Situ: Extending Field Research Methods. *International Journal of Human-Computer Interaction*, *22*(1&2), 1–6. doi:10.1207/s15327590ijhc2201-02_1

Hagen, P., Robertson, T., Kan, M., & Sadler, K. (2005, 21-25 November). *Emerging research methods for understanding mobile technology use.* Paper presented at the OzCHI'2005, Canberra, Australia.

Hartson, H. R., Andre, T. S., & Williges, R. C. (2003). Criteria For Evaluating Usability Evaluation Methods. *International Journal of Human-Computer Interaction*, *15*(1), 145–181. doi:10.1207/S15327590IJHC1501_13

Hertzum, M. (1999, 28th November - 1st December). *User Testing in Industry: A Case Study of Laboratory, Workshop, and Field Tests.* Paper presented at the 5th ERCIM Workshop on "User Interfaces for All" – Special Theme "User-Tailored Information Environments", Dagstuhl, Germany.

Isomursu, M., Kuutti, K., & Väinämö, S. (2004). *Experience clip: method for user participation and evaluation of mobile concepts.* Paper presented at the 8th conference on Participatory design: Artful integration: interweaving media, materials and practices, Toronto, Ontario, Canada.

Jambon, F. (2006, 5-8 septembre). *Retours d'expérience lors d'évaluation de dispositifs mobiles en situation réelle.* Paper presented at the 3e Journées Francophones Mobilité et Ubiquité - Ubimob'06, Paris, France.

Jambon, F., Golanski, C., & Pommier, P.-J. (2007, November 4-9). *Meta-Evaluation of a Context-Aware Mobile Device Usability.* Paper presented at the International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies (UBICOMM'07), Papeete, French Polynesia.

Jambon, F., Mandran, N., & Perrot, C. (2007). La RFID au service de l'analyse du parcours muséal des visiteurs. *La lettre de l'OCIM (Office de Coopération et d'Information Muséographiques)* (113), 11-17.

Jensen, K. L., & Larsen, L. B. (2007). *Evaluating the usefulness of mobile services based on captured usage data from longitudinal field trials.* Paper presented at the 4th international conference on mobile technology, applications, and systems and the 1st international symposium on Computer human interaction in mobile technology, Singapore.

Kaikkonen, A., Kekäläinen, A., Cankar, M., Kallio, T., & Kankainen, A. (2005). Usability Testing of Mobile Applications: A Comparison between Laboratory and Field Testing. *Journal of Usability Studies*, *1*(1), 4–17.

Kellar, M., Reilly, D., Hawkey, K., Rodgers, M., MacKay, B., Dearman, D., et al. (2005). *It's a jungle out there: practical considerations for evaluation in the city.* Paper presented at the CHI'05 extended abstracts on Human factors in computing systems, Portland, OR, USA.

Kjeldskov, J., & Graham, C. (2003). *A Review of Mobile HCI Research Methods.* Paper presented at the Mobile Human-Computer Interaction – MobileHCI'2003, Udine, Italy.

Kjeldskov, J., Graham, C., Pedell, S., Vetere, F., Howard, S., & Balbo, S. (2005). Evaluating the Usability of a Mobile Guide: The Influence of Location, Participants and Resources. *Behaviour & Information Technology*, *24*(1), 51–65. doi:10.1080/01449290512331319030

Kjeldskov, J., Skov, M., Als, B., & Høegh, R. (2004, 13-16 September). *Is It Worth the Hassle? Exploring the Added Value of Evaluating the Usability of Context-Aware Mobile Systems in the Field.* Paper presented at the Mobile Human-Computer Interaction - MobileHCI'2004, Glasgow, UK.

Kjeldskov, J., & Skov, M. B. (2007). Studying Usability In Sitro: Simulating Real World Phenomena in Controlled Environments. *International Journal of Human-Computer Interaction*, *22*(1), 7–36. doi:10.1207/s15327590ijhc2201-02_2

Kjeldskov, J., & Stage, J. (2004). New Techniques for Usability Evaluation of Mobile Systems. *International Journal of Human-Computer Studies - IJHCS, 60*(5-6), 599-620.

Macefield, R. (2007). Usability studies and the Hawthorne Effect. *Journal of Usability Studies*, *2*(3), 145–154.

Molich, R. (2000). *Usable Web Design (In Danish)*: Ingeniøren|bøger.

Pirhonen, A., Brewster, S., & Holguin, C. (2002, April, 20-25). *Gestural and audio metaphors as a means of control for mobile devices.* Paper presented at the ACM-SIGCHI Conference on Human Factors in Computing Systems (CHI'2002), Minneapolis, Minnesota, USA.

Po, S., Howard, S., Vetere, F., & Skov, M. B. (2004, September, 13-16). *Heuristic Evaluation and Mobile Usability: Bridging the Realism Gap.* Paper presented at the Mobile Human-Computer Interaction (MobileHCI'2004), Glasgow, UK.

Roto, V., Oulasvirta, A., Haikarainen, T., Lehmuskallio, H., & Nyyssönen, T. (2004). *Examining mobile phone use in the wild with quasi-experimentation* (Technical Report No. 2004-1). Helsinky, Finland: Helsinky Institute for Information Technology (HIIT).

Schulte-Mecklenbeck, M., & Huber, O. (2003). Information search in the laboratory and on the Web: With or without an experimenter. *Behavior Research Methods, Instruments, & Computers*, *35*(2), 227–235. doi:10.3758/BF03202545

Waterson, S., Landay, J. A., & Matthews, T. (2002). *In the lab and out in the wild: remote web usability testing for mobile devices.* Paper presented at the CHI'02 conference on Human Factors in Computing Systems extended abstracts, Minneapolis, Minnesota, USA.

Chapter 10
How it Started:
Mobile Internet Devices of the Previous Millennium

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ABSTRACT

Internet access on cellular phones, after emerging as a new technology in the mid-1990s, is now a thriving activity despite the global economic recession. IDC reported smartphone sales of 1.18 billion units in 2008 (IDC, 2009), compared to the unconnected personal digital assistants approaching merely 1 million units per quarter in the second half of 2003. However, the concept of using handheld devices for wide-area data applications began 25 years prior to the beginning of the end of PDAs.

INTRODUCTION

The key year in the history of PDA devices is 1978. That year, a start-up called Lexicon sold its handheld electronic language translator (Levy, 1979) called the LK-3000. Its interchangeable modules included database and notepad applications, and the product was licensed by Siemens-Nixdorf. Meanwhile independent inventors Robert Hotto and Judah Klausner patented what may be the world's first PDA (Klausner & Hotto, 1977). Toshiba acquired the rights and produced it as the Memo Note 30 model LC-836MN. It combined a handheld calculator with an alphanumeric keypad and had the ability to store up to 30 data entries.

Noteworthy in these devices were their applications to the intelligence community. Lexicon founder Michael Levy revealed in 2003 (Koblentz 2003) that an encryption module was created for the U.S. National Security Agency, while Toshiba's product was featured for its own cipher value in the April 1980 issue of Cryptologia. In both cases,

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the intention was that military and intelligence staff would use proprietary hardware to send data over public landline telephone networks – a technique not dissimilar from modern commercial VPNs.

More ambitious devices developed in the realm of science fiction, such as Douglas Adams' *The Hitchhiker's Guide to the Galaxy* on BBC radio beginning in March, and Gordon Dickson's story *Thank you, Beep* published that summer[1] in the Hewlett-Packard Calculator Journal.

It would take time for reality to equal the hype. Miniature landline acoustic modems only available to the defense and intelligence community in 1978 were publicly launched by the early- and mid-1980s. Two examples of devices which could employ such technology were Panasonic's RLH-1400 Hand Held Computer (introduced in 1981) and Psion's Organiser (introduced in Britain in 1984), both in support of applications such as file transfer and remote access to larger computers.

Data advances in handheld devices finally began changing from wired into wireless in the first half of the 1990s. Among the most successful advances was the Nokia 1011 introduced in 1992. It was the first commercial GSM phone and therefore the first with text messaging. Texting is based on radio protocols, not Internet protocols, but at the time it showed consumers and service providers alike that mobile phones had applications potential beyond telephony. Also that year, IBM targeted its 9075 "PCradio" subminiature laptop at Sears field technicians, so they could access service documents. Similar technology was available for Atari and Hewlett-Packard's own handhelds (Gregg 1992). Next, an optional cellular modem was available for AT&T's EO 440 in 1993. Motorola's L3000 phone introduced the iDen push-to-talk application in 1994; and cellular modems appeared in Apple Newton clones such as the Motorola Marco and Digital Ocean Seahorse in 1995 and 1996, respectively. By this point, Tim Berners-Lee's nascent World Wide Web was engulfing the Internet, and laboratories such as the Xerox Palo Alto Research Center began evaluating the feasibility of Web browsers for prototype mobile devices such as the ParcTab (Theimer et al., 1993).

However, it appears that the first mobile *consumer* device *with native* Internet applications was the IBM Simon, developed by engineers at IBM's Boca Raton, Fla. facility in 1992 and 1993. "To me it was somewhat of an obvious idea," lead architect Frank Canova said in a 2007 interview. IBM's executives were convinced to allow the development of a smartphone when members of the Simon team appeared at meetings carrying a bag with a portable computer, fax machine, organizer, and telephone. Bigger challenges included battery life, component miniaturization, and designing a user interface without any previous examples, he said. The pioneering smartphone also included a memory card slot, predictive text entry, a touchscreen, and wireless software updates – all still considered modern features today. Code-named Sweat Pea, it entered the market through BellSouth in 1994, but was discontinued later that year despite plans among Canova's team for improved versions.

Simon was not without its problems, namely that it cost $899, weighed 1 lb., 2 oz., and ran software bound by the limitations of DOS. Nor did its impressive capabilities include a Web browser. Smartphones in the second half of the decade quickly became more modern, such as Nokia's 1996 application of a QWERTY keyboard in the 9000 Communicator; Research In Motion's "push" e-mail focus for its first BlackBerry pager device in 1998; and Qualcomm's use of the then-leading PalmOS design in the pdQ Smartphone in 1999. That year also saw the birth of Wireless Access Protocol browsers, with Nokia's 7110 phone as the first deployment.

REFERENCES

Gregg, Lynne (1992). Living in a wireless world with PDAs. *Infoworld.*

IDC (2009, February). *Worldwide Quarterly Mobile Phone Tracker*.

Klausner, J., & Hotto, R. (1977). Electronic pocket directory. U.S. Patent 4,117,542

Koblentz, E. (2003, January 30). Unpublished telephone interview of Michael Levy.

Koblentz, E. (2007, August 29). Unpublished telephone interview of Frank Canova.

Levy, M. (1979). Electronic dictionary and language interpreter. U.S. Patent 4,158,236

Theimer, M., Demers, A., & Welch, B. (1993). *Operating System Issues for PDAs*. In Proceedings of the Fourth Workshop on Workstation Operating Systems. IEEE.

Week, W. (2008, September). *Gunning for the Hockey Stick*. Retrieved February 24, 2009, from http://www.wireless week.com/ Article- Gunning-Hockey- Stick.aspx

ENDNOTE

[1] Republished at http://www.snarc.net/pda/ty-beep.htm by permission of Hewlett-Packard

Chapter 11
User Experience of Mobile Internet:
Analysis and Recommendations

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ABSTRACT

Mobile access to the Internet with handheld devices has been technically possible for quite a while and consumers are aware of the services but not so ready to use them. A central reason for the low usage is that user experience of the mobile Internet is not yet sufficiently good. This paper analyses the mobile Internet from the end-user perspective, identifying factors and solutions that would make Internet usage on a mobile device an enjoyable experience. User experience can be improved by a better understanding

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of users and usage contexts, by developing mobile services that better serve the needs of mobile users, easing service discovery and by developing the infrastructure needed for the mobile Internet. This paper discusses all these aspects and gives development recommendations. Multidisciplinary and multicultural cooperation between the various actors in the field is needed to improve user experience.

INTRODUCTION

Internet access on mobile devices not only changes the way the Internet is used but also some of its characteristics. In addition to enabling personal mobile devices to access existing Internet content, mobilizing the Internet enables totally new kinds of Internet content and services. Mobile Internet services can be made topical and personal by utilizing location and other contextual data. Mobile users may play an important role in uploading topical content to web services. We have already seen the first steps in this direction. User experience of the mobile Internet is affected by device hardware and software, connection, gateway, services, and the seamless flow between these (Roto, 2006). All of these should work smoothly together to facilitate positive user experiences. There is still a lot to do to improve mobile Internet user experience as recent user acceptance studies from different parts of the world show that consumers are aware of mobile Internet services but not yet so ready to use them (Chu & Pan, 2008; Lopez-Nicolas et al., 2008; Lu et al., 2008).

A major change in Internet usage is predicted for developing countries, where mobile phones may provide the primary way to access the Internet (Ipsos Insight, 2006). The entire Internet infrastructure will be different there, and the infrastructure should be built to provide the best possible user experience with the given resources. Internet access may affect the development of the whole society.

This paper is based on two Mobile Internet User Experience (MIUX) workshops held in conjunction with Mobile HCI 2007 and 2008 conferences (Roto & Kaasinen, 2007; 2008). The international workshops gathered viewpoints and experiences from different cultures and stakeholders. Together with the participants we identified four aspects where mobile Internet user experience can be improved: 1) understanding the users and usages of the mobile Internet better; 2) improving services and service discovery; 3) improving device hardware and software, and 4) improving infrastructures such as connectivity, network proxies, pricing policies, guidelines and standards.

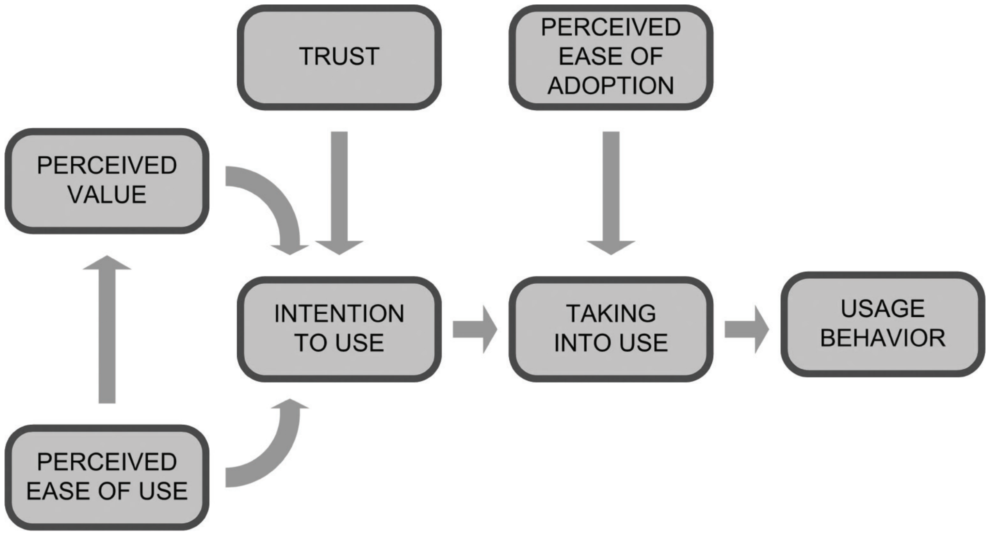
This paper analyzes issues that affect user experience of the mobile Internet. First, in the next section we define what is meant by user experience. Then we discuss who are potential mobile Internet users, why they are potential users and where the usage may take place. Next we discuss individual mobile Internet services and suggest services that would be valued by mobile users. The following section discusses how people can be helped in discovering relevant services. Finally, infrastructure-level enablers for successful user experience are discussed in the last section.

USER EXPERIENCE

User experience is a term that describes a user's feelings towards a specific technology, system, or object during and after interacting with it. Various aspects influence the feelings, such as the user's expectations, the conditions in which the interaction takes place, and the system's ability to serve the user's current needs.

Taking the mobile Internet into use proceeds via the intention to use to the actual adoption. The Technology Acceptance Model for Mobile Services, TAMM (Kaasinen, 2005), states that the perceived value, perceived ease of use, and trust towards the mobile Internet all trigger the

Figure 1. Technology acceptance model for mobile services, TAMM (Kaasinen, 2005)



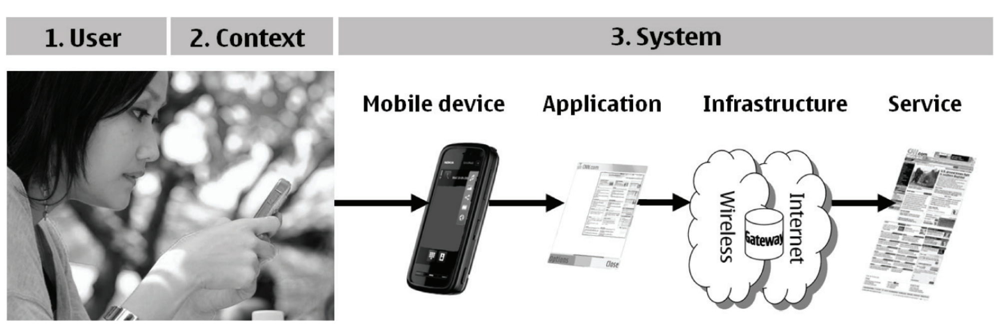
intention to use. If the adoption phase is also seen as being easy, people will start using the mobile Internet (Figure 1).

By the time the user starts to use the mobile Internet, s/he has certain expectations of it. If the expectations are low, user experience may be good even if the system is not perfect. People also evaluate the value they experienced with the mobile Internet, and that may overcome the possible difficulties and thereby make the user experience positive. So, although the mobile Internet system might not be perfect yet, it does not mean that the user experience has to be poor.

There are many elements that affect the user experience, and the user experience is often determined by the weakest link among these. According to Hassenzahl and Tractinsky (2006), the three main elements are the user's internal state, the context of use, and the actual mobile Internet system. The system, in turn, consists of four main components in the case of the mobile Internet: the device, the software needed to use the Internet on the device, the network to transfer the packages, and finally the services available through the Internet (Figure 2). All these system components may come from different parties, making it challenging to provide a seamless user experience.

The user's internal state affects user experience, as each user has a specific need, motivation,

Figure 2. Elements affecting user experience of the mobile Internet (adapted from Roto, 2006)



and expectation for the Internet on a mobile device. Even the current mood of the user may affect user experience. The situation where mobile Internet use takes place is more influential than with PC Internet use, which typically happens in a stationary context. In the case of the mobile Internet, we should understand the physical, social and temporal context, and how the mobile Internet use relates to the overall goal that the user wants to achieve.

Closest to the user is the mobile device with many aspects affecting user experience: display size, keyboard, memory space, processing power, user interface style, and the general attractiveness of the device. The Internet software on the device may either be preinstalled on the device or the user can install it afterwards, in the same way that (s) he can install web browsers on PCs. The browser, feed reader, e-mail client, and any Internet software on the device have different levels of usability, content support, and functionality, which influence user experience. In addition, in order to connect the various devices, and to the various services, an infrastructure of connections and gateways is needed (Roto, 2006).

At the other end of the mobile Internet system, there are Internet services that the user wants to access with the device. The value and usability of the service in the mobile context affect user experience, but less obvious aspects of user experience are trust and the way in which the service provider can serve the user outside the Internet, e.g. informing about available services and easing access to them.

WHY, WHERE AND HOW PEOPLE USE THE MOBILE INTERNET

Understanding current users and usages of the mobile Internet is crucial for improving user experience for the future. In the following we will give an overview of current knowledge about the market, the users and usage contexts.

Mobile Internet Market Development

The mobile Internet has undergone huge developments in the early years of this millennium, and the improvements in technology have led to better user experience and higher market penetration. Whereas in 2001 less than 1% of Western Europeans used the mobile Internet at least once a month, by 2008 the user base had grown to 28%, and is estimated to reach 40% by 2011 (Strategy Analytics, 2008). The highest mobile Internet penetration is in Japan, where more than 75% of the population use a web browser on their mobile device at least once a month (Strategy Analytics, 2008). According to Comscore (2007a), in January 2007 5.7 million people used a mobile device to access the web in the UK alone, compared with the 30 million UK people who accessed the Internet from a PC. It is noteworthy that people under 35 accounted for 67% of the overall users. Gender is also an influencing factor, as 63% of mobile Internet users in the UK are male, compared with 54% of PC Internet users (Comscore, 2007a). Mobile Internet usage answers a variety of user needs and usage situations. Internet sites accessed via mobile terminals are most often related to news (both “serious” and gossip-type news), real-time messaging, searching, gaming, blogs and weather information (Comscore 2007a; 2007b).

A study by Comscore (2007b) in Japan reveals that despite the significant usage numbers, only 12.6% of the respondents stated that they were very satisfied or satisfied with accessing the Internet over a mobile device. This poses immense design challenges for the developers of both mobile terminals and mobile Internet sites.

User Acceptance of the Mobile Internet

Kuo and Yen (2008) have studied user acceptance of the mobile Internet in Taiwan. Their studies showed that users with high personal innovativeness (willingness to adopt new technologies) perceived higher ease of use of the services than other users. Their results show that the most important factor in increasing consumer behavioral intention to use 3G mobile value-added services was attitude, followed by perceived ease of use, perceived costs and perceived usefulness. Perceived usefulness had the strongest effect on attitude. Lopez-Nicolas et al. (2008) have studied user acceptance of mobile services in the Netherlands. They also found that innovative people have a more positive perception of usefulness and are more likely to start using advanced services. Their results show that social factors exert an important influence on people's decision to adopt advanced mobile services. The opinions of friends and relatives had a significant impact, and perceived benefits were related to flexibility and status.

Koivumäki et al. (2008) found that the duration of service usage did not affect consumer perceptions of mobile services but familiarity with the device and user skills had an impact on the perceptions of the services. The tolerance of service imperfections decreased with device familiarity, i.e. people who were familiar with mobile devices were more demanding of the services. Koivumäki et al. (2008) emphasize the importance of enhancing the technology skills of the general public and potential mobile service users. They claim that skills can be enhanced by tutoring workshops, easily accessible user aids and providing hands-on user guidance in situations where new mobile phones are purchased.

Lee et al. (2007) indicate four factors in the relationship between the user's cultural profiles and post-adoption beliefs about the mobile Internet. They concluded that uncertainty avoidance, individualism, contextuality, and time perception have a significant influence on the user's perceptions of mobile Internet services and that the cultural characteristics of users have a strong effect on how services are adopted and used later on.

Fang et al. (2006) present a study of task technology fit by classifying the effects of task type on wireless technology acceptance. They argue that in the mobile context, when a user is performing general tasks, perceived usefulness and perceived ease of use are emphasized, but when s(he) is playing games, perceived playfulness is important. Furthermore, when the task is transactional, perceived usefulness and perceived security are emphasized.

The mobile Internet is increasingly being used also in work-related services. The users may be of very varying ages, educational levels and technology-adaptation readiness. Their usage motivation may not always be strong, as it is often for the company's benefit – and not necessarily that of the individual worker – that the mobile service is taken into efficient usage (Väänänen-Vainio-Mattila et al., 2007).

Contexts of Use

Mobile Internet usage takes place in different places and even while on the move. The context of use influences both the user's intrinsic state and the way the system may work and can be interacted with. The design for different contexts of use should take into account not only the physical context (lighting, temperature, unstable usage positions, noise levels, etc.) and environmental factors (moving surroundings, network coverage, technology compatibility, etc.) but also the social context, i.e. people around the user and other, wirelessly connected people (Väänänen-Vainio-Mattila & Ruuska, 2000).

The context of use includes also temporal and activity-related dimensions (Maehr, 2007). The temporal context denotes how important time is for the user at that moment. The user may be highly stressed as the goal of going online is to find time-critical information such as the fastest connection to some place. In contrast, in some other situations the mobile Internet may provide entertainment to kill time. In terms of activity, the browsing may take place as a secondary task when the user's main attention is on some other primary task, e.g. walking downtown.

The context of use may change rapidly in mobile use, even in the middle of a usage session (Kaasinen, 2009). Short attention spans are typical in mobile use (Roto, 2006, p. 55), requiring good glanceability of the contents. Especially in work environments mobile Internet usage is often embedded in the context of a counterproductive superordinate chain of tasks. These tasks may interrupt the browsing session and force the user to continue it at a later time. Such incidents may be incoming calls, unexpected traffic situations or the lack of pen and paper to jot down the discovered information.

In everyday life users typically adapt themselves to widely changing usage contexts. Suri's book "Thoughtless Acts" (2005) presents a range of examples such as holding a finger in the other ear while phoning, moving to the shade to read the phone display or moving to the sides of a room to talk on the phone. The mobile Internet should support this kind of adaptation to the context.

Usage Patterns

For some users, the mobile Internet is their first and only Internet experience as they may have never accessed the Internet from a desktop computer. Other users may by default use desktop Internet but have to rely on the mobile Internet as an additional means of access when a desktop computer is not available. While in the first usage pattern the mobile Internet user experience is the standard experience, the second usage pattern introduces comparison and specific characteristics of mobile usage. This prior expectation creates a need for a positive user experience with the major advantage of mobile access coming from the mobility and flexibility of the handheld device; the user can access the full Internet anywhere at any time (Maehr, 2007).

Hinman et al. (2008) studied mobile Internet usage with eight test users who were obliged to use only the mobile Internet for four days. They found that during the trial the test users were accessing only familiar sites. With the mobile Internet a high investment of time often returned a low value of accessed content. High investment of time was related to difficulty in inputting text and bandwidth constraints. Content had a high mobile value when it addressed a special need or when information was time- or context-sensitive.

In terms of usage scenarios, two scenarios are specifically of interest (Maehr, 2007, p. 31): The first scenario is the query for information where the user looks for a specific piece of information *right now.* Often only a few information channels are available and the time pressure is high. In this scenario the user's motivation and satisfaction of success will be high but it also carries high stakes as the cost of failure is high, temptation to take any easier route is big and contextual factors are likely to be adversarial. The second scenario is the *killing-time* scenario where the user looks for entertainment or tries to complete tasks (e.g. answer an e-mail) because time is available. In this scenario the motivation for use is low and the user is likely to change to other entertainment sources or activities if problems are encountered. These two usage modes are also reported elsewhere, e.g. in Hassenzahl (2003).

Cultural Issues and Developing Countries

In developing countries the mobile phone may be the first wave of the information society. Unlike the developed world, which has experienced a rich, high bandwidth Internet with a desktop, large parts of the developing world are experiencing the Internet for the first time on a mobile phone.

Culture plays an important role in how the mobile Internet-based services are used. For example, the perception of trust is different in developed nations than in developing ones. Furthermore, in developed economies, transactions tend to be performed in a more predictable manner by both involved parties. There is often also access to better redress, such as an efficient judiciary, efficient arbitration and reliable enforcement of redress decisions in the case of failed transactions (Bajaj & Leonard, 2004). This is not the same in developing countries. Such factors will decide the acceptance and/or failure rates of mobile services especially those involving some form of financial transaction.

Adoption and use of the mobile Internet is highly dependent on the language and the literacy level in developing countries. Studies carried out in India show that the majority of the mobile phones are available in English only; however, most of the people know only basic English. Also, it was found that there was a clear dependence on younger people for any help regarding the operation and use of mobile phones (Joshi, 2006).

In developing countries, the need for and consumption of mobile Internet (or Internet-like) services also depend on the economic status of the user population. For example, small farmers worldwide have traditionally been at the mercy of middlemen and have been victims of their own lack of timely information. A private firm, Kenya Agricultural Commodities Exchange (KACE), has contracted with the African mobile provider Safaricom Limited to sell timely market information and intelligence via SMS. Although farmers who can pay for SMS services are not among the poorest of the poor, many of them aren't very much richer (Rheingold, 2005).

Lu et al. (2008) have studied the adoption of the mobile Internet in China. They point out that a strong current trend in China is Internet data services delivered via mobile phones because the wireless telecommunication infrastructure is more completely developed than its fixed-line counterpart and mobile phones are more affordable.

The design of mobile Internet-based services should be sensitive to the social, economic and cultural situations of the users. The design should address issues such as what is the 'perceived reliability' and trust in services among the target users, how much does the service cost, and are the services available in the local language or in basic English.

MOBILE SERVICES

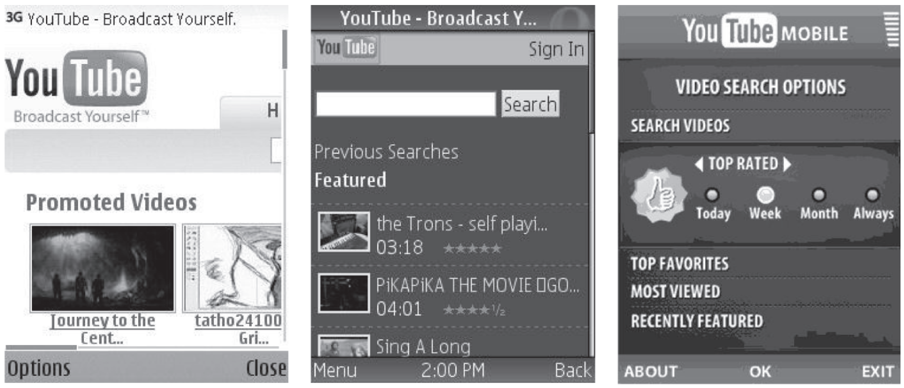
Each service provider can improve the user experience of his/her service by considering mobile users when designing the main site or by implementing a separate version of the site for mobile users. In the following we will analyze the motivations for implementing unique mobile services and give recommendations of future service possibilities based on mobile values.

Mobile Version of Existing Service vs. Unique Mobile Service

An important decision regarding the implementation of individual services is whether to provide mobile users access to the existing web service or whether to provide a separate mobile service. Services specifically designed for mobile use can take into account the limitations of the mobile devices and networks. The services can even utilize special facilities of the mobile device and contextual information such as location or tag-based information in the environment. With ordinary web content mobile user experience is not always good. The layout of the site may be too complex to be easily navigated, the site may be slow and it may include elements that do not work on the mobile device. Sites specifically designed for mobile devices can offer content that is easier and quicker to access but maintaining it may not be affordable for the service provider unless mobile usage is a significant part of the usage. Figure 3 illustrates the difference between accessing the main web site and accessing a site specially designed for mobile use.

In his recent Alertbox article, Jakob Nielsen (2009) proposes that for the best user performance, you should design different websites for each mobile device class — regular cellphones, smart-

Figure 3. Left: Mobile access to YouTube web service, Middle: mobile version of YouTube service and Right: The same service as an experimental Internet-connected application (Zuverink, 2008. Used with permission).



phones and full screen phones (iPhone). The smaller the screen, the fewer features, and a more scaled-back design is needed. Nielsen proposes as the very best option to go beyond browsing and offer a specialized downloadable mobile application for the most devoted users. In practice, however, he admits that only the biggest and richest sites can afford all this extra work on top of their desktop-optimized website.

Recommendations for Future Services

Mobile Web Best Practices by W3C (2008a) defines key guidelines to follow to provide an appropriate user experience on mobile devices. Mobile Web Application Best Practices by W3C (2009) extend the guidance to taking advantage of the capabilities of each device. These two guidelines provide practical guidance with which to design mobile Internet services, taking into account the restrictions of mobile devices and the fact that user goals for mobile use are different than those for desktop browsing (Daoust & Hazaël-Massieux, 2008). Key issues include relying on standards, taking into account device limitations, optimizing navigation, checking graphics and colors, keeping it small, using the network sparingly, helping and guiding user input as well as giving consideration to users on the go (Daoust & Hazaël-Massieux, 2008). Hinman et al. (2008) suggest designing mobile services for “skimming the surface”. They point out that valuable mobile experiences are not immersive but mobile services have to be designed with interruptions in mind. Trust becomes increasingly important as mobile services get more and more embedded in people’s personal lives (Kaasinen, 2009). The most important issue, however, is to provide value to the mobile user. The following subsections highlight some promising service possibilities based on mobile values.

From Mostly to Always Online

The change from mostly online to always online may be the biggest effect of the mobile Internet. Having a portable device that is continuously connected to the Internet enables continuous activities that may even span across different devices. This means that users may for instance start an activity such as reading e-mails or news feeds on their mobile phones on the way from work to then continue reading and answering them on their TV or desktop. In this way the mobile service extends the usage of the original service.

The always-on nature of mobile devices makes them an ideal choice for brief activities where long start-up and shutdown time is an overhead. Such activities can be checking to-do list items (i.e. grocery lists), looking up addresses and reading news and sports results. In the business world, the mobile Internet can provide fieldworkers with direct form input functionality. This facilitates reporting in-place with customers and the problem at hand, thus improving quality and productivity of work.

Context Awareness

Context awareness in mobile services has been studied a lot but actual implementations are still rare. Time and location data are relatively easily available for context-aware services, but the other relevant elements of context are more difficult to detect. Location-based services are promising in providing the user with situationally relevant and topical data (Kaasinen, 2009). Applications based on the mobility and location of the user can provide new functionalities such as pedestrian navigation systems, transport coordination or local service guides. Context recognition does not to need to be fully automatic. For example, in tag-based context recognition the user him/herself updates context information by touching contextually relevant objects in the environment (Kaasinen et al., 2006). The user may also update context data based on his/her current mode (Kaasinen, 2009). The location of the mobile device can be utilized in sampling of real-time data for better traffic reports, travel plans and other self-learning systems. Such systems would lead towards Kindbergh and Barton's (2000) Real-World Wide Web vision. Add-on services connected to a certain mobile TV programme also represent an approach to context-aware services. These services can provide the user with situationally relevant service that enhances the viewing experience (Kaasinen et al., 2008).

Internet-Connected Applications and Widgets

Access to the Internet can be embedded in mobile applications. Mobile applications can offer graphically rich, branded, and highly interactive experiences (Zuverink, 2008). As a browser is not needed, the usability of the application can be developed without browser constraints. As the main application is stored locally on the phone, the user gets access to the application immediately, even if (s)he needs to wait for the actual content from the Internet (Zuverink, 2008). Mobile applications with embedded Internet connections can utilize phone features, e.g. a finder service can give the user information about the caller of a missed call and a navigation service can utilize GPS data and search maps and other topical information from the Internet. Figure 3 illustrates how the same service (YouTube) looks when accessing the main site, the site designed for mobile use and as an experimental Internet-connected application.

Access to the mobile Internet may also take place via specialized widgets. These small mobile applications with embedded Internet access can provide quick access to timely information chunks, e.g. weather or traffic information, whereas the browser allows access to in-depth information. Glanceability of the interface facilitates utilizing the widget even when the usage session is very short. If the user needs further information, the widget can allow seamless transition to the browser (Mihalic, 2008).

From General to Personal

People would like to have and would benefit from personalized content but many studies have revealed that personalization is a major effort even in a desktop environment. In mobile contexts and with mobile devices that include many limitations regarding usability, the obstacles to personalization are even greater. Also, as typically mobile services are used only occasionally, the motivation for personalizing individual services is not very high (Kaasinen, 2009). The mobile context introduces the possibility and challenge of context-awareness: the user should be provided not only with personally relevant content but with both personally and contextually relevant content. Personalizing each individual service for different contexts of use may be overwhelming for the user. It would be beneficial to be able to use the same user profile with different services. On the other hand, location awareness as such makes access to services easier and makes the mobile Internet feel more personal (Kaasinen, 2009).

User-generated content is increasing and it is making the mobile Internet more personal. Internet and mobile communities such as Jaiku (www.jaiku.com), Facebook (www.facebook.com) and Myspace (www.myspace.com) are modern ways to communicate with close friends and others globally. Mobility is important in these as they are based on continuous connectivity to friends. Blogs and mash-ups provide new channels with which to share and express content by combining data from multiple sources into a single integrated service. These services can rely on low-effort user input (e.g. taking pictures, entering brief messages, etc.) while providing connectivity and quick entertainment. This makes them highly interesting for mobile use. This GEMS (get, enjoy, maintain, share) life cycle (Lehikoinen et al., 2007) enabled by cheap omnipresent connectivity can be the next step towards a sharing lifestyle spanning geographical distances.

From Expensive to Cheap Internet

While mobile Internet data transfer is typically far more expensive than traditional Internet access, the prices for the mobile Internet are dropping. This will broaden the market reach of the mobile Internet and also enable other devices to cheaply connect to the Internet using the mobile phone as a hub. Just as it is possible to directly download music on the mobile phone and then sync it back to a computer, the mobile Internet brings devices closer to the Internet's vast information repository. Especially for emerging markets where desktop computers are expensive, this enables cheap bi-directional communication such as e-mail, mobile blogging, electronic voting, bank access or information sharing (Maunder et al., 2007).

From Semi-Private to Private Internet

The mobile phone is for many - in contrast to the *semi-private* desktop computer - a genuinely *private* device (McGuire, 2007). It is private and is usually treated like one of the most personal items. This enables a mobile phone not only to be a personal hub that collects data (pictures, activity organizer, health records, etc.) but also to function as a key, identification token or digital wallet for booking and payment.

Novel Interaction Possibilities

Although the mobile user interface is often a constraint to service design, the development of multimodal mobile user interaction technologies may facilitate novel interaction paradigms and even new activities. The Nintendo DS gaming system (www.nintendo.com/systemsds) gives a peek into future interaction possibilities taking advantage of touch screens, accelerometers, GPS receivers and specialized sensors. These sensors can be utilized in novel types of web applications where besides positioning, sensors can be used to track, analyze and support user habits and activities. Such self-learning systems could also provide quite accurate cues about the usage context.

Work-Related Services

In addition to the consumer segment, a remarkable but perhaps an undervalued user group is the segment of work- or business-related mobile service users. Mobile services designed specifically for certain work practices may increase both productivity and satisfaction of employees, as well as advance the functioning of entire business networks. Thus work-related services should be seen as an essential part of the development of the mobile Internet. The development of mobile Internet services has introduced great potential for benefiting businesses in different fields (Alahuhta et al., 2005). For example, health care, the construction business, and logistics are fields where mobility is a crucial part of the work. Work-related services can support both white-collar (office) and blue-collar work, e.g. on construction sites, forestry and passenger transport.

In work-related situations, loss of data, mistakes in input of business information and general difficulties in interaction with the service may occur. These issues can cause intense frustration in mobile service usage for the individuals and economic losses for the user's company. Thus, context-sensitive design is required throughout the mobile business value chain to support mobile Internet service development (Väänänen-Vainio-Mattila et al., 2007).

SERVICE DISCOVERY

Easy service discovery is an important part of mobile Internet user experience as the value of the mobile Internet is in the wide selection of services rather than in any individual service (Kaasinen, 2009). A major obstacle in adopting commercial mobile services has been user unawareness of available services, as well as problems anticipated in taking services into use. Furthermore, as usage needs are typically quite occasional, people often do not have enough motivation to find out about these issues (Kaasinen, 2009). Increasing public awareness of available services as suggested by International Usability Partners (IUP, 2008) is important but technical solutions can also ease service discovery.

The following subsections suggest solutions to ease discovering mobile Internet services.

Predictable Content

When accessing Internet content users would benefit from differentiating between mobile-optimized and ordinary sites..mobi is a domain name that indicates mobile sites that are designed for small mobile devices. These domain names have been available since September 2006. In search results or as a link a.mobi link name directly indicates to the user that the site is mobile friendly. Mobile search engines may also look especially for.mobi sites. Moreover, popular sites can have mobile versions that the users can easily find just by changing the domain name (Haumont & Siren, 2007).

W3C (World Wide Web Consortium) has developed the "mobileOK" trust mark. mobileOK conformance tests (W3C, 2008b) provide the basis for making a claim of W3C® mobileOK™ Basic conformance and are based on W3C Mobile Web Best Practices. Passing these tests indicates that providers of the service have taken some steps to provide a functional user experience for users of basic mobile devices. Work on the mobileOK trust mark includes provision of machine-readable and human-readable forms of the mark, as well as discoverability of the mark (Hoschka & Smith, 2007). There are already some implementations of automatic mobileOK checkers (Daoust & Hazaël-Massieux, 2008). Once a service is mobileOK, it can be further developed by improving user experience on specific classes of devices ((Daoust & Hazaël-Massieux, 2008).

Service Portals

One approach, familiar from the early days of the mobile Internet, is to make mobile portals that provide only content targeted at mobile devices. These portals provided, e.g., by mobile operators still have an important role in the mobile Internet. Operator portals, local portals and generic portals that include thematically organized selections of services typically needed in mobile use help users to acquaint themselves with available services. Links to or offline versions of the portals can even be preinstalled on the device to ease getting started with the mobile Internet.

Mobile users may benefit from personalized context-aware portals that provide easy access to services that the individual user would need or typically uses in that context. As configuration is a major effort for the user, it is often made available on the desktop. Some mobile operators provide desktop tools that facilitate updating bookmarks on the mobile. The desktop service gives a simple snapshot of titles available for the mobile user to choose. The user can then save the ones (s)he wants to get onto his/her mobile. The configuration is automatically synchronized on the phone.

It has to be kept in mind that portals are only starting points and the users should have ways to access other sites as well. Walled gardens, i.e. portals that do not allow users access other websites, are very likely to frustrate users in the long run. Since user experience with walled gardens is poor, most walled-garden portals have already torn down the walls and let users access any web sites.

Sharing Information of Services

In addition to commercial information of services, word of mouth is also important in informing users about new services. The success of the Japanese i-mode was partially based on users sharing web links via e-mail and personal home pages (Funk, 2004). In the field study by Arter at al. (2007), users appreciated incidental, location-based information that they got in the form of local queries made by other users. Providing users with technical enablers to copy applications from each other would also be beneficial (Roto & Kaasinen, 2008).

Local Services

In mobile use, the need for local services is emphasized, for instance when visiting a strange city. In an unfamiliar environment mobile users need guidance services but find it difficult to get information on what is available, and what it costs to use those services. Tag technology provides interesting tools to ease taking local services into use by touching or pointing tags embedded in environmental objects (Kaasinen et al., 2006). Besides exploration ("what potentially interesting services are in my vicinity"), technologies such as Bluetooth messaging can be used to deliver content and services and enable proximity services (Jones, 2007).

Search Services

Search has emerged as a key enabling technology to facilitate access to information for general Internet users (White & Drucker, 2007). In the mobile world, search can also be expected to become the main means for users to discover sites and content (Escofet, 2007). Based on a large-scale study of wireless search behavior, Kamvar and Baluja (2006) approximate that inputting a search query with a mobile phone takes approximately 60 seconds. In their studies of mobile Internet use, direct links were preferred to search. Internet search providers such as Google, Yahoo or MSN already propose solutions suitable for mobile use, giving the user the possibility to search for mobile-optimized sites such as.mobi domains. Even if these search services facilitate searching only mobile websites, going through the list of results may be overwhelming in mobile use.

Church et al. (2008) have carried out an extensive study of mobile Internet search requests with searches by 260 000 individual European users. Their results point out that only 8-10% of mobile Internet users use regularly search services. Queries are short and users tend to focus on the first few search results. The vast majority of searches (over 90%) failed to attract result selections from the searcher. This is a strong indicator that people failed to find relevant information from the search results.

There is a clear need to improve mobile search services and there are actually quite a few research activities that aim to develop search technologies. Heimonen and Käki (2007) propose automatic categorization of search results to facilitate going through the results. Startups such as *kannuu* already offer search solutions that actively predict and match the most likely search selections, letting users quickly create search phrases (Communications Direct, 2007). Search can also be augmented by new techniques such as proactive notification based on needs and location (Jones, 2007). Kamvar and Baluja (2007) propose using contextual signals such as application in use, location and time to complete queries in mobile use. A local search that utilizes location data is useful in searching points of interest in a certain district or its environs. Simon and Fröhlich (2007) propose a framework for spatial selection of content based on the user's field of view.

MOBILE INTERNET DEVICES AND INFRASTRUCTURES

To give the user access to mobile services requires a mobile handset with a browser and a mobile network. The number of choices available of any one of these brings in the challenge of numerous different combinations of devices, browsers and networks. The infrastructure may also include proxies that adapt contents to different browsers and devices. Also pricing policies can be seen as part of this infrastructure. These elements of the mobile Internet infrastructure and their influence on user experience are discussed below.

Mobile Devices

When Swisscom Mobile asked mobile users how important different phone features were for them when buying a new mobile phone on a scale from 1 (not at all important) to 10 (very important), 77% of users rated mobile Internet access between 1 and 5, with a total average of 3.5 (for comparison: camera scored 5.5) (Swisscom, 2007). When purchasing a mobile device, consumers consider external attributes such as price, size, robustness or design of a mobile handset rather than Internet access. In some developing countries, the situation may be different. In South Africa, for example, the ability to go online was the second most important feature after camera when buying a mobile phone (Kreutzer, 2008)

Mobility is a fashion-driven consumer market, and unlike PCs, there are fewer drivers for technical consolidation. Consequently, leading handset vendors maintain complex customer segmentations and large device portfolios. Although many of these devices will increasingly use common platforms and web standards, there will still be large variations in all kind of features influencing the mobile Internet user experience, i.e. implementation details, display sizes, processor power, storage capacity, power consumption, navigation tools, text input interface, broadband bearers and many variants of web tools, such as browsers, media players, application viewers or positioning tools (Jones, 2007).

Mobile devices are increasingly equipped with facilities that assist in connecting the physical world to the mobile Internet. Device features such as cameras that read bar codes and preinstalled applications on phones let users get directly to online content and services (Browne, 2007). Similarly, radio frequency tags embedded in everyday objects can give access to Internet services related to the object in question (Kaasinen et al., 2006). An embedded GPS system in a mobile device facilitates services that are connected to the actual physical location of the user. However, services utilizing these new technical facilities have been suffering from 'chicken-egg' problems: because only some devices include these technical facilities, service providers are reluctant to provide services that utilize these unique features. On the other hand, as service selection is modest, users are not willing to invest in the devices and device manufactures hesitate about including the features in new devices.

Internet players such as Yahoo and Google, by providing their own devices, may take the advantage of integrating hardware and services to deliver an optimized user experience and understand the user's interests better (Jones, 2007). The Apple's iPhone has shown how successful integrated hardware and services may be.

Forrester Research suggests that a new category of consumer devices that blend the best of the PC, wireless, and web to deliver a superior mobile Internet experience is needed (Jackson, 2007). Gartner predicts that although cellular handsets will dominate through 2011, the mobile web will extend onto devices such as Ultra Mobile PCs (Jones, 2007).

Networks

In the fixed network world consumers have got used to xDSL download speeds with up to 16 Mbit/s. Where mobile networks run on GPRS technology they merely reach 56 kbit/s which not only results in a slow service but moreover is not sufficient for a lot of applications, such as streaming video. While in some rural areas EDGE (up to 384 kbit/s) might remain the maximum broadband mobile network, in regions with a higher population density there will be more and more 3G and 3.5G (HSPA) networks available with 7.2 Mbit/s downstream capability since operators are continuously adding bandwidth to enable new services. In regions where the spectrum is limited, capacity will moreover be increased with additional metro-area wireless networks, such as WiMAX (70 Mbit/s for up to 50 km distance), a further development of WLAN (Jones, 2007).

In a focus group study carried out in China and in six European countries (IUP, 2008), current users of the mobile Internet mentioned unreliable connections as well as network security as obstacles for using transaction services in China, Italy and France. Also non-users were concerned about unreliable connections and security issues. This study points out the importance of extending geographical coverage of 3G networks and improving speed and reliability of connections. Lu et al. (2008) have studied mobile Internet adoption in China. They also found data security concerns and they emphasize mobile trust as a key factor affecting user adoption of mobile services.

Apart from bandwidth aspects, mobile networks can also add to a better mobile Internet user experience by providing enabling services such as payment platforms or location information to 3rd parties.

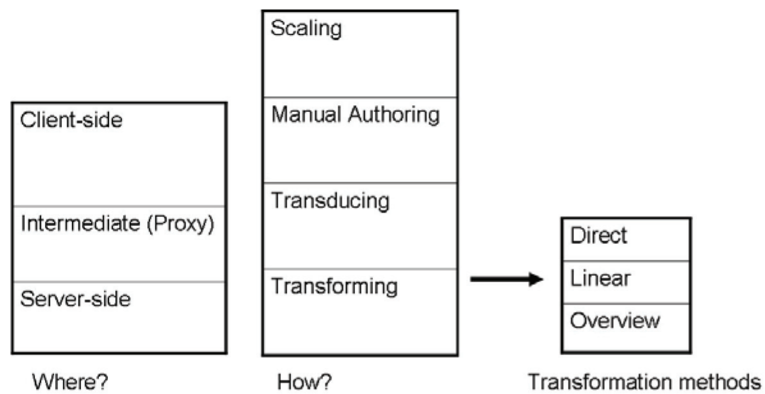
Browsers and Proxies

The number of different mobile browsers may decrease via standardization efforts but on the other hand the number of browsers may increase as the number of Internet-capable devices increases. The variety of browsers is a challenge for service providers who should provide content accessible by all the different browsers.

Quite a few mobile web browsers can access standard web content that was originally designed for large-screen viewing. The browsers adapt the content to make it more suitable for handheld access (Jones & Marsden, 2006). Adaptation can be implemented as server-side, client-side or intermediate adaptation (Laakko & Hiltunen, 2005). Algorithms used to transform the content of web pages into smaller units making it suitable for viewing on small-screen mobile devices typically fall into four categories (Schilit et al., 2002): Scaling, Manual Authoring, Transducing and Transforming. Web page transformation, whether at the site or at the browser level, can be grouped into three broad transformation categories: Direct Migration, Linear and Overview (MacKay et al., 2004) (Figure 4).

These technologies face challenges due to increasing website complexity, use of JavaScript, browser differences, lack of useful device data and failing compliance with standards (Moore,

Figure 4. Mobile adaptation techniques



2007). Each transformation technique has navigational advantages and constraints (MacKay & Watters, 2003) as well. Many current automated transformation options do not consider features such as user task, familiarly with information, web-page layout and mobility of the user, and their impact on the usability of the resultant transformed page (MacKay et al., 2004). Further research to improve these solutions and user experience will be required.

Pricing

With respect to paying for the mobile Internet, consumers want predictability, simplicity, and affordability (van Veen, 2007). When Forrester asked European regular Internet users why they did not use the mobile Internet, 55% stated that it was too expensive (Forrester Research, 2006).

In a focus group study in China and six European countries (IUP, 2008), non-users of the mobile Internet were assuming mobile Internet costs to be high, and they did not know how much they would be charged for mobile services nor the pricing policies. In this study, flat rates were of interest to many participants as they were familiar with this kind of pricing from their home and work broadband charges. Kuo and Yen (2008) suggest, based on their user studies in Taiwan, that if service tariffs cannot be reduced, service providers should develop more valuable and special services.

To improve user experience, users need to be able to understand, follow, and control the mobile Internet costs (Roto et al., 2006). Affordable usage costs should be accompanied with clear pricing structures. One option is time-based tariffs where the user pays for each minute, 15 minutes or by the hour. The interviewed Swiss customers clearly preferred such time-based tariff models to volume-based ones (van Veen, 2006). Another option is bundling a small package of mobile Internet usage with another subscription or even giving it away for free and thus letting the customer have a risk-free entry to mobile Internet usage.

CONCLUSION

The mobile Internet has great potential in providing users with personal access to topical information and services. There is still a lot to do to improve user experience of the mobile Internet, however. Service providers can improve user experience by providing services specifically designed for mobile use and even utilizing location and other contextual information in the services. To make this affordable, the service has to provide clear value for mobile users.

The motivation to use the mobile Internet may be based on the usage situation where no other alternative is available. It may also be the quickest and easiest way to access the Internet. In some cultures, the mobile Internet may become the primary means of accessing the Internet because PC penetration is low. This introduces totally different requirements for mobile services than in cultures where mobile access is an alternative to desktop web access.

User experience of the mobile Internet is affected not only by the mobile service properties but also by many infrastructure-level solutions related to wireless connections, various device types, browsers, proxies, and service discovery. Standardization efforts and guidelines are needed to support service providers in designing mobile-friendly services and in labeling those services so that users can recognize them.

The users will need more support in finding mobile Internet services. Search engines are important but for mobile use they will need improved hit rate and efficiency. Novice users would benefit from readymade service packages and portals, while expert users might appreciate context-sensitivity and personalization to help service discovery.

Mobile Internet research has mainly been carried out in the context of individual services or techniques. This paper has outlined an overview of the wide body of issues that affect user experience of the mobile Internet. The authors see this holistic view as being very beneficial for improving the mobile Internet user experience, since pleasing and engaging the user will require multidisciplinary and multicultural cooperation between the different actors in the field.

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REFERENCES

W3C. (2008a). *Mobile Web Best Practices 1.0. Basic Guidelines.* W3C Recommendation 29 July 2008. Retrieved February 28, 2009, from http://www.w3.org/TR/mobile-bp/

W3C. (2008b). *W3C mobileOK Basic Tests 1.0.* W3C Recommendation 08 December 2008. Retrieved February 28, 2009, from http://www.w3.org/TR/mobileOK-basic10-tests/

W3C. (2009). *Mobile Web Application Best Practices.* Editors' Draft 01 January 2009. Retrieved February 28, 2009, from http://www.w3.org/2005/MWI/BPWG/Group/Drafts/BestPractices-2.0/ED-mobile-bp2-20090101

Alahuhta, P., Ahola, J., & Hakala, H. (2005). *Mobilizing Business Applications – A survey about the opportunities and challenges of mobile business applications and services in Finland.* Technology Review 167/2005. Helsinki, Finland: Tekes.

Strategy Analytics. (2008, November). *Mobile Internet: Global Market Forecast.*

Arter, D., Buchanan, G., Jones, M., & Harper, R. (2007). Incidental Information and Mobile Search. In *Mobile HCI 2007 Proceedings* (pp. 129-136).

Bajaj, A., & Leonard, N. (2004). The CPT Framework: Understanding the Roles of Culture, Policy and Technology in Promoting Ecommerce Readiness. *Problems and Perspectives in Management*, *3*, 242–252.

Browne, J. (2007). *How Japanese Companies Guide Their Customers To Mobile Internet Experiences.* Forrester Research.

Chu, C., & Pan, J.-G. (2008). The forecasting of the mobile Internet in Taiwan by diffusion model. *Technological Forecasting and Social Change*, *75*, 1054–1067. doi:10.1016/j.techfore.2007.11.012

Church, K., Smyth, B., Bradley, K., & Cotter, P. (2008). A Large Scale Study of European Mobile Search Behaviour. In [ACM.]. *Proceedings of MobileHCI*, *2008*, 13–22. doi:10.1145/1409240.1409243

CommunicationsDirect. (2007). *Searching for a Better Mobile Search Solution*. Retrieved October 22, 2007, from http://www.communicationsdirectnews.com/do.php/100/27206

Comscore (2007a). *Press release.* Retrieved October 25, 2007, from http://www.comscore.com/press/release.asp? press=1432

Comscore (2007b). *Press release.* Retrieved October 25, 2007, from http://www.comscore.com/press/release.asp?press=1742

Daoust, F., & Hazaël-Massieux, D. (2008). From pages to applications: Mobile Web Best Practices. In *Mobile Internet User Experience Workshop.* Retrieved http://wiki.research.nokia.com/images/b/b6/Daoust-HazaëlMassieux.pdf

Escofet, G. (2007). SMS-based WAP push to wither away once mobile search services get their act together. *Mobile Media,* 19*(8)*.

Fang, X., Chan, S., Brzezinski, J., & Xu, S. (2006). Moderating Effects of Task Type on Wireless Technology Acceptance. *Journal of Management Information Systems*, *3*(22).

Forrester Research. (2006). [ECTAS]. *European Consumer Technology Adoption Study*, *Q4*, 2006.

Funk, J. L. (2004). *Mobile disruption. The technologies and applications driving the mobile Internet.* Wiley-Interscience.

Hassenzahl, M. (2003). The Thing and I: Understanding the Relationship Between User and Product. In M. A. Blythe, K. Overbeeke, A. F. Monk & P. C. Wright (Eds.), *Funology: From usability to user enjoyment*. Kluwer Academic Publishers.

Hassenzahl, M., & Tractinsky, N. (2006). User Experience – a Research Agenda. *Behaviour & Information Technology*, *2*(25), 91–97. doi:10.1080/01449290500330331

Haumont, S., & Siren, R. (2007). dotMobi, a Key Enabler for the Mobile Internet. In *Mobile Internet User Experience Workshop.* Retrieved http://research.nokia.com/events/miux.html

Heimonen, T., & Käki, M. (2007). Mobile Findex – Supporting Mobile Web Search with Automatic Result Categories. In *Mobile HCI 2007 Proceedings* (pp. 113-120).

Hinman, R., Spasojevic, M., & Isomursu, P. (2008). They Call It "Surfing" for a Reason: Identifying mobile Internet needs through PC deprivation. In *CHI 2008 Proceedings. Case Studies* (pp. 2195-2207).

Hoschka, P., & Smith, M. (2007). Best Practices: Making Mobile Browsing Better. In *Mobile Internet User Experience Workshop*. http://research.nokia.com/events/miux.html

Insight, I. (2006). *Mobile Phones Could Soon Rival the PC As World's Dominant Internet Platform*. In The Face of the Web. http://www.ipsos-na.com/news/pressrelease.cfm?id=3049

IUP - International Usability Partners. (2008). *IUP Mobile Transactions Report – 2008.*http://www.amber-light.co.uk/iup/IUP-MobileTransactionsReport.ppt

Jackson, P. (2007). *Defining Mobile Internet Devices*. Forrester Research.

Jones, M., & Marsden, G. (2006). *Mobile Interaction Design*. England: John Wiley and Sons Ltd.

Jones, N. (2007). *Mobile Web Trends 2007 to 2011. Gartner ID Number: G00148175*. Gartner Research.

Joshi, D. (2006). *Mobility as an extension of Man.* Post Graduate Dissertation, National Institute of Design / Motorola India Research Labs, India.

Kaasinen, E. (2005). *User acceptance of mobile services - value, ease of use, trust and ease of adoption.* Doctoral dissertation. Finland: VTT Publications 566. http://www.vtt.fi/inf/pdf/publications/2005/P566.pdf

Kaasinen, E. (2009). User Acceptance of Mobile Services. *International Journal of Mobile Human Computer Interaction*, *1*(1), 79–97.

Kaasinen, E., Ermolov, V., Niemelä, M., Tuomisto, T., & Välkkynen, P. (2006). Identifying User Requirements for a Mobile Terminal Centric Ubiquitous Computing Architecture. In *Proceedings of FUMCA 2006: System Support for Future Mobile Computing Applications*. Retrieved http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4021039

Kaasinen, E., Kivinen, T., Kulju, M., Lindroos, L., Oksman, V., Kronlund, J., & Uronen, M. (2008). *User Acceptance of Mobile TV Services- Finpilot2 Final report.* Helsinki, Finland: Forum Virium Helsinki. www.finnishmobiletv.com/finpilot2

Kamvar, M., & Baluja, S. (2007). The Role of context in Query Input: Using contextual signals to complete queries on mobile devices. In *Mobile HCI 2007 Proceedings* (pp. 121-128).

Kamvar, M., & Baluja, S. A. (2006). Large Scale Study of Wireless Search Behaviour: Google Mobile Search. In *CHI 2006 Proceeding.* (pp. 701-709).

Kindberg, T., & Barton, J. (2000). Towards a real-world wide web. In *Proceedings of the 9th Workshop on ACM SIGOPS European Workshop* (pp. 195-200). ACM Press. http://doi.acm.org/10.1145/566726.566766

Koivumäki, T., Ristola, A., & Kesti, M. (2008). The perceptions towards mobile services: an empirical analysis of the role of use facilitators. *Personal and Ubiquitous Computing*, *12*, 67–75. doi:10.1007/s00779-006-0128-x

Kreutzer, T. (2008, July). Assessing Cell Phone Usage in a South African Township School. In *Proceedings of e/merge 2008 conference.*

Kuo, Y.-f., & Yen, S.-N. (2008). Towards an understanding of the behavioural intention to use 3G mobile value-added services. *Computers in Human Behavior*, *1*(25), 103–110.

Laakko, T., & Hiltunen, T. (2005). Adapting Web Content to Mobile User Agents. *IEEE Internet Computing*, *2*(9), 46–53. doi:10.1109/MIC.2005.29

Lee, I., Choi, B., Kim, J., & Hong, S.-J. (2007). Culture-Technology Fit: Effects of Cultural Characteristics on the Post-Adoption Beliefs of Mobile Internet Users. *International Journal of Electronic Commerce*, *4*(11), 11–51. doi:10.2753/JEC1086-4415110401

Lehikoinen, J., Salminen, I., & Aaltonen, A. (2007). *Personal Content Experience, Managing Digital Life in the Mobile Age.* Wiley-Interscience.

López-Nicolás, C., Molina-Castello, F. J., & Bouwman, H. (2008). An assessment of advanced mobile services acceptance: Contributions from TAM and diffusion theory models. *Information & Management*, *45*, 359–364. doi:10.1016/j.im.2008.05.001

Lu, J., Liu, C., Yu, C.-S., & Wang, K. (2008). Determinants of accepting wireless mobile data services in China. *Information & Management*, *45*, 52–64. doi:10.1016/j.im.2007.11.002

MacKay, B., & Watters, C. (2003). The Impact of Migration of Data to Small Screens on Navigation. *IT&Society*, *3*(1), 90–101.

MacKay, B., Watters, C., & Duffy, J. (2004). Web Page Transformation When Switching Devices. In *Proceedings Mobile HCI'04* (pp. 228-239). LNCS, vol. 3160.

Maehr, W. (2007). *User Experience of the Mobile Internet*. Unpublished master thesis, Chalmers TH, Gothenburg, Sweden. www.t2i.se.

Maunder, A., Marsen, G., & Harper, R. (2007). Creating and Sharing Multi-media Packages Using Large Situated Public Displays and Mobile Phones. In *Proceedings of the MobileHCI 2007 Conference* (pp. 188-191). ACM Press.

McGuire, R. (2007). *On Kelly Goto's Gotomobile*. http://www.gotomobile.com/archives/mobile-20-fireside-chat

Mihalic, K. (2008). Widgetization of Mobile Internet Experience. In *Mobile Internet User Experience Workshop, 2008.*http://wiki.research.nokia.com/images/7/71/Mihalic.pdf

Moore, E. (2007). *Content Transformation* [OpenWave]. Retrieved October 22, 2007, from http://mobilemonday.org.uk/ [accessed 2007, 10/22]

Nielsen, J. (2009). Alertbot February 17, 2009. Mobile Web 2009 = Desktop Web 1998. http://www.useit.com/alertbox/mobile-usability.html

Rheingold, H. (2005). *Farmers, Phones and Markets: Mobile Technology In Rural Development*. Retrieved October 24, 2007 from http://www.thefeaturearchives.com/topic/ Technology/Farmers__Phones_and_Markets__Mobile_Technology_In_Rural_Development.html

Roto, V. (2006). *Web Browsing on Mobile Phones - Characteristics of User Experience.* Doctoral dissertation, TKK Dissertations 49, Helsinki University of Technology, Finland. http://research.nokia.com/people/virpi_roto/ dissertation.html

Roto, V., Geisler, R., Kaikkonen, A., Popescu, A., & Vartiainen, E. (2006). Data Traffic Costs and Mobile Browsing User Experience. In *MobEA IV workshop on Empowering the Mobile Web*.

Roto, V., & Kaasinen, E. (2007). *Workshop on Mobile Internet User Experience.* Retrieved February 24, 2009, from http://wiki.research.nokia.com/index.php/MobileInternetUX-2007.

Roto, V., & Kaasinen, E. (2008). *2nd International Workshop on Mobile Internet User eXperience (MIUX'08).* Retrieved February 24, 2009, from http://wiki.research.nokia.com/index.php/MobileInternetUX-2008.

Schilit, B., Trevor, J., Hilbert, D., Res, I., & Seattle, W. (2002). Web interaction using very small Internet devices. *Computer*, *10*(35), 37–45. doi:10.1109/MC.2002.1039516

Simon, R., & Fröhlich, P. A. (2007). Mobile Application Framework for the Geospatial Web. In *Proceedings WWW2007* (pp. 381-389).

Suri, J. F. (2005, November). *Thoughtless Acts.* San Francisco, USA: Chronicle Books.

Swisscom. (2007). *Mobile market research, December 2007.*

Väänänen-Vainio-Mattila, K., Oksman, V., & Vainio, T. (2007). Exploring the User Experience Factors in Designing Successful Mobile Internet Services for Business Use. In *Mobile Internet User Experience Workshop, 2007.*http://research.nokia.com/events/miux.html

Väänänen-Vainio-Mattila, K., & Ruuska, S. (2000). Designing Mobile Phones and Communicators for Consumers' Needs at Nokia. In E. Bergman (Ed.), *Information Appliances and Beyond: Interaction Design for Consumer Products* (pp. 169-204). Morgan Kaufmann.

van Veen, N. (2006). *Breaking The Mobile Internet's Low Adoption Spell*. Forrester Research.

van Veen, N. (2007). *Mobile Internet Pricing Strategies Mature.* Forrester Research.

White, R. W., & Drucker, S. M. (2007). Investigating Behavioral Variability in Web Search. In *Proceedings WWW2007* (pp. 21-30).

Zuverink, D. (2008). Beyond Browsers: Taking Mobile Applications Online. In *Mobile Internet User Experience Workshop, 2008.*http://wiki.research.nokia.com/images/9/92/Zuverink.pdf

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Chapter 12
How People Really Use the Mobile Web:
A Framework for Understanding Motivations, Behaviors, and Contexts

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ABSTRACT

Mobile data services offer a viable and growing alternative means of accessing the World Wide Web and have drawn significant attention from the mobile industry. However, design efforts are hampered by the fact that we do not fully understand people's motivations, behaviors, and contexts of use when they access the Web on their phones in naturalistic settings. To help address this need, the authors conducted a study to explore the following questions for U.S. mobile phone users: (1) What motivations lead people to access the Web on their mobile phones?;(2) What do they do?; and (3) Where do they do it? We studied active U.S. mobile Web users via questionnaires, semi-structured interviews, and a field diary system that participants used to record their daily Web activities. Based on the findings from Part One of the study, they constructed a taxonomy of behaviors, motivations, and contexts associated with mobile Web usage. In Parts Two and Three, the authors validated the taxonomy as well as compared iPhone versus non-iPhone user behaviors. The authors conclude this report of the three-part study by considering the design implications of their findings and future research directions for further understanding the mobile Web.

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INTRODUCTION

Why, and in what settings, do people access the Web on mobile phones? What Web information do people access and how do they make use of that information? Understanding the answer to these questions is important for understanding how mobile Web services can be made more useful and accessible in people's daily lives. According to Morgan Stanley ("Mobile Internet Report," 2009), mobile Internet devices are predicted to reach 10 billion units by the end of 2010. This creates tremendous opportunity for carriers to offset the decline in voice service revenues with new Web-enabled services. The mobile design and development community would benefit from a better understanding of the underlying motivations and patterns of current mobile Web usage to help them target key user needs and desires for future mobile services.

Past research on mobile Web usage has focused mainly on characterizing behaviors, settings, and types of content accessed. This study looks at *motivations* as well—*why* people access the Web on their mobile phones. In a review of recent research we found most still focused on adoption factors and information needs and very little on underlying motivations that might predict future use of mobile Web services in a naturalistic setting.

For our study, we defined the mobile Web strictly as access to Web information available through either a carrier's portal or a Web site accessible via a palm-sized mobile device. Using an augmented diary-study approach, the study first derived (Taylor et al., 2008) and subsequently validated (Taylor, Samuels, & Ramey, 2009) a behavioral, motivational, and contextual framework for understanding mobile Web use.

RESEARCH BACKGROUND

This study builds on and extends earlier research studies that have yielded classifications of Web usage (both stationary and mobile), descriptions of patterns of adoption of mobile services, as well as motivations for mobile technology use. Also, in designing this study, we took into account recent work on methods for studying mobile usage.

Usage Classifications

Several studies (before our research and since) have yielded classification schemes that characterize usage of the Web and/or mobile phones, most with a focus on information needs and behaviors. Heimonen (2009) examined the physical and situational contexts of users' mobile information needs and the information access practices used to fulfill them to develop a classification of 15 topical mobile information need categories. The largest was *trivia* (26.5% of entries), followed by *work/studies/hobbies* (15.6%), and then *public transportation* (12.2%). The top mobile information needs they identified were consistent with our top behavioral classifications of Fact Checking, Information Gathering, and Action Support. They also discovered correlations between types of information need and the access method.

Church and Smyth (2008) reported a study of mobile information needs that categorized user intent as regarding information, geographical data (local explicit, local implicit, and directions), and management of personal information; the conclusion stresses the importance of the geographical and temporal context of mobile information needs. In a subsequent diary study of mobile information needs, Church and Smyth (2009) examined the intent behind those needs and how those needs change based on context, focusing on browsing versus search behavior. The study compared users' needs at home, at work, and on-the-go and found the clearest time and location dependencies among on-the-go users. Nearly half (42%) of the activities pertained to geographical or personal time management information, with local services and travel and commuting ranking highest (>44%). Their findings also suggest that traditional

Web navigation taxonomies are ill suited to the mobile context.

Sohn, Li, Griswold, and Hollan (2008) also explored mobile informational needs and how they were addressed. Of special interest here, they asked how (if at all) the mobile Web changed informational needs and behavior. They found that, in using the mobile Web, people were better able to meet their informational needs by themselves, and used somewhat clever strategies to do so, but ultimately felt that the mobile Web was not sufficient for meeting their informational needs.

Dearman, Kellar, and Truong (2008) looked more broadly at general information needs and found that people often have highly context-sensitive information needs that require assistance from individuals in their social network. Through a diary study, they categorized all information needs into nine primary categories: Persons, Establishments and Organizations, Offerings, Events, Environmental Conditions, Trivia and Pop Culture, Finding, Availability, and Guidance. Often people's social network is not broad enough to include the right people in the right situations or circumstances who can satisfy context-sensitive information needs in a timely manner. The mobile information channel might help offset those gaps.

Chigona, Kankwenda, and Manjoo (2008) enlist the uses and gratifications (U&G) framework to understand the motivations and extract the intrinsic needs of mobile phone users in South Africa; they derive three categories of motivations: Content, Process, and Social. The study found the U&G's of the mobile internet are an intersection of the U&G's of the mobile phone and traditional Internet.

Kellar, Watters, and Inkpen (2007), identified six information tasks in *non-mobile* Web-based activities: browsing, communications, fact finding, information gathering, maintenance, and transactions. Our results support refining and extending this basic scheme to describe *mobile* Web usage, and can be compared to the findings of Cui and Roto (2008). Based on a large multi-method study, Cui and Roto constructed a taxonomy of mobile Web use focused on "activities." In their taxonomy, which also builds on Kellar et al. and other earlier work, they posit four main categories of activity: information seeking (for knowledge or entertainment), communication, transactions, and personal space extension. *Information seeking* includes fact-finding, information gathering (not common in their study), and casual browsing. *Communication* includes e-mail (in which they saw primarily monitoring rather than sending or replying) and activity in online communities. In *transactions*, they saw a small amount of activity but found most of it postponed for stationary Web or phone use. Finally, *personal space extension* entailed maintaining content objects online for personal access.

They identify four contextual factors: spatial, temporal, social, and access. Concerning the spatial factor, they found (as we did) that the mobile Web was also used from stationary sites (for example, at home, instead of using an available home computer). Regarding the temporal factor, they also found that mobile use was tucked into free moments in the day (the "micro-break"). Concerning the social factor, their findings agree with ours that mobile Web use occurs both when people are alone and when they are with a group. Our study differs in that it distinguishes between motivations and behaviors in activities, and does not specifically address e-mail behavior, but their findings are largely consistent with ours.

Studies of Adoption

Wang and Wang (2010) defined a model for user acceptance of mobile Internet based on the Unified Theory of Acceptance and Use of Technology. The study identified the primary adoption factors: Performance Expectancy, Effort Expectancy, Social Influence, Perceived Playfulness, Perceived Value, Palm Sized Computer Self-efficacy. The most significant areas of friction impeding mobile Internet adoption were performance expectancy (how well does it meet users needs), effort expectancy (how much effort users thought would be required to learn it), and social influence (from users' friends and colleagues).

Kaikkonen (2008) looked at the question of the use of full Web sites versus sites tailored for use in the mobile environment between Asia and the U.S./Europe. She found that the Asian use of the mobile Web could be characterized as "mass market," whereas the U.S. and Europe werestill early adopters, which leads to different usage patterns. Asian users often used tailored operator portals, whereas European and American users were more likely to use full Web sites and new gadgets. But in general, her findings about contexts and patterns of use are consistent with those found in the study reported here. Schmiedl, Seidl, and Temper (2009) confirmed Kaikkonen's findings that some user populations benefit from more mobile-tailored information and sites. Their findings showed that users prefer and effectively do benefit from mobile optimized versions. However, content providers sometimes do not understand the mobile scenarios in which their sites are used and consequently begin optimizing the functionality at the wrong end.

In Japan, Ishii and Mikami (2002) examined a number of factors influencing mobile Web adoption: the setting of Web use (home, at work, on the street); differences in the types and number of sites accessed; and preferences for where to access different types of content (lifestyle versus business). The study found that people reported an increased level of sociability from Web use on mobile phones compared with degrees of sociability reported in previous studies of the stationary Web.

Kim, Kim, Lee, Chae, and Choi (2002) also examined personal contexts (standing/moving/sitting) versus environmental contexts (alone/with people) and high versus low emotions, and found that people used the mobile Web most frequently when happy and when they were in a calm and quiet environment. Another Korean study (Chae & Kim, 2003) focusing on the commercial implications of Web usage found that the mobile Web was associated with low-risk commercial activity, synchronous (real time) communications, low-intensity information, and less resource-intensive applications. The stationary Web was associated with higher-risk commercial activity, asynchronous communication (for example, e-mail) high-intensity information (for example, online games), and more processor-intensive applications. Our findings also support this distinction.

Motivations for Using Mobile Technology

Mobile applications are becoming increasingly Web-enabled, blurring the distinction between mobile Internet and mobile application usage. Ho and Syu (2010) developed a classification of motivations for mobile application use: entertainment, instrumentality, informativity, sociability, mentality, trendiness and learning. The study found users had a higher level of motive gratification with entertainment oriented applications, and a lower level for learning, instrumentality and informativity applications, where developers would benefit from a deeper understanding of user requirements.

Kim et al. (2002) divided mobile Web use into the categories *hedonic* (related to pleasure) and *utilitarian* (related to doing tasks), a distinction that our findings support. Hassenzahl (2006) conducts an extensive analysis of the concepts of *hedonic* and *utilitarian* usage that traces their evolution in the literature and usefully elaborates the nuances of meaning subsumed by the terms.

A longitudinal study of novice users of a new mobile communication device found that people's motivations for using mobile communication technology are initially influenced more strongly by their perceptions about the expected use, which is more task-oriented (Peters & Allouch, 2004). Over time, due to quick habituation to the new mobile communication device, important initial gratifications, like permanent access and social interaction, become more latent, while gratifications like fashion/status and entertainment become more dominant.

Method for Studying Mobile Usage

Studies that have relied only on statistical analysis of Web usage data to understand the unique behavioral characteristics of mobile Web use have not fully examined the complex contexts and underlying motivations influencing mobile use. We concluded that, to gain a more complete picture of real-life use, we needed to examine people who have been actively using Web-based data services for a period of time and we needed to study their use of their own personal mobile phones.

Mobile voice-mail diary studies have proven to be a successful method of capturing richer contextual information in mobile settings (Hagen, Robertson, Kan, & Sadler, 2005; Palen & Salzman, 2007). Many earlier studies have also used (as we did) one form or another of the method of the combined diary study and interview and/or survey (for instance, Nylander, Lundquist, & Brännström, 2009; Church & Smyth, 2009; Heimonen, 2009; Sohn et al., 2008; and Kellar et al., 2007). Other important earlier work (which was summarized and extended in Kahn, Markopoulos, Eggen, IJsselsteijn, & deRuyter, 2008) has focused on technologies to support experience-sampling methods like diary studies. We drew on an interesting data-capturing technique dubbed "snippets" that was employed to aid self-reporting by respondents in one study. Users were offered multiple media options for recording data and the researchers identified strengths and weaknesses of different types of reporting (Brandt, Weiss, & Klemmer, 2007). They also identified possible "trivial" data that could be captured in the data-gathering stage and that might easily be missed using other methods, but which could potentially inform the interview stage in a study. This study influenced our decision to use a diary system where users immediately recorded, via voicemail (in study Part One) or a mobile Web-based survey (in study Part Two), brief snapshots of their sessions of use for closer examination later during in-person interviews.

Our method was also informed by a qualitative study about the viewing of video content on a broad range of portable devices (Palen & Salzman, 2007). This study demonstrates how diary studies can be combined with ethnographic interviews to achieve a richer understanding of the motivations for mobile use.

THE STUDY

The following research questions motivated this three-part qualitative study:

1. **Part One of the study:** What motivations lead people to access the Web on their mobile phones? What do they do? And where do they do it?
2. **Parts Two and Three:** Is the framework of motivations, contexts of use, and behaviors identified in the earlier study valid for a new set of users and a later stage of mobile Web evolution?

Study Part One

Our original study, conducted in the summer of 2007, tracked 11 active U.S. mobile Web users (usage of at least twice a day for at least 3 months) from the greater Seattle area who had actively incorporated the mobile Web into their personal (rather than business) lives using a variety of their own personal phones. Participants included an approximately equal number of males/females, 18-24/25-34 year olds, and smart phone/regular phone users from the four major U.S. carriers (to mitigate any differences between carriers' mobile Web portal experiences). Over a five-day period, participants recorded brief voicemail messages describing their Web access sessions immediately

Table 1. Motivational classifications

Utilitarian	Hedonic
1. Awareness	3. Curiosity
2. Time Management	4. Diversion
	5. Social Connection
	6. Social Avoidance

after each use, and then at the end of the five-day period took part in an individual semi-structured 90-minute retrospective interview based on the content of their own voicemails and on general usage-related questions.

For our initial data analysis we used the constant comparison methodology from Glaser's grounded theory of qualitative analysis (Glaser, 1965). A team of six researchers each analyzed data from a subset of participants. The team then collectively devised the classification scheme based on the motivations and behaviors observed from the voicemail entries and interview sessions, coded their participant's data using the agreed upon scheme, conducted a cross comparison with two other researchers' data sets, and collectively revised the scheme. We conducted eight rounds of cross comparison and concurrently made revisions to the scheme and coding to arrive at 100% agreement amongst the researchers.

Preliminary Findings, Part One

This work conducted in Part One yielded the classification scheme for motivations, behaviors, and contexts described below.

Classification of Motivational Data

For motivations, we divided Kim's broad characterization of utilitarian and hedonic (Kim et al., 2002) into finer classifications to accommodate the complex patterns of motivation we observed.

Motivation 1. Awareness: Desire to stay current, to keep oneself informed in general. Examples: scanning for new e-mail and checking news sites.

Motivation 2. Time Management: The desire to be efficient, manage projects, or get things done. Examples: looking up an address; checking traffic maps; looking for supplies/ jobs/ roommates; getting class assignments.

Motivation 3. Curiosity: The interest in an unfamiliar topic, often based on a tip or chance encounter. Examples: looking up information about a country of interest; looking up information to settle a friendly bet in a bar.

Motivation 4. Diversion: The desire to kill time or alleviate boredom. Examples: browsing favorite sites; checking social networking sites.

Motivation 5. Social Connection: The desire to engage with other people. Examples: arranging to get together; sending e-mail; posting to social networking sites.

Motivation 6. Social Avoidance: The desire to separate oneself from others, to appear occupied so as not to be bothered. Examples: using cell phone activity as a "cover" to prevent others from striking up a conversation.

Classification of Behavioral Data

The classification of behaviors adapted several stationary-Web information-monitoring categories from Kellar et al. (2007) to describe the mobile behaviors that we observed: Information Seeking (fact finding, info gathering, and browsing); and Information Exchange (transaction, communication). In addition, we added Status Checking as an Information Seeking behavior and created a new category, Action Support, with the two subdivisions of Planning and In-the-Moment.

Behavior 1. Status Checking: Checking a specific piece of non-static information. Examples: weather; news; sports scores (during a game).

Table 2. Behavioral classifications

Info Seeking	Action Support (AS)
1. Status Checking	5. In-the-Moment
2. Browsing	6. Planning
3. Information Gathering	**Info Exchange**
4. Fact Checking	7. Transaction
	8. Communication

Behavior 2. Browsing: Trolling for new information of interest without any apparent goal. Example: following site links selected on the fly.

Behavior 3. Information Gathering: Looking up information about a given general topic. Examples: searching multiple sources about a band; seeking information for the common interests of a social group.

Behavior 4. Fact Checking: Checking or validating a specific piece of static information. Examples: who starred in a movie; the definition of a word; sports scores (after the game is over).

Behavior 5. Action Support/In-the-Moment: Seeking information to aid the immediate course of action. Examples: checking to see the movies/times while walking to the local theater; looking up the driving directions for a business to run the next errand.

Behavior 6. Action Support/Planning: Seeking information to aid events beyond the immediate course of action. Examples: picking a movie to attend tomorrow night; checking the weather for a weekend trip.

Behavior 7. Transaction: Exchanging information with another person or an institution to conduct an exchange of financial resources, goods, or services. Examples: an e-commerce purchase or bank transfer.

Behavior 8. Communication: Engaging in a two-way sharing of information with another person or group. Examples: communicating through e-mail; using social networking sites to respond to others' posts; posting a picture/text to be shared.

Classification of Physical Contexts of Use

We found, based on Part-One data, that participants used the mobile Web in ten distinct physical settings (in order of reported frequency):

Context 1. On Transit: While waiting for transit (examples: a bus or taxi, or during the bus or taxi trip).

Context 2. Walking: Walking with the phone in hand, simultaneously accessing the Web.

Context 3. At Work: During the workday, either while on break in a separate break area or while at the desk or other worksite.

Context 4. Service Facility: In restaurants, cafes, bars, or fast-food outlets, sometimes while in line to order and sometimes after being served; in nail or hair salons or other personal-services facilities, during gaps in the activity.

Context 5. Store: In a store (example: a grocery or retail store), sometimes while waiting and sometimes in support of the task at hand (example: checking on the ingredients needed to prepare a specific recipe).

Context 6. Recreation Site: At recreation sites (example: bowling alley or ball park).

Context 7. At Home: At the participant's own home, even when he/she was located close to a desktop computer.

Context 8. Other's Home: While a visitor at someone else's home. We saw three different scenarios: all members of the group present were pursuing separate activities; all members of the group were interacting together (example: sharing pictures); or the phone user was accessing the Web separate from a group activity (example: at a family dinner).

Context 9. Car Driver: Reported both for situations when the car was stopped and when the car was actually moving. For the moving-car context, use was often described as interleaved with driving rather than simultaneous (example: at one point, entering a URL, then at a later point, looking at the result).

Context 10. Car Passenger: Passenger use might be collaborative with the driver (example: looking up the address for the current destination) or might be unrelated.

Study Parts Two and Three

In the spring of 2008, we conducted Parts Two and Three of the overall work. In Parts Two and Three, we addressed the same research questions as before, but with the goal of assessing the robustness of the taxonomy in describing the motivations, behaviors, and contexts of mobile Web use for a second similar group a year later (and after the introduction of the iPhone).

In Part Two, a second in-depth field study, we modified the participants' reporting format in line with the goal of validating the classifications; we asked participants to select from a fixed set of categories via a questionnaire rather than giving us free descriptions. We tracked 13 users (6 iPhone and 7 non-iPhone users), ages 18-34, from the greater Seattle area over a week's time. iPhone users were all with ATT; non-iPhone users represented all four major US carriers and included a range of manufacturers and styles, with a majority consisting of smart phones (with a full or partial keyboard). Immediately following each mobile Web use, participants filled out a short mobile Web-based survey, based on the framework previously developed, to self-identify the motivation, context, and behavior for that use. For each response, they also had an "Other; please specify" option. We then conducted 90-minute retrospective interviews with each participant to review their overall patterns of use.

Part Three of the study, a PC-based Web survey, was used to further determine whether there were any gaps in our coding scheme. The 167 respondents were all active mobile Web users (45 iPhone and 122 non-iPhone users) who accessed the Web over their phones at least twice a day. Participants were asked to read brief descriptions of each classification and select their top motivation, context of use, and behavior for Web use. If they felt that the descriptions we provided did not match their experience, they were asked to add a category via an "other—please specify" response.

OVERALL FINDINGS

In this section, we first present the findings with respect to the validation of the preliminary scheme proposed in Part One for the classification of motivations and behaviors. We then discuss the findings with respect to context of use and propose a modification of the original schema. Finally, we compare the findings for non-iPhone users and iPhone users.

Coding Scheme Validation

In examining the data from Part Two (the second field study), we found that the taxonomy derived in Part One for motivations and behaviors robustly accommodated the self-reported motivations and behaviors. Of the 177 reported instances of mobile Web use in Part Two, there were 20 reported "other" motivations, of which 13 had sufficient contextual data from the interviews to be classified into an existing category (leaving 7 unclassified or 4%). Of those motivations that were not classified, participants reported general activities like as visiting Web sites (for example, *"I clicked on a Web link someone sent me"*) but did not include sufficient detail to recall the specific Web destination or motivation for visiting it. There were 15 reported "other" behaviors, of which 12 had sufficient contextual data from the interviews to be classified into an existing category (leaving 3 unclassified or 2%). Of those behaviors that were not classified, participants report sufficient detail to identify their motivation (such as, *"fooling around to kill time"*) but did not provide sufficient detail to identify the specific behavior exhibited by that motivation. For the participants in the second field study, the motivation/behavior framework was at least 96% accurate.

In examining the data from Part Three, we found similar results for motivations and behaviors. There were only 4 instances of "other" motivations (3%) and 6 instances of "other" behaviors (4%). As in Part Two, the "other" instances that could not be classified were primarily due to lack of sufficient detail reported by the participants to determine the specific context. Thus, for the survey respondents, the motivation/behavior framework was at least 96% accurate. Thus we found the framework sufficiently well defined to cover the vast majority of mobile Web motivations and behaviors currently exhibited by active U.S. mobile users.

Modifications to Context Schema

Based on the data analysis conducted for Parts Two and Three, we identified the need to modify the contextual classification to improve the overall accuracy of the framework.

In Part Two, participants reported a total of 134 locations in which they accessed the mobile Web. Note that the survey instrument that participants used to track their instances of use allowed for reporting more than one activity per location, so the number of instances of motivations and behaviors (177) was higher than the number of reported locations (134). In addition, an error occurred in some survey pathways where users were not able to select the applicable location from a pre-set list and had to choose "other" and specify a location. This resulted in a higher instance of reported "other" locations. However, the additional descriptions participants provided, combined with the additional detail gathered through in-person interviews, allowed us to accurately identify instances where "other" locations could be classified into existing location categories. Out of 134 instances of reported locations, there were 33 reported as "other," of which 20 could not be reclassified into an existing category based on contextual data from the interviews. Of those, 7 reported a new location of Gym and 6 reported a new location of School (leaving 7 unclassified or 5%). Examples of locations that did not fit into the original classification scheme or occur often enough to warrant a new category included "library" and "church." In addition, several instances did not include sufficient detail to identify a physical location for the setting including "at a meeting" and "at a job interview."

Of the 167 responses in Part Three, there were 22 reported instances of "other" locations (13%). We found 17 of those "others" commented that they accessed the mobile Web "everywhere." We omitted those instances because they were too general to be meaningful, leaving 5 "others" (3%) that all self-identified their location as "school."

Therefore, based on the findings from Parts Two and Three, we added the two new location categories (see Table 3) of "School" and "Gym" for physical settings, defined as follows:

Context 11. At School: While in a classroom setting or on a school campus.

Context 12. Gym: While at a physical fitness facility.

These additions make the contextual framework at least 95% accurate.

iPhone Motivations, Behaviors, and Contexts of Use

We applied the framework to understanding whether a specific device experience made a difference in how people used the mobile Web. In

Table 3. Re-classifications of physical settings

1. On Transit	6. Recreation Site
2. Walking	8. Other's Home
3. At Work	9. Car Driver
4. Service Facility	10. Car Passenger
5. Store	11. At School
7. Home	12. Gym

the Part-Three PC-based Web survey, 45 iPhone and 122 non-iPhone mobile Web users identified their primary motivation, context of use, and behavior for mobile Web use. Non-iPhone users had a broad range of both feature and smart phones from multiple U.S. operators and handset manufacturers including Samsung, Motorola, Sanyo, Sony, Nokia, Kyocera, LG, HTC, Palm/Treo, and RIM/Blackberry. The responses they could select from corresponded to our coding scheme items using shortened descriptions. They also could choose "other" as a response and specify additional details.

Motivations

In terms of top motivations, iPhone users were more likely to report Diversion (27% versus 11%) and non-iPhone users were somewhat more likely to report Time Management (18% versus 11%) or Social Connection (11% versus 4%) (as shown in Table 4). However, we found no significant difference in reported motivations between groups ($x^2(5, n=167) = 8.3, p=0.14$).

Behaviors

In terms of top behaviors, iPhone users were somewhat more likely to report Action Support/In-the-Moment (24% versus 11%) and non-iPhone users were more likely to report Communicate (11% versus 4%) (see Table 5). However, we found no significant difference in reported behaviors between groups ($x^2(5, n=167) = 6.6, p=0.25$).

Context and Frequency

While non-iPhone users were twice as likely to report the context of Home (23% versus 11%), and iPhone users somewhat more likely to report Transit (24% versus 20%) there was no significant difference in reported context between groups ($x^2(5, n=167) = 6.7, p=0.76$).

iPhone users reported accessing the mobile Web more often than non-iPhone users (56% versus 37% > 6 times daily; 19% versus 28% 4-6 times daily; 20% versus 32% 2-3 times daily). Overall there was not a significant difference in reported frequency between groups ($x^2(5, n=167) = 4.7, p=0.95$).

Although in this part of the study we looked only at the primary motivation, behavior, and location, and at frequency of use, on these points the differences between the two groups did not prove to be significant.

DISCUSSION OF OVERALL FINDINGS

We found a number of relationships between motivations and behaviors and between motivations and context. We also observed patterns of use that can be characterized more broadly: the "ritual" of

Table 4. iPhone vs. non-iPhone motivations

	iPhone %	Non-iPhone %
Awareness	47%	48%
Diversion	27%	11%
Time Management	11%	18%
Social Connection	4%	11%
Curiosity	7%	6%
Social Avoidance, Other	4%	7%

Table 5. iPhone vs. non-iPhone behaviors

	iPhone %	Non-iPhone %
Browsing	47%	48%
Status Checking	13%	18%
AS/In-the-Moment	24%	11%
Communicate	4%	11%
Info Gathering	7%	6%
Fact Checking, AS/Planning, Transactions, Other	4%	6%

accessing mobile information, opportunistic access, information-based decision-making, solitary access, using the mobile Web as a individual social companion while with others, using the mobile Web for social facilitation, skimming along the surface of Web information, using the mobile Web as a complement to the stationary Web, importance of the convenience factor, and usage shaped by concerns with security. These observations (discussed below) help us understand how the mobile Web has been adopted and provide insight into how to design services that will better suit people's needs and increase adoption.

Relationships between Motivations and Behaviors

Common patterns of motivations and behaviors exhibited themselves across all participants in both Parts 1 and 2 of the study (see Figure 1). Social avoidance was omitted from this figure because it was rarely reported.

Awareness

Awareness was the most frequent motivation, usually satisfied with Status Checking behavior. Participants used a "support aura" of information—such as e-mail, news, and Facebook—to maintain a sense of broader connection to the facets of the world most important to their lives. *"…to figure out the local weather, as well as the local news…checking my e-mail."* (Participant 12, Part 1)

Time Management

Time Management was primarily satisfied by In-the-Moment behaviors. Participants made remarkably efficient use of time to support the decisions affecting daily actions. *"Work on the cell phone is much more…task driven. I'm going to my phone for one purpose or a set of defined purposes—but they are defined."* (Participant 12, Part 2)

Curiosity

Curiosity was satisfied through a range of different Info Seeking behaviors that varied depending on the scope of the topic of curiosity. *"I really like being able to, when I am interested in something and I want to know more about it, just picking up my phone and finding out immediately. I love that."* (Participant 2, Part 1)

Diversion

Diversion was satisfied primarily through Status Checking. It was typically exhibited by a habitual use of the mobile Web to fill idle time. *"It's boring if I'm just sitting there. Everyone else is sleeping or staring."* (Participant 7, Part 2)

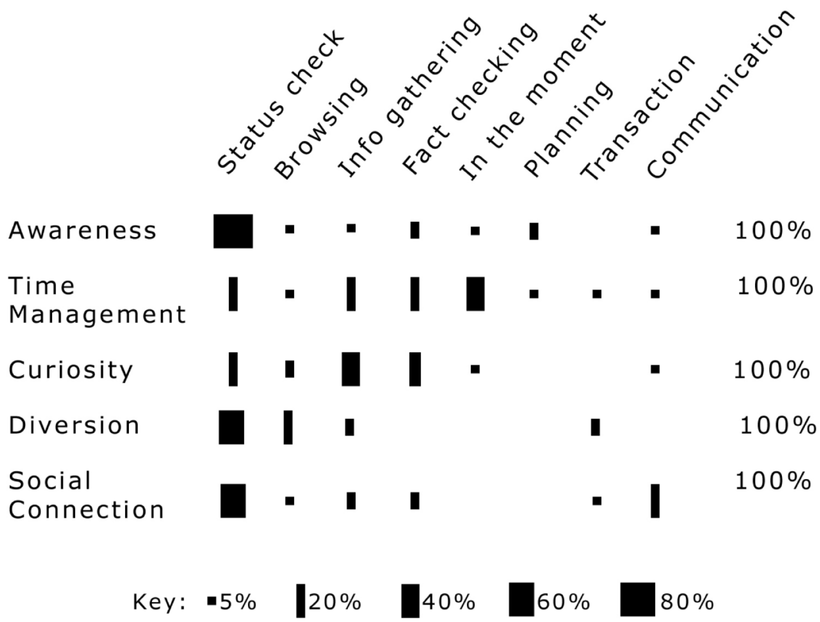
Social Connection

Social Connection was satisfied mainly through Status Checking and Communication behaviors, typically by sharing information with friends via e-mail or social networking site posts, and sometimes in person as a means to enliven the group experience. *"Just to see if anyone has invited me to anything …write to somebody…see what other people are up to, how their lives are going."* (Participant 5, Part 1)

Social Avoidance

While rarely reported explicitly, Social Avoidance was exhibited by participants as an exclusionary tactic for those riding public transit or in public service facilities. *"At my house there're always parties going on and I definitely don't like having my computer out when there're tons of people. So, a lot of times I'll just sit on the couch and totally ignore people—just go on my websites on my phone."* (Participant 13, Part 2)

Figure 1. Percentage of behaviors exhibited for each motivation



Relationships between Motivations and Context

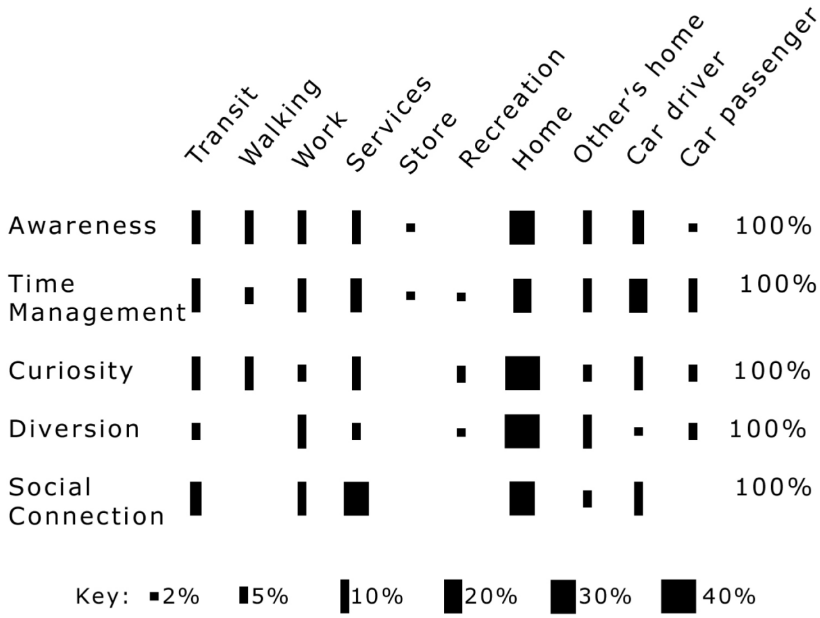
We examined the relationship between the session motivations and the physical settings in which they took place (see Figure 2). A substantial amount of activity took place at work, home, at service facilities and alarmingly even while acting as the driver of a car. People used their phone frequently even when a computer or laptop was available because of comfort and convenience. *"I mean it sounds pretty lazy, but instead of having to get up off the couch, or off the edge of the chair, I just… got the sports score."* (Participant 1, Part 1). Figure 2 reflects the 10 settings originally derived from and tracked in Parts One and Two.

The "Ritual" of Mobile Information Access

The most common behavior we observed by far was the "ritualistic" monitoring of common information sources to see what has changed. Participants showed a strong need to maintain an ongoing situational awareness through a "support aura" of information and connection each had constructed for themselves. *"It's kind of my ritual, either I'm reading a book or surfing Craigslist either to or from work on the bus."* (Participant 7, Part 2) It became an automatic, subconscious activity that people would perform frequently, running through the same list of sites and locations repeatedly. *"I guarantee I checked it when I woke up. And then I probably surfed around on MySpace and Facebook and checked my website. That's my routine."* (Participant 2, Part 2)

By having this information "always on," they maintained a sense of broader connection to daily news and events and control over their own lives. *"Kind of gives you an idea what's going on out there…I could check like local news and everything if I wanted to, or the weather, just try to figure out how to prepare for the day or the upcoming days."* (Participant 12, Part 1) For some, this phenomenon of continuous connection prompted a compulsive behavior of plugging in whenever people had a spare moment. *"I'm a little OCD [obsessive compulsive disorder]. It's habit I don't*

Figure 2. Percentage of settings for each motivation



know why, but when I step on the elevator I check my e-mail." (Participant 2, Part 2)

Karlson et al. (2010) conducted mobile task flow analysis of smartphone usage and found that the situational constraints of the mobile context influenced users' behavior and choice of activity. Users have adapted to the limitations of the mobile medium and have gravitated towards tasks that don't require continuous focus such as quick information checks. Just as we found with personal users, information workers' most common behavior was habitually checking specific information to keep abreast of changes in status (e.g., do I have a new email). The lines between personal and business usage are increasingly blurring as a greater number of users adopt smartphones and use shared mobile Internet access for both personal and business purposes.

Opportunistic Access

Mobile Web sessions are frequently short, conducted in between, around, and sometimes in conjunction with the many activities of people's daily lives. Participants freely admitted accessing the mobile Web even while driving. *"My dog had to be picked up from the groomers at the same time I was checking out a restaurant---yes I did this while driving. I called them."* (Participant 14, Part 2) Participants would frequently start out with one motivation and wander into one or more others (for example, Awareness leading to Time Management). *"As I was walking I remembered I had to look on eBay, and then looking at one thing led to another."* (Participant 5, Part 1)

Information-Based Decision Making

Participants were also making remarkably efficient use of their time by utilizing information from the mobile Web to inform and support the decisions affecting the actions of their daily lives. *"I'll go do things I need to get done. Yeah, like try to find a store or look up a store."* (Participant 6, Part 1) We observed active decision-making and changes in people's daily plans of action directly influenced by information obtained real time from the phone. *"I was in Everett and I wanted to find* *a nail salon that was still open. So I Googled the street I was on and called."* (Participant 4, Part 2) Participants made active use of the mobile Web to locate and access maps and directions for Action Support both in advance and en route. *"Before I started driving…I typed in the name of my tattoo shop, and it brought up the website with the phone number…and I called him up."* (Participant 6, Part 1)

Social Companion

While the majority of access was conducted while people were by themselves, we observed an interesting social phenomenon of people accessing the mobile Web while with other people because they were not interested or participating in the particular event taking place (such as watching a movie, playing a basketball game, practicing with a band). *"Each group had their own thing going on…where everyone was working on the guitar and recording, they were talking about that kind of stuff. And since I don't really have anything to do with the band, I was just kind of like watching the TV and using my Internet [sic]."* (Participant 6, Part 1) Having the mobile Web allowed them to still spend time with their friends and loved ones while having something of personal interest to occupy their time. This parallel information access provided a socially acceptable means of accessing the Web while still staying connected with other people and fulfilling social obligations.

Social Facilitation

Another social phenomenon we observed was people using Web information on phones, like photos or entertainment stories, as a means to enliven the group experience and connect with other people in person. *"So I was like, oh, well, I'm going to show her pictures on here…then I would show it to my other friends, too, because we saw some really funny pictures of a hamster."* (Participant 6, Part 1)

In addition, we saw the mobile Web being used in a social context as a tool for accessing information relevant to a group discussion (for example, settling a factual argument in a bar with friends). *"The truth is right here. I got the truth right here in my hand, buddy. Let's end this argument right now."* (Participant 13, Part 1) The mobile Web also helped facilitate group activity by directly supporting the decision-making and actions of a group (for example, deciding which bar to go to, checking on the time for the next movie, and getting directions to a restaurant). *"We were out and about. We wanted to go somewhere like within an hour maybe, but we didn't have any paper, so we're like look it up real quick, so see what's around."* (Participant 13, Part 1)

Finally we saw an increase in the amount of access to social networking sites (primarily Facebook and MySpace) between the first and the second diary study. *"Any little thing I want to look up like if I'm on MySpace I can just look up on my phone. Unless I'm sending photos to somebody"* (Participant 7, Part 2) Participants did use these sites as a way to maintain social connections *"[Regarding Facebook] it's a great way to keep in contact rather than making a hundred phone calls."* (Participant 5, Part 1) However, much of the social networking activity involved checking text messages and wallsfor a new message or post. People used social networks as an alternative to e-mail, as well as a means to learn about upcoming social events (for example, band concerts and local social gatherings). And it was rare for people to update their personal page or blog using a mobile device. Most indicated they would wait to do so on a computer. *"I never check my website on my phone. 'Cause there's [sic] a lot of graphics, and it's [the mobile display is] just too small."* (Participant 2, Part 2)

Skimming the Surface

Mobile Web usage was seamless and superficial: users constantly skimmed along the surface of Web information, monitoring and sampling information opportunistically to meet unfolding needs and impulses and to stay abreast of the facets of the world most important to their lives. Information needs of any depth or complexity, on the other hand, drove these users to the stationary Web. *"Honestly it's for the little gaps of time that you have to check something or get something done immediately. But as for being super productive and getting things done quickly, I still have to carry my computer."* (Participant 2, Part 2)

Complement to Stationary Web

The mobile Web is also a complement to the stationary Web when access is either restricted or inconvenient. With mobile Web access, people maintain some connection to the information most important to them, providing flexibility in how and where they consume content. *"I take it everywhere. I just hate not being able to find something out if I need to."* (Participant 14, Part 2) The reasons most often given for waiting to use the stationary Web were time and difficulty required to access the information on a mobile (for example, complicated e-commerce sites), and difficulty in typing anything of length. Most participants indicated that they read e-mail and blog postings on their phone but wait to respond until at a PC unless it is something really urgent. *"Just to see if I have any [e-mail]—maybe just like a update from my teacher or something urgent that I would want to know about before I got home."* (Participant 2, Part 1)

Hinman, Spasojevic, and Isomursu (2008) explored the question of mobile-Internet user needs via a PC Internet deprivation study; by asking users to rely solely on phone-based Internet access, they were able to delve into the perceived shortcomings of mobile access, and found that false expectations of performance based on people's experience with PC-based Internet access constituted a main barrier to a satisfactory user experience. They concluded that designers need to build from the familiar PC experience to create successful mobile-Internet "moments" and should consider developing "micro-services" that deliver consumption-ready information and allow users to "skim the surface" of the Internet. Our findings directly support this conclusion.

Convenience Factor

Mobile does not always mean in motion or on the go. We found that the contexts of use varied widely among participants but the majority of access was at home or work rather than while en route someplace (walking, driving, on public transit). Participants used the mobile Web from their bed or while lounging on a couch or floor even when a PC is often available in the same house. *"I don't have wireless and I was probably in bed or like not close to my laptop. So it's just easier to hop on my phone, especially when I'm in my bedroom because my laptop is in my living room."* (Participant 14, Part 2) All our participants had access to a PC, and many had laptops they frequently carried with them, but most cited convenience and start-up time as the main reasons to use the mobile Web instead. *"I have Internet [sic] at the house, and I don't use it as much as I use it on my phone. It's just right here in my hand, or I'm already thinking to myself, just look up that real quick."* (Participant 13, Part 1)

Karlson et al. (2009) researched patterns of use across mobile devices, laptops, and PCs. Their results concurred with ours in many findings. People access email and Web from their mobile phones outside of working hours and throughout the day to stay up to date. People found it more convenient to use their phones even when a computer was nearby.

Security Concerns

Participants expressed a concern about conducting online transactions. There was a lack of trust that the wireless network would sufficiently protect their personal information, and that the network would be sufficiently reliable to successfully process their request. *"Especially if it involves credit cards, I don't really trust the phone. If you lose connection, then Oh no!" Did the transaction go through?"* (Participant 13, Part 2)

DESIGN IMPLICATIONS

Mobile Web services that support people's daily lives and decision-making with faster and more immediate access to relevant information are likely to have a broad universal appeal. Although the advent of more powerful phones and network connections may change the types of idle-time activities people engage in (for example, watching movies or playing games), there is a fundamental opportunity now for mobile Web to offer access to the information people want to shape their daily lives and sphere of awareness. Based on the findings of this study, we can propose several design directions that would address the user behaviors and desires we discovered: providing information snacks, non-mobile services, custom content aggregation, voice-enabled services, and richer Web experiences.

Information Snacks

People value quick, short bursts of information on the mobile Web and are willing to wait until they can use the stationary Web to access lengthy or complicated content. The more quickly and easily people are able to access relevant information, the more likely they are willing to do soon a mobile phone. Simplifying access to the most important information, and avoiding loading phones with extraneous features and content, will help facilitate fast and routine access to the most relevant content that people value.

Non-Mobile Services

Our research found that the home was the top location for accessing the mobile Web. Nylander et al. (2009) conducted a diary and interview study to investigate where and why people use cell phones to access the Internet and similarly found that in 50% of the cases, participants chose a phone even though they had access to a computer, and the most frequent location for cell phone Internet access was the home. Much recent mobile product design has focused on location-aware applications for use on the go. Since people are frequently using the mobile Web in non-mobile settings, with the home being the most common, mobile Web services can also be targeted to stationary settings.

As mobile phones become more capable, Web-based mobile services could begin to supplant other in-home media players and controls. Tufegdzic (2010) of the research firm, iSuppli Corp., predicted that in 2010 factory shipments of game-capable mobile phones would increase 11.4% while game consoles and handhelds would experience flat or declining growth.

Custom Content Aggregation

Our early adopters reported combining a host of different browsing and searching interfaces, showing a willingness to piece together a patchwork of information that fits their complex and multi-motivational goals. The effort required for this re-articulation of technology has been a major deterrent in the mass adoption of mobile Web services. Aggregating content of interest from multiple sources, and for use in specific settings (for example, home, work, transit) into a single location with a consistent interface would provide tremendous value. Mobile services can take advantage of non-location-based cues such as time of day and users' patterns of access to tailor information implicitly based on context of use.

Voice-Enabled Services

Our research demonstrated that people regularly use mobile internet to do e-mail, to get messages, and to locate nearby businesses while in their cars, on the bus, and walking. Increasingly, laws are prohibiting hand-held mobile phones while driving. Voice-enabled web systems would enable people to find businesses and to listen to and send emails and messages more safely while driving. People with eyesight and dexterity challenges find the small mobile screens and keyboards difficult to use. Those users would also benefit from voice interfaces. Chang, Chen, and Liu (2009) researched participants' acceptance of voice-enabled internet using three models, including the technology acceptance model (TAM) and the theory of planned behavior (TPB). The results showed that participants will adopt voice-enabled Web systems which they find useful, easy to use, and fun.

Richer Web Experiences

According to a recent release by Teng (2010) of the research firm iSuppli Corp., global smartphone shipments are expected to increase 105% to 506 million units in 2014 from 246.9 million expected in 2010. As the proliferation of smartphones continues to expand, devices are increasingly capable of delivering richer mobile experiences akin to gaming and media devices. Part Three of our study illustrated this phenomenon: participants with iPhones reported 27% of their mobile phone use being for diversion whereas other participants turned to their phones only 11% of the time for diversion. Many smartphones come with capable mobile browsers and promise eventual support for the W3C's HTML5 standards. Better browsers enable hybrid mobile Web applications and richer UI and media experiences like those available via downloadable client applications. Designers of Web services have an opportunity to integrate information, communication, and entertainment needs into a richer set of mobile Web experiences that are valuable and enjoyable.

Explosion in Social Networking

Since our studies were conducted, use of the mobile Web to access social networking sites has increased dramatically. comScore ("Facebook," 2010, March 3) found that access to leading social networking sites via mobile browsers continues to grow. In January 2010, 25.1 million mobile users accessed Facebook via their mobile browsers—up 112 percent from the previous year. Twitter attracted 4.7 million mobile users in January—up 347 percent versus year ago. This shifts the emphasis of mobile Web as primarily an information medium to a social communications medium. Designers have the opportunity to understand and weave social networking behaviors into a host of next generation Web services. Further research is needed into mobile social networking behavior to better understand the impact on user motivations and behaviors, as well as information needs.

CONCLUSION

In this study we derived and validated a framework for describing the motivations, behaviors, and contexts of use for the mobile Web. Our proposed framework provides the mobile design, development, and research communities with a valuable tool for further study of mobile Web use and for creating products and services that improve the mobile Web user experience. By more closely examining how people are currently incorporating available mobile Web information into their daily lives, we can help inform the creation of the next generation of Web data devices and services that truly address the needs of potential users and increase adoption of the mobile Web.

REFERENCES

Brandt, J., Weiss, N., & Klemmer, S. R. (2007). txt 4 l8r: Lowering the burden for diary studies under mobile conditions. In *CHI 2007 proceedings: Special interest group on computer-human interaction conference* (pp. 2303-2308). Amsterdam: ACM.

Chae, M., & Kim, J. (2003). What's so different about the mobile Internet? *Communications of the ACM*, *46*(12), 240–247. doi:10.1145/953460.953506

Chang, S. E., Chen, S., & Liu, Y. (2009). A user study of accessing web applications via voice cellular phone: a model comparison approach. *Behaviour & Information Technology*, *28*(5), 471–484. doi:10.1080/01449290802479711

Chigona, W., Kankwenda, G., & Manjoo, S. (2008). The Uses and Gratifications of Mobile Internet among the South African Students. In *Portland International Conference for Management of Engineering and Technology 2008 Proceedings* (pp. 2197-2207) PICMET.

Church, K., & Smyth, B. (2008). Understanding Mobile Information Needs. In *Proceedings of the 10th international conference on human computer interaction with mobile devices and services* (pp. 493-494). ACM.

Church, K., & Smyth, B. (2009). Understanding the Intent Behind Mobile Information Needs. In *Proceedings of the 13th International Conference on Intelligent User Interfaces* (pp. 247-256). ACM.

Cui, Y., & Roto, V. (2008). How people use the Web on mobile devices. In *Proceeding of the 17th international conference on World Wide Web* (pp. 905-914). New York: ACM.

Dearman, D., Kellar, M., & Truong, K. (2008). An Examination of Daily Information Needs and Sharing Opportunities. *CSCW '08: Proceedings of the 2008 ACM conference on Computer supported cooperative work* (pp. 679-688). New York: ACM.

Facebook and Twitter Access via Mobile Browser Grows by Triple-Digits in the Past Year (2010, March 3). *comScore*. Retrieved September 28, 2010 from http://www.comscore.com/Press_Events/Press_Releases/2010/3/Facebook_and_Twitter_Access_via_Mobile_Browser_Grows_by_Triple-Digits

Glaser, B. (1965). The constant comparative method of qualitative analysis. *Society for the Study of Social Problems, 12*(4), 436–445. University of California Press. Hagen, P., Robertson, T., Kan, M., & Sadler, K. (2005). Emerging research methods for understanding mobile technology use. In *Proceedings from the 19th conference of the computer-human interaction special interest group (CHISIG) of Australia* (pp. 1-10). ACM.

Hassenzahl, M. (2006). Hedonic, emotional, and experiential perspectives on product quality. In Ghaoui, C. (Ed.), *Encyclopedia of human computer interaction* (pp. 266–272). Great Barrington, MA: Berkshire Publishing Group.

Heimonen, T. (2009). Information Needs and Practices of Active Mobile Internet Users. In Mobility '09: *Proceedings of the 6th International Conference on Mobile Technology, Application & Systems*. ACM.

Hinman, R., Spasojevic, M., & Isomursu, P. (2008) They call it "surfing" for a reason: Identifying mobile Internet needs through PC deprivation. In *CHI 2008 proceedings: Special interest group on computer-human interaction conference: CHI '08 extended abstracts* (pp. 2195-2207). ACM.

Ho, H., & Syu, L. (2010). Uses and Gratifications of Mobile Application Users. In [IEEE.]. *Proceedings of the International Conference on Electronics and Information Engineering*, *1*, 315–319.

Ishii, K., & Mikami, S. (2002). Communication and technology: Diffusion, use, and impact of the Internet around the world. In *Proceedings from the 52nd Annual International Communication Association Conference* (pp. 1-14). InternationalCommunications Association.

Kahn, V.-J., Markopoulos, P., Eggen, B., IJsselsteijn, W., & de Ruyter, B. (2008). Reconexp: A way to reduce the data loss of the experience sampling method. In *Proceedings of the 10th international conference on human computer interaction with mobile devices and services* (pp. 471-476). ACM

Kaikkonen, A. (2008) Full or tailored mobile Web- Where and how do people browse on their mobiles? In *Proceedings of the International Conference on Mobile Technology, Applications, and Systems* (8 pp. unnumbered). New York: ACM.

Karlson, A., Iqbal, S., Meyers, B., Ramos, G., Lee, K., & Tang, J. (2010). Mobile Taskflow in Context: A Screenshot Study of Smartphone Usage. In *Proceedings of the 28th international conference on Human factors in computing systems* (pp. 2009-2018). ACM.

Karlson, A., Meyers, B., Jacobs, A., Johns, P., & Kane, S. (2009). Working Overtime: Patterns of Smartphone and PC Usage in the Day of an Information Worker. In *Dub Human-Computer Interaction and Design*.http://dub.washington.edu/pubs/183. University of Washington.

Kellar, M., Watters, C., & Inkpen, K. M. (2007). An Exploration of Web-based Monitoring. In *CHI 2007 proceedings: Special interest group on computer-human interaction conference* (pp. 377-386). New York: ACM.

Kim, H., Kim, J., Lee, Y., Chae, M., & Choi, Y. (2002). An empirical study of the use contexts and usability problems in mobile Internet. In *Proceedings from the 35th Hawaii International Conference on System Sciences* (10 pp. unnumbered). Institute of Electrical and Electronics Engineers.

Mobile Internet Report. (2009). *Morgan Stanley.* Retrieved September 28, 2010, from http://www.morganstanley.com/institutional/techresearch/pdfs/2SETUP_12142009_RI.pdf

Nylander, S., Lundquist, T., & Brännström, A. (2009). At Home and with Computer Access – Why and Where People Use Cell Phones to Access the Internet. In *Proceedings of the 27th international conference on Human factors in computing systems* (pp. 1639-1642). New York: ACM.

Palen, L., & Salzman, M. (2007). Voicemail diary studies for naturalistic data capture under mobile conditions. In *Proceedings from the 2002 ACM conference on computer supported cooperative work* (pp. 87-95). New York: ACM.

Peters, O. B., & Allouch, S. (2005). Always connected: A longitudinal field study of mobile communication. [Washington, DC: Elsevier.]. *Telematics and Informatics*, *22*(3), 239–256. doi:10.1016/j.tele.2004.11.002

Schmiedl, G., Seidl, M., & Temper, K. (2009). Mobile Phone Web Browsing – A Study on Usage and Usability Of The Mobile Web. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services (article 70).* New York: ACM.

Sohn, T., Li, K., Griswold, G., & Hollan, J. (2008). A diary study of mobile information needs. In *CHI 2008 proceedings: Special interest group on computer-human interaction conference* (pp. 433-442). New York: ACM.

Taylor, C., Onicello, A., Somohano, S., Samuels, N., Whitaker, L., & Ramey, J. (2008). A framework for understanding mobile internet motivations and behaviors. In *CHI 2008 proceedings: Special interest group on computer-human interaction conference* (pp. 2679-2684). New York: ACM.

Taylor, C., Samuels, N., & Ramey, J. (2009). Always On: A Framework for Understanding Personal Mobile Web Motivations, Behaviors, and Contexts of Use. [IJMHCI]. *International Journal of Mobile Human Computer Interaction*, *1*(4), 24–41. doi:10.4018/jmhci.2009062603

Teng, Tina. 6/7/10. *iSuppli Issues Fast Facts on Latest iPhone*. http://www.isuppli.com/Mobile-and-Wireless-Communications/News/Pages/iSuppli-Issues-Fast-Facts-on-Latest-iPhone.aspx. iSuppli Corp.

Tufegdzic, Pamela. (8/10/10). *Cell Phone Gaming Soars as Consoles and Handhelds Sputter*. http://www.isuppli.com/Home-and-Consumer-Electronics/News/Pages/Cell-Phone-Gaming-Soars-as-Consoles-and-Handhelds-Sputter.aspx. iSupply Corp.

Wang, H., & Wang, S. (2010). User Acceptance of Mobile Internet Based on the Unified Theory of Acceptance and Use of Technology: Investigating the Determinants and Gender Differences. *Social Behavior and Personality*, *38*(3), 415–426. doi:10.2224/sbp.2010.38.3.415

Chapter 13
Improving the User Experience of a Mobile Photo Gallery by Supporting Social Interaction

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ABSTRACT

Today, photo gallery applications on mobile devices tend to be stand-alone and offline. For people who want to share photos with others, many add-on tools have been developed to connect the gallery applications to Internet services to enable photo sharing. The author argues that photo-centric social interaction is best supported when the gallery application is fully integrated with an Internet service. In this case, no additional tools are needed and the user's image content is fully synchronized with the service. To research the topic, Image Exchange, a service-integrated mobile gallery application with a corresponding Internet service, was designed and implemented. Moreover, a field study was conducted with 10 participants to compare Image Exchange with a state-of-the-art gallery application combined with an add-on photo sharing tool. Image Exchange was preferred by most participants and it was especially appreciated because of the user experience. Above all, the results show that social activity increased amongst the participants while using Image Exchange.

INTRODUCTION

People are starting to use their mobile devices as their primary cameras because the quality of mobile cameras is improving (Nokia, 2008). As most mobile devices are also capable of connecting to the Internet, they can be used to publish photos to photo sharing Internet services and also browse and comment the photos hosted by those services. However, photo sharing on mobile devices still tends to be a laborious task and on that account users might not be able to share their mobile photos at all.

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Nowadays, users are able to share their photos on their mobile devices by using applications that are essentially upload tools for certain Internet services (Facebook, 2010; Share Online, 2010; ShoZu, 2010). The upload tool applications are usually add-ons to existing gallery applications offering functionalities for separately uploading and downloading images and their data. However, the gallery application and the user's photo collection are not fully integrated and synchronized with the service. Also, the upload tool applications require account creation and configuration of settings before they can be used. In the mobile context, users who might be on the move and have only a limited and possibly fragmented time to spend on a task is unable to use a mobile application that is hard and slow to use and configure. Furthermore, the upload tools might be developed by a different party than the developers of the gallery application or the corresponding Internet service. This might result in a mismatch between the available functions and features on the mobile gallery application and the Internet service. Thus, the upload tool applications cannot guarantee a deep integration of the gallery application and the service.

Mobile photo gallery applications continue to be stand-alone and offline, even though many mobile devices today are connected to the Internet with a flat-fee, always-on network connection. The gallery applications have not yet utilized the opportunity of integrating directly with a corresponding Internet service and having user's images in sync with the service. If the gallery application was deeply integrated to the service, it would enable users to share images in real-time on the go in an easy and fun way. Users would not need to configure or separately synchronize their image collection when they want to communicate using images. Hence, we argue that as the overall user experience improves via the deep integration of a mobile gallery application and a corresponding Internet service, it also facilitates the social interaction among the users of the Internet service.

In this paper, we introduce Image Exchange, a mobile gallery application that aims at offering great user experience by being fully integrated to a corresponding Internet service. The application provides an easy and fun way for users to share and interact with photos in real-time. We tested Image Exchange in a field study of 1+1 weeks (a test period of 1 week for each application) by comparing it to a state-of-the-art mobile image gallery application combined with an Internet service upload tool. The goal was to investigate whether the social interaction is best encouraged when users are using a mobile service-integrated gallery application compared to state-of-the-art applications and tools existing on the market today.

RELATED RESEARCH

Mobile photo sharing has been an important topic in the research literature. Many photo applications have been developed around the topic of mobile photo management and sharing process, but we are not aware of any research on seamlessly integrating personal photo management and photo sharing between a mobile device and a corresponding Internet service and how that would affect the user experience and social interaction. Instead, the previous research on mobile photo applications can be divided into two groups: studies on the usage and management of personal photos and studies on sharing images.

The studies on personal photo collections have revealed many ways to help users to organize and locate their photos (Ames & Naaman, 2007; Bentley et. al., 2006; Frohlich et. al., 2002; Gurrin et. al., 2005; Jacucci et. al., 2006; Naaman et. al., 2004; Wilhelm et. al., 2004). However, the research has not focused on improving the photo back-up, which is an important part of the management process. Users would value a seamless process where all the steps in mobile photo management as designed to be as fluent and easy to use as possible (Ames et. al, 2010). Photo browsing (Harada et. al., 2004; Khella & Bederson, 2004; Pauty et. al., 2005; Wang et. al., 2003) and displaying (Liu et. al., 2003) have been explored to define how to design photo viewing in an effective way on a mobile device in terms of user's personal photo collection. On a mobile device, user interface and system designs for mobile photo management and representation need to overcome the challenges of limited resources, such as input/output capabilities and navigation (Wilhelm et. al., 2004).

The research on mobile photo sharing has been focusing on how people share photos (Clawson et. Al, 2008; Olsson et. al, 2008; Van House et. al, 2005) and how to improve the photo sharing process (Ahern et. al, 2007; Ahern et. al., 2005; Counts & Fellheimer, 2004; Sarvas et. al., 2005). For example, the mGroup project (Jacucci et. al., 2006) studied the collective creation of mobile media in terms of instantaneous messaging, while the Zurfer project (Naaman et. al., 2008) concentrated on consuming and viewing shared mobile images. The studies have been done in an environment, where mobile photo sharing applications have been designed and implemented separately from the server, and thus been forced to use the existing APIs that have not been optimized for mobile devices or use.

Earlier studies have emphasized the importance of ensuring that the basic features of a system for managing photos should be efficient, reliable, and well-designed (Ahern et. al., 2007; Cooper et. al., 2005; Cui et. al., 2007; Frohlich et. al., 2002; Kirk et al., 2006; Kuchinsky et al., 1999; Rodden & Wood, 2003; Shneiderman et. al, 2006). The user interface of a digital photo album demands more than using a file manager type of solution derived from a PC. Nonetheless, most of the earlier research has not been focusing on improving the user experience but to include "easy to use" functions on mobile devices, in other words, enhancing the usability. Users' emotional satisfaction should be a key part of enhancing the user experience of digital photo albums (Balabanovic et. al., 2000; Harada et. al., 2004; Jin et. al., 2004). Indeed, there are a couple of projects that considered user experience also an important aspect. In the Flipper project (Counts & Fellheimer, 2004), one of their design goals was to provide a minimal set of features, but maintain focus on photo content. In the Zurfer project (Naaman et. al., 2008) their design goals included enabling simple and easy access to the user's own photos and their contacts' photos. The design also aimed for intuitive and playful interaction with the content. Our focus was also to design a mobile application and photo sharing service in such a manner that the enjoyment aspects of use and the whole user experience were the first priorities.

Earlier studies in the human-computer interaction community have developed definitions and models for user experience that have incorporated such aspects as pleasure, beauty and hedonism (Forlizzi & Battarbee, 2004; Hassenzahl & Tractinsky, 2006; Jordan, 2000; Norman, 2004). Hassenzahl (2003) has presented a model that takes into account both pragmatic (individuals' behavioural goals) and hedonic (individuals' psychological well-being) attributes of a product. This model defines aspects of user experience such as the subjective nature of experience per se, perception of a product, and emotional responses to products in varying situations. Roto, Ketola, and Rautava (Ketola & Roto, 2009; Roto & Rautava, 2008) built on the earlier studies on user experience definitions and defined user experience elements that take into consideration the brand promise of Nokia. They defined user experience elements to be utility, usability, social value and enjoyment, which can be used when evaluating user experience. We have taken these aspects into account in the user evaluations.

IMAGE EXCHANGE

To create a mobile gallery application that would be fully integrated with a corresponding Internet service, we defined the requirements for the application and implemented a functional prototype of the system, called Image Exchange.

Requirements

The requirements for a mobile photo sharing application were derived from our user studies and evaluations of current mobile photo sharing applications (Vartiainen et. al., 2008). They were also in line with previous research (Naaman et. al., 2008):

1. An easy way to register to a photo sharing Internet service
2. An automatic uploading and backing up images to the Internet service
3. An easy way to browse images from the user's own collection or other users' collection
4. An easy way to publish images
5. An easy way to add and modify titles and descriptions of images
6. An easy way to add and view comments

To meet the first requirement of simplifying and facilitating the registration process, we investigated ways to minimize the registration effort. After several brainstorming sessions, the identification number of the device was decided to be used as an initial user name. Thus, a user account (including the user name and password) would be created to the service without any user input except from asking the permission to use network connection. Afterwards, the user would be notified of the successful registration. Typing text with a mobile device can be a laborious task, especially when some users may not use any dictionary, or if the task requires text entry without any typographical errors. That is why by removing the need for any input, we would lower the entry barrier for the user to start using the application. The user could easily change their user name into something more descriptive by using the Internet service from a PC later on.

The captured images would be transparently transferred without requiring any user interaction to fulfill the second requirement of backing up users' images. As a result, a user would have a feeling of having his image collection always present on the device and in the service. The application would not only be an offline gallery or a tool for uploading images to a online photo sharing service, but a fully integrated photo sharing application that is always in sync with the corresponding service.

To satisfy the third requirement of browsing images, the photo sharing application would have two modes: one for browsing local (user's own images) and another for online (published by others) photos. When the user would start the application, a main menu would immediately indicate the two modes for local and online browsing. We wanted to minimize the amount of steps that would be required to show the latest image in both modes full-screen: The first selectable item in the main menu would be "Latest" in both modes. As the first item in the menu would be selected when the application was started, the user would be one click away from his latest image and two clicks away from the latest public image. After clicking on a menu item, the user would be taken to an image browsing view, where he could browse his/public images with the left and right arrow keys.

Finally, an image menu was defined to meet the fourth, fifth and sixth requirements of letting users to publish and add/view titles, descriptions and comments of photos. The menu would be accessible when browsing the images and would show the options that were relevant for a particular image. The title, description and comments of an image would be in sync with the corresponding Internet service: Whenever the user decides to change a title or description or add a comment either on the mobile device or in the service, the changes would also appear in the other end. This would in turn improve the user's perception that the application was fully integrated to the service and the content appeared to be common in both ends.

Implementation

The photo sharing application was implemented on the Nokia N95 mobile device using the Symbian S60 platform. The device had a display with a resolution of 320x240 pixels and hardware graphics acceleration with OpenGL ES. The N95 device also worked in the High-Speed Downlink Packet Access (HSDPA) network, where the data transfer speed can be up to 3.6 Mbit/s.

Figure 1 shows a screenshot of the main menu of the application. The left side of the view displays all the options that were available in the current mode. On the top, the text "My Images" explains that the current menu relates to the local, user's own images. The arrow beside the text indicates that by pressing the right arrow key, the user moves to the other mode of the main menu used for accessing "Public Images", namely online photos published by other users of the service. The background image was the current image in the selected photo set. When the application was started, the last captured image was shown as the background image.

For local images, we decided to create screen-size thumbnails to make image browsing faster and decrease memory consumption. For online photos, we used the Web service to fetch the latest images published by other users of the service and cache them to the device memory. The service would also send only screen-size thumbnails of the images to make the transfer fast and save network bandwidth. As our target device supported HSDPA and we had a cache implemented, fetching the online images could be done in real-time without any disturbing waiting periods.

The image browsing view is shown in Figure 2, which shows the photo full-screen. The left and right arrow keys were used to browse to the next and previous image, respectively. Figure 3 shows the image menu that was used to show functions that were available for the selected image. The image menu was activated with a joystick press in the image browsing view. When the user selected to publish a photo, modify the title or the description or add a comment, the changes were sent to the service automatically. The synchronization also worked the other way around: the service notified the mobile application of changes on the service-side. The update messages only contained textual data, not the image itself. The commenting view is shown in Figure 4. The commenting view was activated from the image menu. Comments were always up-to-date with the service.

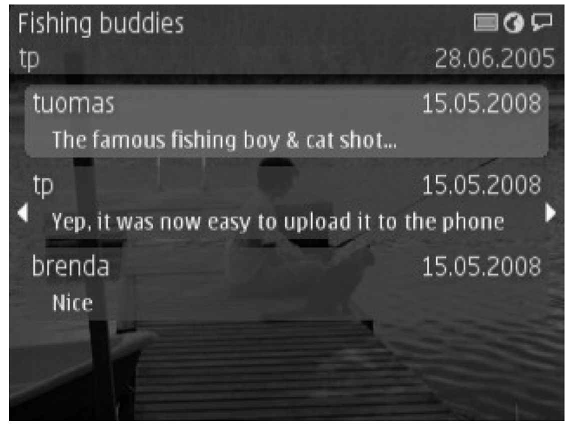
Image Exchange also included a Web user interface that users could use to access the same information as with their mobile devices. The Web user interface also offered the same func-

Figure 1. The main menu

Figure 2. The image browsing view

Figure 3. The image menu

Figure 4. The commenting view



tionality as the mobile application: the user could view and publish his images, add and modify titles and descriptions of images, browse images published by other users, and view and add comments.

USER STUDY

We conducted a field study of 1+1 weeks to compare our service-integrated mobile gallery application, Image Exchange, with a state-of-the-art gallery application combined with an add-on tool for photo sharing. The study included two groups each containing five participants who used Image Exchange and the combination of the gallery application and the upload tool for seven days each. The focus of the study was on the overall user experience of implemented features and how that would affect the social activity within the group during the testing periods.

Application for Comparison

The state-of-the-art gallery application used for comparison was the default Gallery application in the Nokia N95 mobile device. The upload tool used with the Gallery application was a mobile Symbian S60 application developed for posting images from a mobile device to a photo sharing Internet service. It was available on the market and used with the Flickr service (2008) during the study. We will later refer to the combination of the Gallery application and the upload tool as "Gallery".

The upload tool was a stand-alone application that offered a way for user to browse, upload and publish images (Figure 5). The user could also view images published by others. The upload tool also included functionality to view and add titles, descriptions and comments. The commands were accessible via a tool bar that was visible when browsing images. Furthermore, the upload tool enabled publishing of images directly from

Figure 5. The upload tool used for the comparison

the Gallery application by adding a command to the application.

The upload tool needed to be configured to use the Flickr Internet service for publishing images. If a user did not have an account to Flickr before starting to use the service, he needed to create the account by using a Web browser. After the configuration, the upload tool was ready to be taken into use. The user could set the upload tool to automatically poll Flickr at certain intervals and download the latest public images from his contacts and all other users of the service. The updating could also be done manually.

While Image Exchange was a prototype, Gallery was a more feature complete product. Especially, the tool was able to show a list for user's contacts in the Flickr service and the user could directly access the contacts' images using the list. Image Exchange did not yet have this functionality implemented. The participants were asked to ignore the features (especially the feature for having contacts in the service) that were available in the upload tool and Flickr but not in our prototype application. However, this did not always happen as seen in the results of the user study.

Participants

We used two groups in the field study both including five participants that were friends with each other and daily in contact. The target was to follow social interaction in a group of friends who all use the same mobile application and corresponding photo sharing Internet service. The participants were students from a university ages ranging 19-25 years. Two of the participants were female and eight of them were male. We decided to recruit students as they belong to the target group of social Internet services and are already actively using such services.

The participants did not have technical background, but some had interest towards technology and considerable IT skills. Seven of the participants described themselves as PC power users while the rest were basic users. Half of the participants had a smart phone, the other half a basic phone. Nine participants owned a digital camera, and five used their phone also as a camera. None of the participants were users of the upload tool application used for comparison nor the Flickr Web service, but they mainly used Facebook (2008) and e-mail to share images.

The participants were paid a small reward after the test period and they did not have to pay the data costs during the test period. We did not reveal the origin of either application during the study.

Procedure

Group 1 used Gallery first and switched to Image Exchange after seven days. Group 2 used the applications in the opposite order. We chose to conduct the field study in this way to ensure that the testing order of the applications did not affect the results. The participants were not given instructions on how to use the applications, because we wanted to simulate the situation where real users take a mobile photo sharing application into use for the first time. The participants were given Nokia N95 devices, which had both applications pre-installed.

We sent one or two tasks to the participants by text message every morning. Together with the message, we sent a multiple-choice question, which they had to answer before the next morning. The questions formed a set to evaluate the usability aspects of the applications. Below, you can find an example of a task:

Discuss about images and add comments to images that other users of the service have published. How easy was it to comment images on a mobile device? 1=Very hard.. 5=Very easy

We selected 6 goal-oriented tasks for each period. The tasks included basic use cases for a photo sharing application: Registration, uploading an image to the service, publishing images, browsing published images, commenting and replying to comments. The tasks were the same for both periods.

In addition to the daily task feedback, the users were asked to keep a diary about their experiences with the applications during the test period. This was to gather their insights during the whole test period as well as experiences about their own use cases and challenges. We also logged data on the server including the number of published images and comments made by a user to measure the social activity within the participant groups.

After testing each application, we asked the participants to fill out a Web questionnaire including closed and open questions about the application. The Web questionnaire included three parts: In the first section, we asked rating questions about the general use; in the second section, we had rating questions about other aspects of user experience than usability; utility, social value and enjoyment (Roto & Rautava, 2008); and the third section included open questions, where we asked the participants to list three best and worst things in the application and improvement ideas.

After both periods, we asked the participants to choose which application they preferred to use for photo sharing in the future. We also organized a 2-hour focus group session separately with each of the two groups to discuss about their experiences during the testing periods.

RESULTS AND DISCUSSION

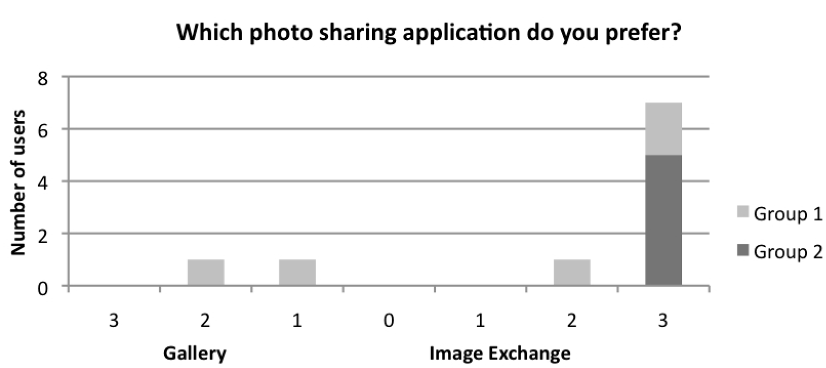
As described in the previous section, we collected various types of feedback from the study participants. In the following sections, we discuss the results related to the user experience and social activity. To analyze the statistical differences between the means of the ratings, we used a two-tailed T-test, with alpha = 0.05.

Preference

After using both applications for 7 days each, we asked the participants to evaluate which application they would prefer to use in the future to publish images with their mobile devices. We used a 7-point scale, 3 meaning strong preference for either application and 0 meaning no preference. 7 out of 10 participants preferred Image Exchange very strongly and 8 participants in total (Figure 6).

All users who first used Image Exchange (Group 2) clearly preferred it, whereas the preference distribution of the group, which started with Gallery (Group 1), varied more. The reason is that Gallery had a feature for adding contacts to a list, and the participants could easily check the latest images from their contacts. Image Exchange did not have this feature yet implemented as it was still a prototype. The participants, who used Gallery first, had used this feature right from the start and missed it in Image Exchange. One participant

Figure 6. The preference of the application



commented that he chose Gallery because the lack of this feature in Image Exchange but otherwise he would have preferred Image Exchange.

Overall Evaluation

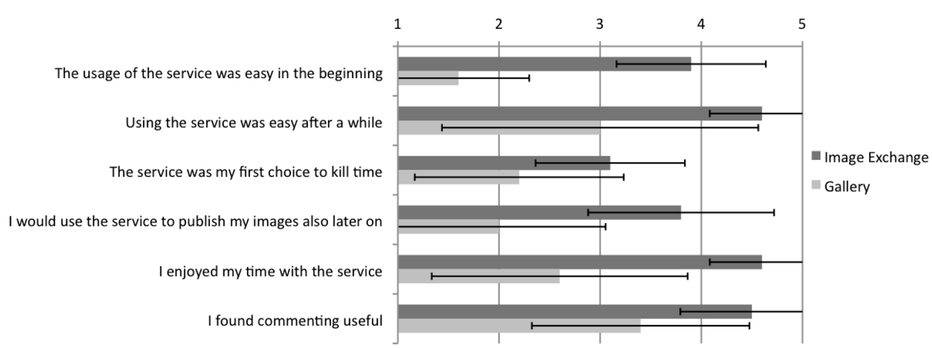
The results of the overall evaluations are shown in Figure 7. We used a 5-point Likert scale, 1 meaning that a user disagrees with the statement and 5 that he or she agrees. The questions aim at evaluating the overall experience of the applications.

The results show that Image Exchange was preferred in all questions. Especially, the start of use was significantly easier in Image Exchange (p=0.00001): The automatic registration was very easy and the instructions were helpful. In regard to Gallery, the participants commented that the registration to Flickr was too laborious to do on a mobile device. Most of the participants spent 1-2 hours to complete the registration on their mobile devices.

Compared to Gallery, Image Exchange also scored significantly better in the questions "Using the service was easy after a while" (p=0.011), "I would use the service to publish images also later on" (p=0.0005), and "I enjoyed my time with the service" (p=0.0003). As the participants enjoyed their time with Image Exchange, they would gladly continue using it also in the future. The participants commented that they were pleased with the fast uploading of images, although it surprised some of them that all images were transferred to the service and not only the ones that they will publish. Image browsing, both with own and online images, felt very fast and commenting also proved to be more useful in Image Exchange as indicated by the significant difference in the score to the question "I found commenting useful" (p=0.001).

Although Gallery was very hard to configure in the beginning, the basic usage afterwards was quite simple and easy. However, as the image collection was not in sync in between Gallery and Flickr, the participants commented that they needed to manually upload all the images that they were going to publish. In addition, when they wanted to check the latest photos that other users had published, the online image collection was not always up-to-date since it is dependent on when the automatic update was done. If the automatic update was done only occasionally or not on at all, the participants needed to manually update the online image collection. The manual update sometimes took too long for the participants to actually view the latest images if one had only a couple of minutes when, for example, waiting for a bus. This irritated the participants and lowered the scores of Gallery in the overall evaluation. The same applies also for commenting. Even though the comments were easily accessible, the hassle with updating the content lowered the usefulness of commenting.

Figure 7. The overall evaluation with standard deviation



The question "The service was my first choice to kill time" indicates that photo sharing is still not the main use case for the participants to kill time. This is quite natural as the participants commented that they were not normally using such services with their mobile devices. Still, Image Exchange scored significantly better in this question as well (p=0.029).

Usability Evaluation

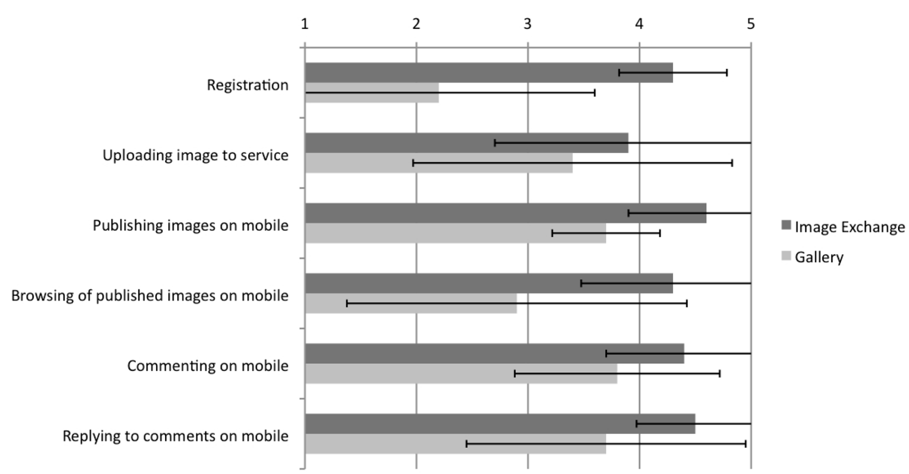
After executing one of the daily tasks, the participants gave their ratings about how easy it was to complete the task indicating the usability factors related to the task. The results of the task ratings are shown in Figure 8. A sample rating question was presented in the Procedure chapter.

Image Exchange scored significantly better in two tasks: "Registration" (p=0.002) and "Browsing of published images on phone" (p=0.039). As explained in the previous chapter, the registration in Image Exchange was simple and completed with one click while in Gallery, the registration process was complex. The participants highly appreciated the easiness of our solution and rated it high. The browsing of published imaged on the phone scored well in Image Exchange because the online image collection was always up-to-date when the user accessed it. In Gallery, the user needed to check, if the collection was recently updated. In the worst case, he needed to do the updating manually and wait for several minutes to see the latest online images.

Also, the task "Publishing images on mobile" (p=0.004) scored clearly better in Image Exchange as the image collection was always in sync between the mobile application and the service. There was no need for separately uploading an image before it could be published but the user could just publish it immediately. However, some participants had problems with uploading due to network problems, which in turn lowered the score for the task "Uploading image to service" (p=0.244, not significant).

On the contrary, Gallery did not offer any information whether the image was already uploaded to the service. Many times the sending was interrupted and had to be reinitiated, as there was no automatic resending. Furthermore, the participants commented that the uploading was quite easy but irritatingly slow. The participants needed to update every section manually if they wanted to get up-to-date information. In addition, comments were not always up-to-date as the updating occurred at certain intervals or only manually. This resulted in the participants adding comments to a discussion,

Figure 8. The results of the task ratings with standard deviation



which was not up-to-date, and the comments ended up being in a "zigzag" order in the discussion. In Image Exchange, the participants felt that they could trust that the discussion was always up-to-date with the service, and they could immediately reply to a comment. However, Image Exchange had limitations regarding the commenting view: It was sometimes slow to view comments and there was not any notification about new comments. This affected the scores for "Commenting on mobile" (p=0.140, not significant) and "Replying to comments on mobile" (p=0.137, not significant).

User Experience Evaluation

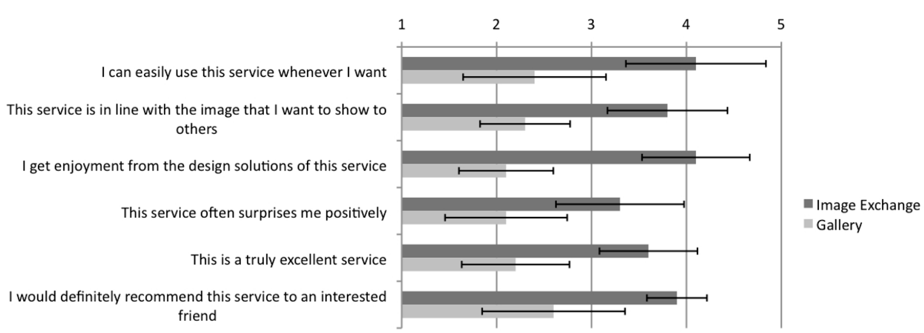
The results of the user experience evaluation are shown in Figure 9, where the ratings evaluated the social, utility, and enjoyment aspects of user experience. The results show that Image Exchange scored significantly better in 5 out of 6 questions. Even though Image Exchange also scored better in the task ratings measuring the usability of the main features, a clearer difference is shown in the ratings and participants' comments related to user experience.

Particularly, the easiness of use ("I can easily use this service whenever I want", p=0.016) and the design solutions of Image Exchange ("I get enjoyment from the design solutions of this service", p=0.0004) attracted the participants as clearly indicated by the results. The participants listed the ease of use and simplicity as one of the key design solutions of Image Exchange. They would rather have less well-designed features than many that are hard to use. The participants enjoyed the use so much that they would even recommend it to an interested friend ("I would definitely recommend this service to an interested friend", p=0.018). This seems to be an important aspect in social Internet services as the participants commented that it is important to have their friends using the service.

Furthermore, the participants considered Image Exchange and service to be rather excellent ("This is a truly excellent service", p=0.013) and support the image that they want to show to the others ("This service is in line with the image that I want to show to others", p=0.003). The participants explained that they highly appreciated the visual looks of Image Exchange and they described it as "stylish", "modern" and "beautiful". Image Exchange also managed to surprise the participants positively from time to time ("This service often surprises me positively") and they commented that Image Exchange was fun to use but the difference was not significant in this question (p=0.066).

On the contrary, Gallery did not score well in these questions: Although it was quite simple and usable after a while, it did not manage to attract the participants or get them excited. The participants commented that it had unnecessary features and the essential functions were sometimes cumber-

Figure 9. The results of the user experience evaluation with standard deviation



some and slow to use. They had problems of figuring out how Gallery works as a whole and what was needed to be done to carry out a task. The participants wanted a mobile application to be fast and smooth to use, as they might not have many minutes to accomplish a task on the go.

The user experience evaluation also explains why Image Exchange was strongly preferred by the participants compared to Gallery, which was not evident in the general or usability evaluation. The participants took pleasure in using Image Exchange even though they also got things done with Gallery. Image Exchange enabled the participants to enjoyably interact with each other in real-time on the go, while Gallery still required the participants to take care of many tasks (e.g. uploading an image, syncing the image data) before they could concentrate on the actual communication.

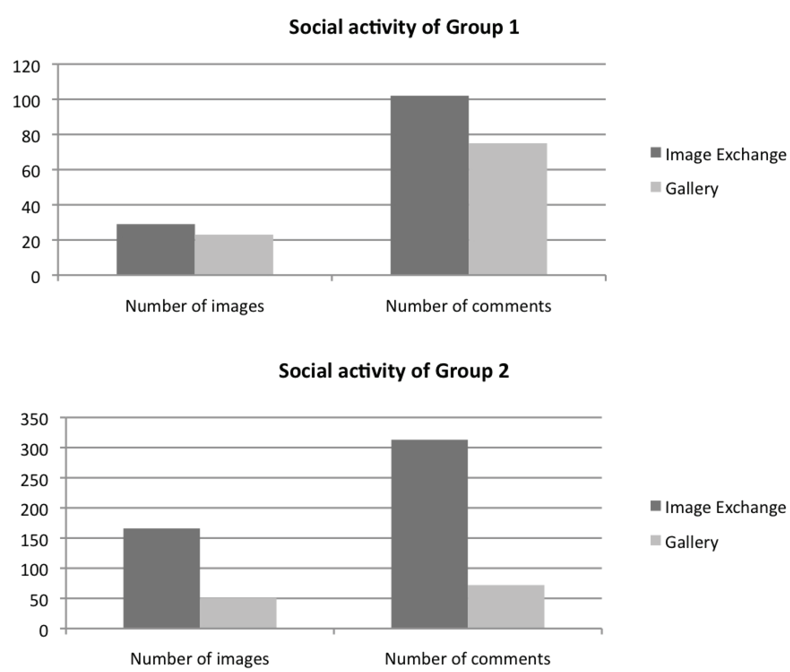
Social Activity

Lastly, the results of the social activity within the participant groups are shown in Figure 10. The figure shows the number of published images during the test periods. It also indicates the number of comments that the participants added to the images. The number includes new comments and replies to existing comments.

The results reveal that both of the groups were more active when using Image Exchange. Group 1 which switched from Gallery to Image Exchange published 26% more images when using Image Exchange. Also, the group added more comments to images when using Image Exchange: the number of comments increased 36%. The figures for Group 2 are even more convincing: Their activity when using Image Exchange for publishing images was 325% higher than when they used Gallery. Group 2 also added 420% more comments when using Image Exchange.

The activity figures show that the groups had different dynamics: Group 2 was clearly more socially active than Group 1. However, the results show that the activity was higher within both groups while using Image Exchange. In addition, the social activity was not dependent on the order

Figure 10. The results of the social activity



in which participants used the applications and services. This is an interesting aspect as usually people might first become very enthusiastic about a new service or application but the excitement subsides over time. In this study, the usage of a photo sharing service on a mobile device was a relatively new method for the participants, which means that they were excited about it during the first period. Still, Group 1 increased their activity after switching from Gallery to Image Exchange.

CONCLUSION

In this chapter, we introduced a mobile photo sharing application, Image Exchange, that is fully integrated to a corresponding Internet service; thus, offering an easy and fun way to share and interact with images. In particular, we put special attention on making the user experience of the implemented features as positive as possible. The research goal was to find out whether social interaction is best nourished when users are using a gallery application that is deeply integrated to the Internet service compared to a solution existing on the market today, which uses an add-on tool to enable photo sharing.

To evaluate Image Exchange, we conducted a field study with 10 participants to compare a state-of-the-art gallery application with an Internet service upload tool to Image Exchange. The results of the study show that 8 out of 10 participants preferred Image Exchange and it also scored better in more detailed usability and user experience ratings. Image Exchange was especially appreciated because of user experience and speed. The gallery application used for comparison scored reasonably well in general and usability related questions but not in the user experience evaluation. This means that the usability or general evaluation did not reveal how satisfied the participants were with the service nor did they explain the participants' application preference. The state-of-the-art gallery application combined with the upload tool was missing the enjoyment aspects of use, which are essential for a mobile application used for social communication. The participants of the study were more socially active when using Image Exchange, which indicates that better user experience encourages users to use social Internet services more actively.

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REFERENCES

Ahern, S., Eckles, D., Good, N., King, S., Naaman, M., & Nair, R. (2007). *Over-Exposed? Privacy Patterns and Considerations in Online and Mobile Photo Sharing*. In Proceedings of the SIGCHI conference on Human Factors in computing systems (CHI 2007),p.357-366. San Jose, CA:ACM Press.

Ahern, S., King, S., & Davis, M. (2005). *MMM2: mobile media metadata for photo sharing*. Proceedings of the 13th annual ACM international conference on Multimedia, Hilton, Singapore.

Ahern, S., King, S., Qu, H., & Davis, M. (2005). *PhotoRouter: destination-centric mobile media messaging*, p. 209-210. In Proc., MULTIMEDIA 2005. San Jose, CA: ACM Press

Ames, M., Eckles, D., Naaman, M., Spasojevic, M., & House, N. (2010, Feb.). Requirements for mobile photoware. *Personal and Ubiquitous Computing*, *14*(2), 95–109. doi:10.1007/s00779-009-0237-4

Ames, M., & Naaman, M. (2007). *Why we tag: motivations for annotation in mobile and online media*, pp. 971-980. In Proc., CHI 2007. San Jose, CA: ACM Press.

Balabanovic, M., Chu, L. L., & Wolff, G. J. (2000). *Storytelling with digital photographs*. InProceedings of the CHI 2000 conference on human factors in computing systems, The Hague, Netherlands, p. 564–571.

Bentley, F., Metcalf, C., & Harboe, G. (2006). *Personal vs. commercial content: the similarities between consumer use of photos and music.* In Proc., CHI 2006. ACM Press, p. 667-676.

Clawson, J., Voida, A., Patel, N., & Lyons, K. (2008). *Mobiphos: a collocated-synchronous mobile photo sharing application*. In MobileHCI '08: Proceedings of the 10th international conference on Human computer interaction with mobile devices and services, pp. 187–195. New York: ACM.

Cooper, M., Foote, J., Girgensohn, A., & Wilcox, L. (2005). Temporal event clustering for digital photo collections. [TOMCCAP]. *ACM Transactions on Multimedia Computing, Communications, and Applications*, *1*(3), 269–288. doi:10.1145/1083314.1083317

Counts, S., & Fellheimer, E. (2004). *Supporting social presence through lightweight photo sharing on and off the desktop.* In Proc., CHI 2004. ACM Press, p. 599-606.

Cui, J., Wen, F., Xiao, R., Tian, Y., & Tang, X. (2007). *EasyAlbum: an interactive photo annotation system based on face clustering and reranking*. Proceedings of the SIGCHI conference on Human factors in computing systems, San Jose, California, USA.

Facebook. (2010). Retrieved September 1, 2010, from http://www.facebook.com.

Flickr. (2010). Retrieved September 1, 2010, from http://www.flickr.com.

Forlizzi, J., & Battarbee, K. (2004). *Understanding experience in interactive systems*. In Proceedings of the 2004 conference on Designing Interactive Systems (DIS 04): processes, practices, methods, and techniques (New York: ACM), p. 261.

Frohlich, D., Kuchinsky, A., Pering, C., Don, A., & Ariss, S. (2002). *Requirements for photoware.* Proceedings of the 2002 ACM conference on Computer supported cooperative work, New Orleans, Louisiana, USA.

Gurrin, C., Jones, G., Lee, H., O'Hare, N., Smeaton, A., & Murphy, N. (2005). *Mobile access to personal digital photograph archives*. Proceedings of the 7th international conference on Human computer interaction with mobile devices & services, Salzburg, Austria.

Harada, S., Naaman, M., Song, Y., Wang, O., & Paepcke, A. (2004). *Lost in memories: interacting with photo collections on PDAs*. Proceedings of the 4th ACM/IEEE-CS joint conference on Digital libraries, Tuscon, AZ, USA.

Hassenzahl, M. (2003). *The thing and I: understanding the relationship between user and product. Funology: From Usability to Enjoyment* (pp. 31–42). Dordrecht: Kluwer.

Hassenzahl, M., & Tractinsky, N. (2006). User Experience – a Research Agenda. *Behaviour & Information Technology*, *25*(2), 91–97. doi:10.1080/01449290500330331

Jacucci, G., Oulasvirta, A., & Salovaara, A. (2006). *Active construction of experience through mobile media: a field study with implications for recording and sharing*. Personal Ubiquitous Computing. *Springer-Verlag London Ltd*, *11*, 215–234.

Jin, Y., Choi, S., Chung, A., Myung, I., Lee, J., Kim, M., & Woo, J. (2004). GIA: design of a gesture-based interaction photo album. *Personal and Ubiquitous Computing*, *8*(3-4), 227–233. doi:10.1007/s00779-004-0282-y

Jordan, P. (2000). *Designing pleasurable products. An introduction to the new human factors*. New York: Taylor & Francis.

Ketola, P., Roto, V. (2009). *On User Experience Measurement Needs - Case Nokia*. In the *International Journal on Technology and Human Interaction (IJTHI) 5* (3).

Khella, A., & Bederson, B. B. (2004). Pocket PhotoMesa: a Zoomable image browser for PDAs. In Proc., MUM 2004, 83, 19-24. New York: ACM Press.

Kirk, D., Sellen, A., Rother, C., & Wood, K. (2006). *Understanding photowork*. Proceedings of the SIGCHI conference on Human Factors in computing systems, Montréal, Québec, Canada.

Kuchinsky, A., Pering, C., Creech, M., Freeze, D., Serra, B., & Gwizdka, J. (1999). *FotoFile: a consumer multimedia organization and retrieval system*. Proceedings of the SIGCHI conference on Human factors in computing systems: the CHI is the limit, p.496-503, Pittsburgh, Pennsylvania, USA.

Liu, H., Xie, X., Ma, W., & Zhang, H. (2003). *Automatic browsing of large pictures on mobile devices*. In Proc., MULTIMEDIA 2003. ACM Press, p. 148-155.

Naaman, M., Nair, R., & Kaplun, V. (2008). *Photos on the Go: A Mobile Application Case Study*. In Proceedings of CHI 2008.

Naaman, M., Song, Y., Paepcke, A., & Garcia-Molina, H. (2004). *Automatic organization for digital photographs with geographic coordinates*. Proceedings of the 4th ACM/IEEE-CS joint conference on Digital libraries, Tuscon, AZ, USA.

Nokia Press Release. (2008). *Multifunctional Mobiles Make the World Go Round: Results of Nokia Nseries Study Reveal Widespread Consumer Demand for Digital Convergence*. Retrieved from April 4, 2008, from http://www.nokia.com/A4136001?newsid=1054096.

Norman, D. (2004). *Emotional Design: Why We Love (or Hate) Everyday Things*. New York: Basic Books.

Olsson, T., Soronen, H., & Väänänen-Vainio-Mattila, K. (2008). *User needs and design guidelines for mobile services for sharing digital life memories*. In Proceedings of the 10th international conference on Human computer interaction with mobile devices and services, pages 273–282. New York: ACM.

Pauty, J., Couderc, J., & Banâtre, M. (2005). *Using context to navigate through a photo collection*. In Proc. MobileHCI.

Pigeau, A., & Gelgon, M. (2005). *Building and tracking hierarchical geographical & temporal partitions for image collection management on mobile devices*. In Proc., MULTIMEDIA 2005. ACM Press (2005), p. 141-150.

Rodden, K., & Wood, K. (2003). *How do people manage their digital photographs?* Proceedings of the SIGCHI conference on Human factors in computing systems, Ft. Lauderdale, Florida, USA.

Roto, V., & Rautava, M. (2008). *User Experience Elements and Brand Promise*. International Engagability & Design Conference (Idec4), in conjunction with NordiCHI'08 conference, Lund, Sweden.

Sarvas, R., Oulasvirta, A., & Jacucci, G. (2005). Building social discourse around mobile photos: a systemic perspective. In *Proc., MobileHCI 2005, 111* (pp. 31–38). New York: ACM Press.

Share Online. (2010). Retrieved September 1, 2010, from http://europe.nokia.com/support/learn-how/sharing-and-blogging.

Shneiderman, B., Bederson, B., & Drucker, S. (2006). Find that photo!: interface strategies to annotate, browse, and share. *Communications of the ACM*, *49*(4).

ShoZu. (2010). Retrieved September 1, 2010, from http://www.shozu.com/.

Van House. N., Davis, M., Ames, M., Finn, M., & Viswanathan, V. (2005). *The uses of personal networked digital imaging: an empirical study of cameraphone photos and sharing*. In CHI '05 extended abstracts on Human factors in computing systems, pages 1853– 1856. New York: ACM.

Vartiainen, E., Kaasalainen, J., & Strandell, T. (2008). *Designing user experience for a mobile imaging application*. Proceedings of IADIS International Conference Interfaces and Human Computer Interaction, Amsterdam.

Wang, M., Xie, X., Ma, W., & Zhang, H. (2003). *MobiPicture: browsing pictures on mobile devices*. In Proc., MULTIMEDIA 2003. New York: ACM Press, p. 106-107.

Wilhelm, A., Takhteyev, Y., & Sarvas, R. Van House, N., Davis, M. (2004). *Photo annotation on a camera phone*. CHI '04 extended abstracts on Human factors in computing systems, Vienna, Austria.

Chapter 14
Touch-Based Access to Mobile Internet:
Recommendations for Interface and Content Design

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ABSTRACT

This chapter reports user experience findings from two field trials, where Mobile Internet access was supported through Near Field Communication (NFC)-based tag infrastructure, The first field trial was done in public urban environment with the infrastructure of 2650 tags and 248 users, and the other field trial dealt with mobile learning with the infrastructure of 11 tags and 220 users. The authors results show that touch-based interaction can provide enhancement to the Mobile Internet user experience. Touch-based access builds a semantic bridge between the physical context of use and the Mobile Internet experience, the user experience converges seamlessly into one where both the physical and digital worlds play a role. The authors report and analyze the subjective experiences of the end users collected during the field trials. As a result, they summarize recommendations for interface and content design.

INTRODUCTION

Internet content and services are becoming increasingly versatile and soon will integrate with practically all the imaginable and yet unimagined areas of our lives. It seems likely that internet use will not be limited to the boundaries set by desktop use, but rather will be needed and sought after also in mobile situations. The fast technological development of wireless networks and wireless communication devices seems to offer solutions that can make that happen. Modern urban environments are evolving towards Mark Weiser's (Weiser, 1991) vision of Ubiquitous Computing, where all objects are computerized and networked.

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The next wave of growth in the technology outside the traditional PC desktop use is often thought in mundane terms - with such things as cell phones and PDAs. In reality, we stand on the verge of an era that will see previously unimagined networked devices and objects (Meloan, 2003). There are already some exciting applications that span the technology spectrum. Such diverse networked "devices" offer concrete evidence of Metcalfe's Law (Metcalfe, 1995). Metcalfe, one of the developers of Ethernet, formulated that the usefulness of a network increases by the square of the number of nodes (users or devices) connected to the network. *"In the future, everything of value will be on the network in one form of another,"* says John Fowler, Software CTO of Sun Microsystems (Meloan, 2003). *"And once they're on the network, we can aggregate data from those diverse devices, and then deliver that data to equally diverse devices - in informative and compelling ways. Most people think of a PC or a PDA as things connected to the network,"* continues Fowler. *"But here we are connecting trees, race cars, and astronauts to the network. It's going to become a much more seamless spectrum."*

We currently see a rise to various concepts that integrate the physical world with the virtual one. One of the most popular is the ability to access electronic information from virtually any objects, a vision of the "Internet of Things" (ITU Internet Reports 2005; Saint-Exupery, 2009), as a parallel to the real Internet. Industry and academia have shown big interest in the "Internet of Things" (IoT) in which the Internet extends into our everyday lives through a wireless network of uniquely identifiable objects. Here real world objects have an individual digital presence as embedded computers or visual markers on everyday objects allow things and information about them to be accessible in the digital world; physical objects are uniquely identified and described in a standardized way which facilitates access to and interaction with them.

The Mobile Internet has shown that technological advances and service availability alone do not result in widespread adoption and use (Constantiou et al., 2007). There are still challenges in the Mobile Internet hindering usage and slowing down adoption rates. An example of such a challenge is our limited understanding of how the Mobile Internet differs from the traditional internet experienced through a fixed desktop environment (Isomursu et al., 2007).

Research on mixed reality user interfaces (Milgram et al., 1994) has explored how our physical environment could be enhanced with digital content and services by mixing digital information and affordances with our physical world. The Internet of Things implies a symbiotic interaction among the real/physical, the digital/virtual worlds: physical entities have digital counterparts and virtual representation; things become context aware and they can sense, communicate, interact, exchange data, information and knowledge. NFC (Near Field Communication) technology provides one alternative for adding a link between an object in the physical world and digital content and services associated with that object. This link can be used by direct physical manipulation to provide digital services through a physical interface. These kinds of physical mobile interactions make it possible to bridge the gap between the physical and virtual world in an intuitive way (Falke et al., 2007). The combination of RFID and visual tagging of everyday physical objects and NFC-enabled devices can foster the "Internet of Things" where every resource that surrounds us and its associated services are available through some kind of networking and programming infrastructure (López-de-Ipiña et al., 2007).

TOUCH TO ACCESS MOBILE INTERNET

Accessing internet content through objects in the physical world is called physical browsing

(Ailisto et al., 2006). In physical browsing, the links are embedded in physical objects, and the user can select and use them to access internet content and services.

The technology used in the research presented in this chapter, NFC, is one technology for implementing physical browsing user interfaces. Other possible solutions include, for example, visual codes that are read through the camera of a mobile device (Rekimoto & Ayatsuka, 2000; Hansen & Grønbæk, 2008), infrared transceivers and tags (Swindells et al., 2002) or infrared beacons (Debaty et al., 2005; Want et al., 1999), and various other RFID variations (Want et al., 1999). Use of 2D barcodes - two-dimensional figures that represent data such as URLs - is widespread for example in Japan allowing users to access related websites by scanning these figures with mobile phone cameras (O'Neill et al., 2007). Japan's NTT DoCoMo, a mobile communication carrier, has been developing "Audio Barcode," a technology that allows data, such as text information describing website URLs, to be carried and transmitted on sound waves in the audible range (music and spoken word) (NTT DoCoMo, 2007). Audio barcode represents and transmits data in a similar way to 2D barcodes. Data embedded in sound waves are picked up by target devices with a microphone (mobile phones, for example), analyzed by special software, and then extracted. NTT DoCoMo expects Audio Barcode's use scenarios to include automatic transmission of website URLs to a mobile phone that is directed at a television set or radio. NTT DoCoMo also expects the barcode to add a new dimension to the mobile phone. For example, at an art museum, the mobile phone could be held before an audio guide in one language but display information in another language.

The user experience of NFC-supported service and content access has been studied in controlled settings. Touch-based service and content access have been found to be easy to learn and use, and users value the simplicity of the technology (Isomursu et al., 2008; Riekki et al., 2006; Välkkynen et al., 2006a). The research presented in this chapter contributes to the prevailing knowledge by exploring the user experience related especially to Mobile Internet access and providing results from the use of technology in field settings in various contexts.

NFC Technology

The field trials reported in this chapter have been implemented within the constraints of a research project that has evaluated applications and services based on Near Field Communication (NFC) technology. NFC is a short-range wireless technology that allows electronic devices to exchange data upon touching. NFC standards have been built over existing radio frequency communication standards (e.g. RFID and smart card standards), so it is a special case of RFID implementation technology.

The most common scenario for NFC use is to integrate the NFC reader into a mobile device, such as a mobile phone. This has already been done by some mobile phone manufacturers, and low quantities of NFC-enabled mobile phones have been available in the market for some years now. Larger quantities are expected to emerge in the market in the near future. The standardization of the NFC technology has progressed well, and leading mobile phone manufacturer Nokia has announced they will use NFC technology in their smartphones in the near future. The mobile device with integrated NFC reader can be used to read NFC tags, or to communicate with other NFC-enabled devices upon touch. NFC tags are small and cheap, and they can be attached to virtually any object or surface. The tag can then act as a link between the physical and digital worlds.

Using an NFC tag as a Mobile Internet access point is very simple. The tag can directly store the URL to the web content. When the user touches the tag, the URL is transferred to the mobile phone using short-range radio frequency.

No resolution services are needed, as the browser available in the mobile phone can directly access the URL transferred from the tag. In this chapter, we explore the usage scenario where a URL is transferred from the tag to the mobile phone. It is important to note, however, that the tag can store other formats of data too, such as phone numbers.

For example, Sony FeliCa has succeeded in bringing electronic presence to objects in the physical world. "FeliCa" is Sony's implementation of NFC and thus fully compliable with the NFC standard (NTT DoCoMo, 2010). Japan's mobile operator NTT DoCoMo sells mobile phones that have a built-in IC chip. This built-in chip is able to emulate FeliCa contactless smart cards. Mobile phones embedded with a FeliCa IC chip are known as "Osaifu Keitai" (means of mobile wallet) by NTT DoCoMo, and mobile phones equipped with those chips can be used as electric money, train tickets, identifications, door keys and so on. Today those chips are embedded in 62 million mobile phones, putting NFC-like capability into the pockets of more than half of subscribers in Japan. Sony recently showed an array of novel uses for its FeliCa contactless technology (NFC Times, 2010), including for example FeliCa-enabled television remote controls to pay for video on demand, FeliCa-embedded glucose meters and pedometers, and "data handover" applications that would enable users to sync photos, music and other big files among their phones, PCs, cameras and other devices with FeliCa chips inside.

Mobile Internet Access Challenges

The expected main benefit of touch-based Mobile Internet access is that the user does not need to type or remember the URL needed to access the Mobile Internet content. Other solutions to this problem explored by previous studies include, for example, context-sensitive search (Church & Smyth, 2008) and adaptive content push (Beaver et al., 2006).

Reducing the number of key presses required to access and use Mobile Internet content has been found to be a one of the key principles in making the Mobile Internet more usable (Buchanan et al., 2001; Kamvar & Baluja 2006). The effort needed to enter a word on a cell phone keypad is more than double that required to enter the same word on a full QWERTY keyboard (Kamvar & Baluja 2006). With touch-based Mobile Internet access, the user does not necessarily need to use the keypad at all. This makes Mobile Internet access easier and faster for all users, and is especially valuable for those who cannot use the small keypad of a mobile phone because of limited vision or poor hand-eye coordination (for example, the visually impaired or elderly), or for reasons of illiteracy (for example, very small children). NFC technology can be used to implement Mobile Internet access requiring no keypad use, or reading of the display. This has proved especially valuable with elderly users (Häikiö et al., 2007).

In a research paper by Rukzio et al., (2004) it was established that finding services in a given context is one of the central issues that needs to be addressed in order to create useful mobile services. A significant problem is that the discovery process of location-based and context-aware services is left to the user alone. In order to solve this problem, the user needs to be made aware of the availability of these services, for example by means of different kinds of visual codes (Rukzio et al., 2004).

RESEARCH METHODS

The research question explored in this chapter deals with existing technology (touch-based interaction enabled by NFC technology) that is commercially available, but not yet widely used in the market. Therefore, to get access to user experiences evoked in normal everyday use, we chose to use field trials. In the trials, selected users were introduced to and provided with the technology and related applications. These then made a commitment to use the technology as a tool in their everyday life, and using selected methods, report their subjective experiences to the researchers.

The two field trials presented are part of a larger three-year (2006-2008) technology research project, SmartTouch, which explores the use of NFC technology in various domains. The field trials were planned and implemented in co-operation with the city authorities, service and technology providers, and research parties. The goal was to achieve as high an experimental reality (Aronson, 2004) as possible, i.e. the trial aimed at providing conditions where users would be able to integrate the evaluated technology and related applications into their everyday life and practices.

In both field trials, the research focus was on the subjective user experience of the trial users. We define the subjective user experience to cover both the sensory experience evoked by the use of Mobile Internet, and the subjective interpretation of the experience. This can be called, for example, "qualia" (Ramachandran & Blakeslee, 1998); which is to say the raw feeling of subjective sensations. Therefore, the approach for understanding the user experience is phenomenological, i.e. the user experience is seen as a subjective, first-person phenomenon (Greenfield, 2000). Methodologically, the problem is how to capture objective research data about a subjective experience. In our trials, the methods for capturing an objective account describing the subjective user experience were tailored individually for each field trial. The primary sources of data were the humans subjectively experiencing the user experience, i.e. the trial users. Research on psychology and experience design shows that describing subjective experiences has its challenges, for example, through recall problems (Robinson & Clover, 2002), or difficulty in verbalising one's emotions (Desmet, 2002; Reijnveld, 2003). However, our hypothesis is that a subjective, first-person description of an experience is still the most reliable source available for understanding and characterizing the subjective user experience, as it is impossible for another person to experience the subjective experience of another person (Greenfield, 2000). Subjective descriptions of user experiences were collected primarily through questionnaires and semi-structured interviews. These descriptions were complemented with observations which provided an external interpretation of the subjective experiences. Observation included both direct observation of behaviour triggered by the user experience, and observation of the use and usage patterns through automatically compiled log data.

In this chapter, we focus purely on analyzing the user experience related to consuming Mobile Internet content and services, and exclude analysis of the socio-economic impacts of the applications used, or how the applications were able to fulfil their goals (e.g. learning goals in the case of the mobile learning trial).

FIELD TRIALS

The results presented in this chapter are based on the findings from two field trials. In the first field trial, NFC tags providing access to selected Mobile Internet content were distributed in public places in the city of Oulu to be used by anyone passing by. In this trial, the vision of ubiquitous Mobile Internet access in an urban environment was explored. The access tags were called "Information tags". In the second trial, a mobile learning environment with an urban adventure realized by the means of an NFC track was investigated. This trial aimed to analyze touch-based Mobile Internet access directed to specific users in a defined context as an implementation technique for mobile learning.

Both field trials were organized in the city of Oulu, Finland. Oulu is the sixth largest city in Finland with 130,000 residents and with a population density of 357 people per km². Today, there are some 850 high-tech companies based in the Oulu area, employing some 18,500 people. (Ministry for Foreign Affairs of Finland, 2009)

Information Tag Trial

In the information tag trial, 2650 NFC tags providing access points to selected Mobile Internet content were distributed in public places in the city of Oulu. The vision of this trial was that tags placed in our everyday environment can provide location-aware access to Mobile Internet content and services for visitors or people passing by. Service and content access could be provided by commercial players, public authorities, communities and even private persons, as NFC tags are cheap and easy to program. In our trial, the tags providing a mixed-reality user interface to access the Mobile Internet were called "information tags" to depict the specific nature of information access.

Information tags were placed in different contexts:

- on parking meters. The parking meters were placed outside on the pavements. People parking their cars used the parking meters, and also people walking by passed the parking meters within touching distance.
- theatre. In a theatre, information tags were placed on large posters on walls, and on stands placed on the tables of cafeterias and halls.
- restaurant. In a restaurant, information tags were placed on stands placed on the tables.
- pub. In a pub, information tags were placed on the bar and tables for clients.
- in a bus and at bus stops. In the bus, information tags were attached within reach of the passengers (see Figure 1).

In all contexts, a selected set of tags providing Mobile Internet content access was provided. This generic set of content contained the following:

Figure 1. A passenger accessing Mobile Internet content through information tags available in a bus. Note that the symbol indicating the area to be touched is different in this version of information tags. It was later changed into an N-like symbol visible in the other figures.

- access to news through a Mobile Internet version of local newspaper
- the menu of a local restaurant
- the menu of a local pub
- the program of local theatre
- an operator portal for city-specific information

In addition to generic content, theatre, bus stops and pub-provided content specific to those environments was given. In the theatre, information about plays including, for example, trailers and the director's comments, could be accessed through tags placed in posters (as seen in Figure 2). At bus stops, the users could access real-time bus schedule information through an information tag. In the pub, the clients could use the information tags to access Mobile Internet content describing the special selection of beers available (see Figure 3). The total number of tags distributed in the city was 2,650.

The goal of the information tags was to provide a generic service for people visiting the places in which the tags were placed. However, for research purposes, we needed to recruit users in order to

Figure 2. Theatre visitors consuming Mobile Internet content about the play

Figure 3. Pub customer accessing Mobile Internet content describing special beers available at the pub

provide them with the NFC-enabled mobile phones. Information tags were available for use for the total of 238 trial users, who were recruited to use other NFC-based applications, namely NFC-enabled parking payment, ticketing in a theatre, ordering lunch and pub customer services. The users were recruited primarily for testing these application concepts, not the information tags. Information tags provided an add-on service that all recruited users (or any other user with an NFC-enabled phone) were able to use during the trial period. The parking pilot users were recruited from companies operating in the city area, as their employees needed and used parking services regularly. Theatre users were also recruited through local companies, who wanted to provide a theatre experience for their employees. Restaurant and pub users were recruited from the regular customers of both places. The individual pilots were active at different times (see summary in Table 1).

Two main sources of data were used for analyzing and interpreting the use and user experience evoked through the information tags. The first data source was the automatically generated logs about use. The logs provided information about who used the tags, which tags were used, and when the tags were used. The second data source was a questionnaire and related interviews. They were used for collecting subjective experiences related to the use of the information tags.

The user's subjective experience was collected immediately after the trial with questionnaires. In some contexts, a web-based questionnaire was used (e.g. for the theatre visitors), and for some, a paper-based questionnaire was applied (e.g. for the parking application users). The choice was made on the basis of practical arrangements: in the theatre, each user used the NFC-enabled mobile phone to access theatre specific Mobile Internet content only once, and they did not meet

Table 1. Timing of information tag pilots and duration of use for individual users

	Period	Duration	Duration of use for individual user
Parking pilot	3 Sep – 1 Nov 2007	approx. 8 weeks	Whole pilot period
Theatre pilot	8 Nov – 19 Dec 2007	approx. 6 weeks	One evening
Pub pilot	12 Nov – 31 Dec 2007	approx. 7 weeks	Whole pilot period
Restaurant pilot	19 Nov – 31 Dec 2007	approx. 6 weeks	Whole pilot period

the researchers face-to-face. Using a web-based questionnaire, the user experience data could be collected immediately after each theatre visit, thus minimizing recall problems. All users returned their online questionnaires within a couple of days after the theatre visit. On the other hand, the parking application users met the researchers in a feedback seminar right after the trial, when they returned their phones to the research team. This provided a perfect opportunity to give the users the paper questionnaires which they could return when they left the seminar. However, not everyone had time to fill out the paper questionnaire, and they were subsequently requested to fill the questionnaire through a web interface. 43 users filled the paper questionnaire in the seminar, and five users filled the web questionnaire right after the trial period. In the restaurant and pub trials the request to fill out a feedback questionnaire was sent to the users by email immediately after the trial ended, and the majority of the users replied within one week (only four out of 39 used more than a week), and more than half responded on the same day that the request was sent (20 out of 39). A summary of the number of test users in each context and the data available through final questionnaires is presented in Table 2.

All the users were adults, the youngest being 22 years and the oldest 72 years. The average age was around 40 years. The gender balance was equal for parking and restaurant application users, but for the theatre, females outnumbered males (76% of the users were females), whereas in the pub context males outnumbered females (88% male users).

Even though the log data and questionnaires provide the primary source of data used in the analysis, we also did some additional, context specific data collection especially for capturing data that could help in understanding the subjective user experience. The users of the parking application were interviewed after the trial in a feedback seminar. Eleven users volunteered for the interview. The interviews were recorded. The average time of the interview was around ten minutes, the majority of which was used for exploring issues related to the parking application, not to information tags. Also, the users of the parking application were able to send feedback during the trial using a feedback form in the Web. The total number of feedback forms received during the parking trial was 26 – most dealing with the parking application itself. The theatre visitors were observed in actual use situations by attending the theatre visits with the users. Observation was done during one selected evening, when the researchers visited the theatre and at the same time, trial used the services themselves to get a first-person experience in addition to observing other users and the responses of bystanders. After visiting the theatre, the researchers verbalized their own experiences and observations through an open-ended questionnaire. Usability testing was performed in the restaurant pilot. A total of five users used the service in the restaurant, and the testing session was videotaped. In the usability test, the users followed a predefined test script, i.e. they all performed the same activities in the same order. Also, personnel of each establishment were interviewed for their interpretation of user

Table 2. Number of users for each trial and reply rates for the final feedback questionnaire

	Total # users	# of returned questionnaires	Questionnaire return %	Questionnaire type	Time of returning the questionnaire
Parking	51	48	94%	paper combined with web	when users returned the phones
Theatre	141	101	72%	web	within a couple of days after the visit
Restaurant	27	23	85%	web	mainly within one week after the trial
Pub	19	16	84%	web	mainly within one week after the trial

experiences evoked, as they had received feedback from the users during the trial, and had observed the users on a day-to-day basis.

The log and questionnaire data was analysed with basic statistical methods, and used for producing charts and other visualizations of data for interpretation. Observation, interviews and feedback were analysed with content-based qualitative methods, where the main goal was to interpret and analyze descriptions of the subjective user experience, and find relationships and explanations with findings based on quantitative data.

Mobile Learning Trial

Our second field trial was implemented in the school environment. The users were 14 to 15 year old pupils of schools located in the Oulu district. A total of 228 pupils attended the trial during May 2008. Participating pupils were from multiple classes of four different schools. The mobile learning concept used in the trial was called "Amazing NFC" after the well known TV series called "The Amazing Race".

Over the course of the field trial, each pupil participated in one Amazing NFC lesson, during which the pupils were guided through an urban adventure track with the help of mobile phone and related Mobile Internet content. On each trial day only one lesson was organized, in which two classes participated at a time. Eleven locations around the city of Oulu were each marked with an NFC-marker, and pupils were to visit all the eleven locations during the lesson. Here, we call these locations "control points". The pupils were grouped into small groups of two, and all were provided with NFC-enabled mobile phones for the duration of the lesson, which lasted an average of three hours. By touching the NFC tag at each control point, the pupils received information about the place where the control point was located (e.g. a fire station), and given a related question that required an answer. In some locations, the question required the user to perform some tasks to acquire the information needed to answer the question. For example, at the social insurance institution, the pupils had to browse the web service of the institution to access information required to answer the question correctly. During the lesson, the teachers were able to follow in real time via a web-based interface how the pairs of pupils proceeded through the adventure track. Also, the pupils were advised to use the mobile phone to call the teacher in case of problems or questions.

In Figure 4, the pupils try Amazing NFC at the city hall of Oulu. This situation was photographed in the design phase to get feedback from the pupils. In the actual trial, the visual outlook of the tag was richer and more colourful, the tag was located in the entrance hall instead of auditorium, and the pupils were wearing their outdoor clothing.

The educational goals of the lesson were to provide the pupils with skills related to landmarks, public buildings and offices in their hometown, and practical skills related to dealing with public authorities in the course of mundane everyday tasks. The locations chosen as control points were the city information centre, fire station, swimming hall, police station, museum, city hall, youth and culture centre, zoological museum (requiring a bus journey to the museum and back), city library, theatre and the social insurance institution. The control points, with the exception of the zoological museum, were located in the city centre

Figure 4. Pupils trying out Amazing NFC at the city hall of Oulu

within a couple of kilometres distance of each other, and the pupils were expected to travel from one control point to another with bikes (although some used mopeds against instructions).

The Amazing NFC lesson was planned and designed in close cooperation with teachers, service and technology providers, and researchers. Special emphasis was put into integrating the concept into the normal practices of the schools, as the goal was to create a concept that could be adopted as a learning instrument to be used also after the research trial. This required the close involvement of teachers and school administration in planning and implementing the applications, and organizing and supervising the trials. During the trial, the researchers were only involved in the data collection activities; teachers took full responsibility for organizing and supervising the actual Amazing NFC lessons.

User experience data was collected in three phases: before use, during use, and after use. Before use, our researchers observed how the pupils learned to use the evaluated technology, and what kind of spontaneous reactions and discussion took place at the introduction of the concept. A mobile questionnaire, comprising of short multiple-choice questions, was used to capture information about the expectations and attitudes towards the technology-supported learning experience just before the Amazing NFC lesson. Unfortunately, there were some technical problems with the mobile questionnaire during the very first trial lessons. Additionally, some teachers forgot to provide the NFC tag used for accessing the mobile questionnaire for their pupils. Therefore, not all pupils were able to report their experiences through the mobile questionnaire (we received 133 valid responses from 228 participants).

User experiences during the Amazing NFC lesson were collected through video recordings, and the automatic creation of log data about how the pairs of pupils progressed. Video recordings were made by placing video cameras at fixed spots where the camera recorded the pupils visiting that specific location on the track, and by providing two pupil pairs (i.e. altogether four pupils) video cameras that they could use to record their experiences during the lesson.

After use, the pupils filled out a multiple-choice mobile questionnaire collecting data about the user experience immediately after the lesson. The data received from both mobile questionnaires was used to survey how pupils' expectations and attitudes changed during the trial; whether their expectations were met and attitudes altered. The pupils were also requested to fill out a web questionnaire within two weeks after the trial. Pupils mainly answered the web questionnaire at school, as their teachers took the initiative to offer pupils time and facilities to fill in the questionnaire in the midst of the school work. A web questionnaire aimed for evaluating in more detail the pupils' experiences about the lesson, and pupils was also asked for generating ideas for improving the mobile learning concept. In addition, we arranged a workshop with twelve pupils exploring their experiences with the Amazing NFC. The workshop included participatory features, i.e. the pupils participated in designing how to iterate the concept for future use. The data collection methods and numbers of users for each method are listed in Table 3.

Table 3. Summary of data collection methods and number of valid cases for each method

Data collection method	Number of valid cases
Mobile questionnaire before use	133
Observation of learning before use	30
Video on selected control points	50
Video shot by pupils during the lesson	4
Log data about lesson	228
Mobile questionnaire after use	133
Web questionnaire after use	81

USER EXPERIENCE FINDINGS

We offer here a combined presentation of the findings related to the Mobile Internet user experience revealed through the analysis of user experience data collected in the field trials described above. The findings are grouped into five groups discussing user experience findings related to (1) ease of use, (2) social acceptance, (3) discoverability, (4) content and (5) technical problems.

Ease of Use

The trials provided all users with their first experience of using NFC technology. Therefore, it is not surprising that learning touch-based interaction required some practice. As NFC technology is based on short-range radio technology, the NFC reader reads a tag not only upon physical touch, but also from a distance of a couple of centimetres. Therefore, the users needed some practice to find the comfortable personal reading distance: some users preferred to physically touch the tag, while others preferred a short reading distance. Also, finding the right contact point both from the phone and from the tag, and learning the response times required some practice. However, all users were able to learn to use touch-based interaction with a few repetitions. Our observations indicate that learning NFC-enabled touch-based interaction requires hands-on practice, but can be adopted within a few minutes. In the information tag trial, over 90% of the users stated that learning touch-based interaction to access Mobile Internet content was easy. Observation of pupils in the mobile learning trial showed that none of the pupils had problems in learning to access Mobile Internet content through touch within a couple of minutes of hands-on training.

The use of tags for accessing Mobile Internet content was perceived as extremely easy in both trials. Users reported that accessing Mobile Internet by touching tags was very easy (92,6% of Amazing NFC web survey respondents stated that using NFC phones and touching tags was easy and natural). Participants also described the experience of touching a tag to access Internet content to be pleasant (depending on context, 70-80% of information tag users said that touching was a pleasant interaction technique). The only inconvenience reported by the users was related to using two phones during the trial. Even when the trial users were allowed to use the trial mobile phone for their personal phone calls, they usually preferred to carry both their own and trial phones with them most of the times. This caused extra worry, as the users were required to keep track of and find space for two devices. Also, this fact probably affected the user experience, as the full possibilities of mobile convergence (i.e. combining internet access with normal functionality of a mobile phone) were not realized. This is well illustrated by the following user comment from an interview concerning an information tag user participating in the parking payment trial:

"I would definitely use this service if it would be made available. However, the prerequisite would be that I would not be required to carry two mobile phones with me." (translated by the authors)

The findings related to ease of use of touch-based internet access are summarized in table 4.

Social Acceptance

In none of the trials did the users report that touching tags would feel socially unacceptable, as has been indicated by some user studies on similar user interfaces conducted earlier (Riekki et al., 2006). However, in some cases users did present concerns on how easy Internet access might negatively affect social interaction. For example, in the pub, users expressed concerns that consuming Mobile Internet content through a mobile device in a pub would decrease social interaction between the pub clients, and the clients and personnel. Pub visitors seemed to value the

Table 4. Summary of findings related to ease of use

Issue	Finding
Ease of adoption and learning	Requires hands-on experimenting, but can be learnt within a couple of minutes with some repetition.
Ease of use	Very easy to use, 92,6% stated touch-based access was easy and natural
Pleasantness	Pleasant to use (70-80% found interaction pleasant) but requires integration with user's personal mobile phone.

social interaction provided by the pub environment. For example, the information tags provided information about the special products available but some users said that they would prefer getting that information directly from the pub personnel.

The nature of current Mobile Internet content typically is most suited for personal use, and consuming it could reduce the interaction between people. However, with good contextual design of the services and content, it is posited that social interaction can also be fostered and encouraged. For example, in the pub context, the service content could be designed to evoke discussion or interaction amongst pub clients and between clients and personnel, for example, in the format of quizzes. In the mobile learning trial, the learning experience was social, as the pupils were instructed to work in pairs. Working in pairs was preferred by almost all (97.5% of respondents of the web questionnaire). In addition, most participants (59.5% of respondents of the web questionnaire) reported that they had formed bigger groups during the Amazing NFC lesson.

In the theatre context, two concerns related to social interaction were identified. First, the placement of the tags had an influence on how people located themselves in the space, and therefore placement seemed to negatively affect group formation, and draw people away from each other into solitary units. When designing NFC based systems, special attention must be given to these kinds of social and behavioural concerns. The optimal placement of tags supports the natural paths and flow of people in the space by allowing people to form groups and engage in social interaction, but at the same time, does not block pathways.

Second, as some of the content that was made accessible by the tags was video with sound, some users seemed embarrassed or startled by the loudness of the suddenly appearing sound. This might also partly explain why the preferred media format in Amazing NFC was text (see Figure 9). As the user usually does not know for sure what kind of content the tag links to, these kinds of embarrassing moments may form a formidable hindrance to the adoption of Mobile Internet usage. As a possible solution, a tag could indicate the media types it links to through its graphical design. Use of symbols has been suggested previously for indicating the type of the service provided through the tag (Välkkynen et al., 2006b) but, according to our knowledge, not for the purpose of indicating media type.

The findings related to the social acceptance are summarized in Table 5.

Table 5. Summary of findings related to social acceptance

Issue	Finding
Feeling of social disapproval of using touch-based access in social situations	Not directly reported by our pilot users, albeit found to exist in previous studies. However, loud audio content was experienced embarrassing in social situations.
Impact on social interaction	As content typically designed for individual consumption, negative effect was experienced. However, also possibilities for content fostering social interaction were identified.
Placement of tags	Has an impact on group formation.

Discoverability

The tags can provide support for service discovery only when the user is able to discover the tags embedded in things and the environment. Therefore, the tags must be marked somehow, or the user must know where the tag is. In small, specific purpose applications, it can be reasonable or even desirable to have hidden tags that are known only by the users to whom they are targeted (e.g. service described in Häikiö et al., 2007). However, for services that are targeted for larger audiences or random users, marking the tag somehow is crucial.

In small-scale prototypes of information tags, we have used special-purpose visual design for each tag. For example, to access bus time schedules we used an icon representing a bus to mark the tag. However, we quickly found out that when there were many services available, the users had trouble discovering tags that did not share common visual characteristics. In the trials presented here, we used a special icon to mark the tag, and then explained the content provided on the space around the tag. In the first trials, we used the icon illustrated in Figure 1 (similar to work presented by Arnall (2006)). The users learned quickly that the round icon was always used to mark a tag. However, soon after, the NFC Forum (http://www.nfc-forum.org) introduced their own standardized visual icon that is illustrated in Figures 2 and 3. We decided to adopt the standardized icon, as standardization seemed to be a good way for introducing a common language to large audiences globally. Amazing NFC trial users reported having experienced no difficulties in locating the NFC tags at the control points: 92.6% of the pupils stated that finding tags was easy.

As the markings we used were based on visual icons, for the visually impaired, discovering tags can be problematic. With NFC technology, it is, however, possible to implement an audio application that can aid in locating a tag. When the visually impaired user brushes a surface with a mobile phone, the phone gives an audio cue when the tag is detected. However, the user should already know that the tag would be available for use somewhere.

In the information tag trial, users discovered tags that did not respond to touch. For example, the tags used for parking payment could be used only by subscribers who had the parking payment Java application installed in their mobile phone. The users found these situations very annoying. Therefore, it could be recommended that standardized markings would not be used on tags that are not targeted for all users. In these cases, the users of a special-purpose application should learn to find the service tags by other means.

We used the same sizing in each trial, i.e. the size of the visual marking was always the same as the size of the tag (c. four centimetres). This seemed to be adequate when the tags were located near the user, i.e. within reach. However, several users complained that the visual markers were too small when the tags were located further away. This was especially noted in the theatre pilot, where the smart posters were placed on the walls of the theatre building. The size of the visual icon was obviously too small to be properly seen from a distance, as is illustrated by the following comments made by the theatre visitors:

"The target marks used in the posters should be printed larger so that one could see it over a distance."

"The tags were too small." (translated by the authors)

On the other hand, if the visual icon used to mark the placement of the tag is larger than the tag itself, the users might face difficulties in finding the correct spot to touch within the visual icon. This could be solved, for example, by having additional visual signals inside the visual icon to indicate the optimum spot to touch.

Table 6. Summary of findings related to discoverability

Issue	Finding
Visual design	Standard, easily recognized visual marking is needed, even though does not help visually impaired.
Expected response	Tag identified as an NFC tag should always respond somehow upon touch and special-purpose visual design for tags should be used to avoid confusions.
Size of the tag	Circa four centimetre diameter is good for locating tags near by, but when the distance is tens of meters, visual markings need to be bigger.

The findings related to discoverability are summarized in Table 6.

Content

The most accessed Internet content during the information tag trial was the news service of the local newspaper. It was the most used when measured by the logs (see Figure 5), and rated subjectively as the most interesting and valuable service provided in the trials.

The program of the local theatre was also rated as interesting in subjective ratings. However, many users were disappointed that the content of the theatre program was static, which meant that it was not updated during the trial, and therefore contained old information.. This observation was repeated in several comments; the users expected digital content to be up-to-date, and they wished that it would be frequently updated.

The information tag users expressed hopes of better utilizing the possibilities of the digital platform by, for example, providing location aware services. The users rated content describing local events and information as most interesting (i.e. local news and the program of local theatre). Some content available through the tags did not take full use of the location information. For example, a tag that provided access to a tourism information service provided information about another city as the default. The users were puzzled why they were provided information about events in the city of Helsinki, when they were located 600 kilometres away in Oulu. Of course, they could access information about events in Oulu by selecting the correct city from a pull-down menu, but the users expected the knowledge about their location to be automatically processed by the service.

The pilot specific tags were used more than generic tags in all pilots (see Figure 6). In the restaurant pilot, the pilot specific tags were used for making an order, and the user had to touch multiple tags to finish an order. This explains the high volume of tag usage in the restaurant pilot.

Even though the pupils attending Amazing NFC lessons mostly reported that the mobile learning experience was better than classroom learning (93,8% of web survey respondents) and that they enjoyed participating in the lesson (see Figure 7), they strongly criticized the Mobile Internet content provided. The majority of pupils reported that the tasks were not challenging enough (70,4% of respondents of the web survey) and

Figure 5. Distribution of access to Mobile Internet content through information tags during a nine-day period estimated not to contain artificial accesses caused, for example, by usability testing or research demonstrations

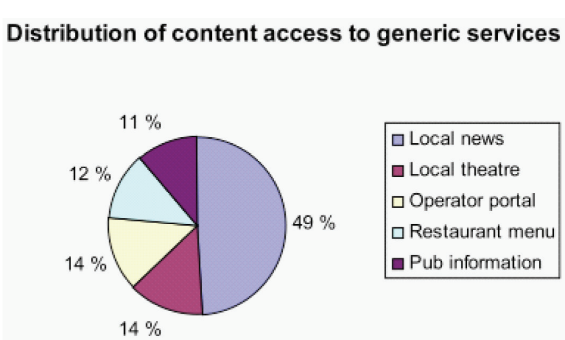
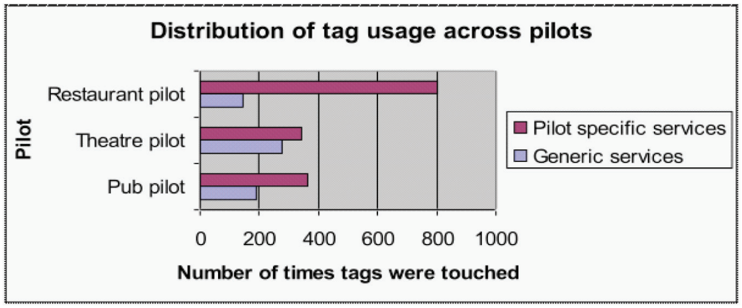


Figure 6. Distribution of tag usage across pilots. Data from the parking pilot was not available for analysis due to technical problem with logs.



40,7% stated that the information provided was not interesting. Most improvement ideas suggested the provision of more challenging tasks, for example by including physical activity and increasing the variety of tasks. The following user excerpts illustrate ideas for improvement related to the content expressed by the pupils after the lesson:

"I would like to have more interesting content and more difficult questions at the control points."

"There should be more challenge at control points. Now the maps were not actually needed and the questions were too easy."

"The tasks should have been longer, and more effort should have been required to find answers to questions, because now all just guessed the answers. There should have been someone supervising the control points to check that all the tasks would be performed correctly." (translated by the authors)

One factor contributing to negative attitude towards the Mobile Internet content provided and related tasks may be the association made by naming Amazing NFC after the popular TV show The Amazing Race. The naming might have set expectations and mental impressions that were not fulfilled. The excitement and challenge level of the TV show was not obviously reached during the lesson.

Clearly the most interesting control point for Amazing NFC participants was the visit to the Zoological museum (see Figure 8).

The visit started with a bus journey, where the pupils were able to use their mobile phones for ticketing and touching information tags available inside the bus. For other transitions, pupils used

Figure 7. Feelings towards Amazing NFC according to the mobile survey made right after the lesson (n=133)

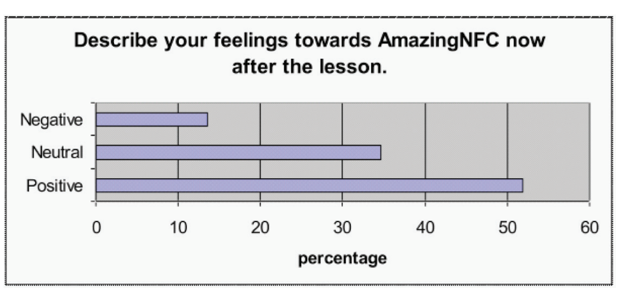
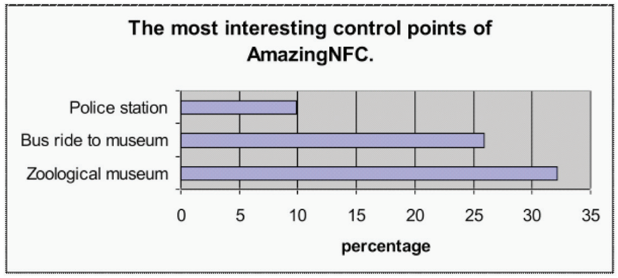


Figure 8. The three most interesting control points of Amazing NFC according to the web survey (n=81)



bikes in all weathers. During some lessons, the weather was cold, rainy and windy. Also, as the lesson lasted approximately three hours, some pupils started to get tired. Therefore, the bus ride was experienced as a welcome change. At the Zoological museum, the pupils were instructed to see the animals on display, and consume Mobile Internet content about the animals through tags attached to the displays (see Figure 9). When compared to other control points, there was clearly more activity required and interaction with the environment. The average time used for the visit was the longest during the lesson, and the Mobile Internet content and related questions integrated seamlessly with the physical activities required and the context of use. Our findings indicate that the Mobile Internet user experience successfully supported and enhanced the museum visit user experience. At most control points, the pupils were only required to quickly visit the entrance hall of a public building for reading the Mobile Internet content to answer the question. In these cases, the physical experience and social context of the location did not successfully integrate with the Mobile Internet content provided, as the pupils did not really interact and experience the space and environment they visited.

In the information tag trial, which lasted for a longer period, the usage was clearly most frequent at the beginning of the trial, and rather quickly faded with time. The users explained this phenomenon most often by highlighting the static nature of the content. When they had seen the content once, it did not interest them anymore. This may also explain the popularity of the news service since it was frequently updated.

Table 7 summarizes the findings related to content.

Technical Problems

Some users were annoyed by the long download times of the content. Especially, at the theatre the download times could be inconveniently long, as the structure of the building impaired the capacity of the wireless network available, and the video content provided needed more network capacity than most commonly used Mobile Internet pages containing primarily text and small pictures. Perhaps because of the long download times of video and pictures, text was the preferred format

Figure 9. A pupil touching an Amazing NFC tag at the Zoological museum

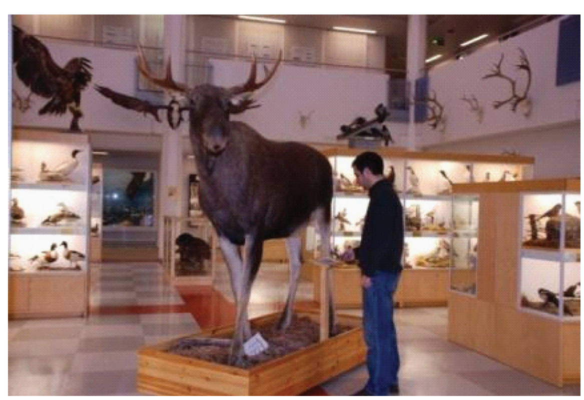


Table 7. Summary of findings related to content

Issue	Finding
Dynamic content	Mobile content was expected to be dynamic; users were disappointed to receive static content.
Location aware content	Users expected direct access to localized content.
Combining digital with the physical	Digital content that integrated with the physical experience was perceived most interesting.

over other content formats in the Amazing NFC trial (see Figure 10). Pupils also reported that they occasionally became frustrated with the long download times:

"You had to wait for a long time for a web site to download." (translated by the authors)

In the information tag trial, tags were ubiquitous and could be placed virtually anywhere in a public space. Some of the tags that the users found were visible and available for touching but not operational because they were broken or set up to work only with certain devices for specific users. The users found these situations very annoying. They expected that they would get some response from all the tags that were available for touching, and when that did not happen, they were irritated.

As tags are cheap and easy to attach almost anywhere, there is a danger of "tag litter" that can destroy the user experience and especially trust towards tags in general. As tags are not continuously connected to a network, it is difficult for service providers to notice when a tag becomes inoperable. As tags can be distributed by virtually anybody, it might not be reasonable to assume all service providers even care to maintain tags after distributing them.

In the Amazing NFC trial, the tags were made available only in selected places, so the pupils did not run into or pay attention towards tags that were not specifically targeted for their use, and they reported no problems with non-functional tags. Maintaining the integrity and functionality of a specific set of tags is of course easier, than maintaining a ubiquitous assembly of tags distributed around the urban environment. Also, reporting malfunctioning tags could be easily done by calling the teacher in charge during the Amazing NFC lesson, whereas error reporting would be considerably more difficult for generic Mobile Internet services available through information tags. However, no problems in the technical functionality of the tags were observed during the Amazing NFC trials.

Table 8 summarizes findings related to technical problems.

Figure 10. Preferred media formats of Amazing NFC participants according to the web survey (n=81)

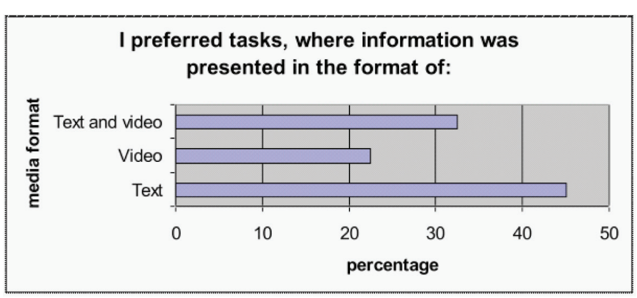


Table 8. Summary of technical problems

Issue	Finding
Downloading data intensive content	The capacity of mobile network was not always optimal for transferring large amounts of data, and as a consequence users got frustrated with long download times.
Non-responsive tags	Users found tags that did not give any response upon touch, and were annoyed about that; service providers should take care of the maintenance of tags.

RECOMMENDATIONS FOR INTERFACE AND CONTENT DESIGN

Our findings both confirm previous findings and the expected benefits of NFC-enabled touch-based Mobile Internet access, and provide some insights that can be used by Mobile Internet content designers for aspiring to provide a successful user experience for Mobile Internet users. Here, we conclude our recommendations for interface and content design into two categories: (1) Tag-based interface for Mobile Internet content and service discovery, and (2) Mobile Internet content.

Designing Tag-Based Interface for Mobile Internet Content and Service Discovery

The mixed-reality user interfaces realized through tagging the environment to allow direct access to the Mobile Internet through the physical interaction of touch can relieve the service discovery problem by bringing the service access points physically to the mobile usage situations the user might face, and visualizing services in our everyday environment. The visual cues embedded into our environment can be used as indicators of services available through the Mobile Internet, and therefore increase user awareness about its content and services. In addition, Mobile Internet services and content can be made available at the locations they are most needed, as NFC tags can be attached virtually anywhere.

Two alternative visions can be seen in embedding visual cues into our environment. In the first scenario, the visual elements naturally available in our environment can be used to provide cues about Mobile Internet content and services available. For example, a medicine package could provide a cue that by touching the package, Mobile Internet content describing the medicine can be accessed (Isomursu et al. 2009). In the second scenario, service and content providers can bring new visual elements into our environment advertising all available Mobile Internet content and services. Information tags described in this chapter represent the second scenario, as they are visual objects that are not directly linked to any physical object in our natural environment, but rather create new visual objects. Both visions require that users have learned the language and signs needed for service discovery, i.e. the new digital literacy skills of mixed reality user interfaces. The users need skills to identify the digital affordances in a mixed-reality environment to be able to discover the digital services and content available. The examples presented in this chapter have suggested one alternative for creating mixed reality interfaces with NFC technology.

The limitations of visual impaired users should also be taken into account when planning for the placement of the tags. To optimize the discoverability of the tags for this user group, the service provider should ensure that the tags are placed consistently on a standard location so that the visual impaired person will know where the tag would be available. For example, at bus stops the tags providing access to bus timetables should always be placed on a same pre-agreed location. In tag design should also be utilized audio cues that would inform the visual impaired user when the mobile phone detects the tag.

In the trials described here, the users quickly learned the visual cues indicating the presence of digital content and services. However, this was not too difficult because of the limited availability of resources, and the limited variations in the visual design used. Our experiences indicate that:

1. The visual design of the tag has an effect on how users are able to recognize digital affordances embedded in their environment,
2. the size of the tag has an effect on how users are able to find digital affordances, and
3. placement of tags can have an effect on how people locate themselves in a space.

In addition, one should keep in mind when designing Mobile Internet services that in order to avoid the confusions and irritations among the users, NFC tags should always respond somehow upon touch, and special-purpose visual design should be used to mark tags that are not targeted for all users.

Mobile Internet Content Design

Three specific issues were identified in designing content accessed through tags. First, as tags are always located in a specific place, they can be used for implementing location specific Mobile Internet application concepts. The users seemed to expect that the tags would automatically use the location data and give a direct access to location specific content. Second, the users valued content that was dynamically updated. The acceptance of outdated information seemed to be very low. Continuously updated information seemed to affect both the perceived interest to revisit the content, and the perceived ease of use. For example, static theatre program displaying the theatre performances for the duration of several months displayed the earliest performances at the top of the screen. This had an effect of perceived ease of use by using valuable screen space for non-relevant information, requiring the user to scroll down the screen to view the performances that were relevant. Also, when the user expected delays in downloading content, downloading non-relevant content may have caused frustration. Third, our experiences show that tag based Mobile Internet access can provide novel opportunities for user experience design through combining the digital internet experience with the situated and embodied experience evoked by physical surroundings, social context and physical sensations. When the user accesses internet content through the static desktop environment, the digital internet experience is often more immersive than in the mobile context, and almost alone responsible for creating sensory stimulation contributing towards the user experience. For a desktop user, the physical surroundings and social context remain rather static and therefore not highly stimulating. However, in the mobile setting, the user can experience the warmth of sunshine on her skin, the smell of fresh bread or the pleasure of walking slowly down a street or beside a river. Through location and context aware service design, this experience can be interwoven with the digital experience evoked by internet use. With Mobile Internet, the internet content and services are more often consumed in the context, where the situated and embodied sensory experiences strongly contribute to the total user experience. The Mobile Internet user experience can seamlessly integrate with the sensory experience and interpretation of the physical environment and social context, and thus create opportunities for flow of experience where digital and physical experiences intertwine and support each other.

Research on psychology suggests that humans are not particularly good at analyzing what actually caused an experience (Dutton & Aron, 1974). Therefore, the Mobile Internet content consumed with good company in pleasant surroundings can evoke a more positive user experience, than the same content consumed in a hurry and in bad weather. We believe, that the successful combination of the interesting and stimulating environment of the Zoological museum, bus journey and very context specific Mobile Internet content integrating seamlessly with interaction with the physical environment resulted in the user experience, that was clearly preferred by the pupils (see Figure 8). The video recordings and average time spent at each control point show, that in other places the pupils only quickly touched the tag and left, and did not really experience the environment. Therefore, the Zoological museum seemed to be the only place that provided a successful combination of the experience of a physical space and the Mobile Internet experience.

Also, in the information tags trial, the implications of Mobile Internet use to the social context and interaction were found to strongly affect the user experience of Mobile Internet content. The users expected the content to be highly relevant and integrated with their current context and needs, and were very disappointed when it failed to do so, as illustrated by the following comment from a theatre visitor:

"If I download restaurant information in Oulu, I certainly do not want to receive information about restaurants in Helsinki! I immediately stopped using information tags when I realized this." (translated by the authors)

Our findings pointed out that in some cases users have concerns on how consuming Mobile Internet content might negatively affect social interaction as the content is typically most suited for personal use. In fact, the social interaction could be fostered and encouraged with good contextual design of the services and content. The user should also be given some kind of indication about what kind of media type the tag links to in order to avoid embarrassing and socially disturbing situations, e.g. when the user accesses the content that is in audio format. For this purpose could be utilized graphical design for indicating the media types. Thus, when designing NFC-based systems, special attention should be given to these kinds of social and behavioral concerns.

LIMITATIONS AND VALIDITY

Even though the goal of the field trials was to provide as high an experimental reality (Aronson, 2004) as possible, there are issues in the trial settings that may have affected the results and probably did so.

Perhaps the most severe limitation of our research setting was the availability, selection and content available through the tags. If information tags were to become popular and tags would be used by commercial service and content providers, there would be considerably more tags available for use. This would mean that the selection of Mobile Internet content and services would be wider, and with experience, commercial content providers would learn to provide more usable, meaningful and valuable content. As the tags were evaluated in a research project, there were no actual goals for business or the public good that would have needed to be met. Tag placement, design and accessed information content were not rigorously designed to meet any specific goals, such as, for example, optimal coverage of a certain user group.

However, in the information tag trial, the content accessed presented the state-of-the-practice in Mobile Internet content design, as it was actual, pre-existing Mobile Internet content provided by commercial actors. The content was not specifically produced for research purposes, but it was provided by the content providers for Mobile Internet users in general. This was not the case in the mobile learning trial. For the mobile learning trial, the content was created for the purpose of the trial, as the learning concept was new and no pre-existing Mobile Internet content was available. Since there is little design knowledge available on how to design engaging and motivating learning material for Mobile Internet, it is understandable that the first versions of such content may be not optimal. However, in the mobile learning trial there were well-formulated learning goals that were used for designing the content.

Another issue that may have an effect on the results is that none of the users were able to use their own mobile phone to access the Mobile Internet through tags, but rather had to use a special NFC-enabled trial phone. This meant that the users usually carried two mobile phones with them, and used their own mobile for voice calls, and the trial phone only for the NFC-enabled features. This might have had an effect on the usage frequency, perceived accessibility and ease of use especially in the information tag trial. In the mobile learning trial, this might have an effect on perceived ease of use, as the pupils had to learn to use a new mobile phone for the duration of the lesson. However, this effect was probably not too strong, as none of the technical problems reported by the pupils were related to the phone model used.

SUMMARY

This chapter explored the Mobile Internet user experience through two field trials where touch-based mixed reality user interaction was used to provide end users with Mobile Internet access points. Our findings confirm that touch-based Mobile Internet access was perceived as easy and fast to use. The users expected to get direct access to location-specific information, and were most interested about location specific and location aware content. One of the keys for achieving a good user experience was successful seamless integration of the Mobile Internet user experience with the experience evoked by the situational and embodied experience resulting from interaction with the physical and social surroundings of the user.

REFERENCES

Ailisto, H., Pohjanheimo, L., Välkkynen, P., Strömmer, E., Tuomisto, T., & Korhonen, I. (2006). Bridging the physical and virtual worlds by local connectivity-based physical selection. *Journal of Personal and Ubiquitous Computing*, *10*(6), 333–344. doi:10.1007/s00779-005-0057-0

Arnall, T. (2006). A Graphic Language for Touch-based Interaction. In *Proceedings of the Workshop on Mobile Interaction with the Real World,* pp. 18-22. Espoo, Finland. Aronson, E. (2004). *The Social Animal*. New York: Worth Publishers, Ninth edition.

Beaver, J., Chrysanthis, P. K., Pruhs, K., & Liberatore, V. (2006). To Broadcast Push or Not and What? In *Proceedings of the 7th International Conference on Mobile Data Management* (pp. 40-45). Los Alamitos, CA: IEEE Computer Society.

Buchanan, G., Farrant, S., Jones, M., Thimbleby, H., Marsden, G., & Pazzani, M. (2001). Improving Mobile Internet Usability. In *Proceedings of WWW* (pp. 673-680). New York: ACM.

Church, K., & Smyth, B. (2008). Who, what, where & when: a new approach to mobile search. In *Proceedings of the 13th International Conference on Intelligent User Interfaces* (pp. 309-312). New York: ACM.

Constantiou, I., Damsgaard, J., & Knutsen, L. (2007). The four incremental steps toward advanced mobile service adoption. *Communications of the ACM*, *50*(6), 51–55. doi:10.1145/1247001.1247005

de Saint-Exupery, A. (2009). *Internet of Things – Strategic Research Roadmap*. European Commission – Information Society and Media DG.

Debaty, P., Goddi, P., & Vorbau, A. (2005). Integrating the Physical World with the Web to Enable Context-Enhanced Mobile Services. *Mobile Networks and Applications*, *10*(4), 385–394. doi:10.1007/s11036-005-1552-2

Desmet, P. (2002). *Designing Emotions*. Doctoral dissertation, Delft University of Technology, the Netherlands.

Dutton, D., & Aron, A. (1974). Some evidence for heightened sexual attraction under conditions of high anxiety. *Journal of Personality and Social Psychology*, *30*(4), 510–517. doi:10.1037/h0037031

Falke, O., Rukzio, E., Dietz, U., Holleis, P., & Schmidt, A. (2007). *Mobile Services for Near Field Communication (Tech. Rep.)*. Munich, Germany: University of Munich, Department of Computer Science, Media Informatics Group.

Greenfield, S. (2000). *The Private Life of the Brain: Emotions, Consciousness, and the Secret of the Self*. New York: John Wiley & Sons.

Häikiö, J., Isomursu, M., Matinmikko, T., Wallin, A., Ailisto, H., & Huomo, T. (2007). Touch-based user interface for elderly users. In *Proceedings of MobileHCI* (pp. 289–296). New York: ACM. doi:10.1145/1377999.1378021

Hansen, F. A., & Grønbæk, K. (2008). Social web applications in the city: a lightweight infrastructure for urban computing. In *Proceedings of the 19th ACM Conference on Hypertext and Hypermedia* (pp. 175-180). New York: ACM.

Internet Reports, I. T. U. 2005 (2005). *The Internet of Things*. Available at: http://www.itu.int/osg/spu/publications/internetofthings/.

Isomursu, M., Ervasti, M., & Törmänen, V. (2009). Medication Management Support for Vision Impaired Elderly - Scenarios and Technological Possibilities. In *Proceedings of International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL)*. Bratislava, Slovak Republic:IEEE.

Isomursu, M., Isomursu, P., & Horneman-Komulainen, M. (2008). Touch to Access Mobile Internet. In *Proceedings of OzCHI*. New York: ACM. doi:10.1145/1517744.1517751

Isomursu, P., Hinman, R., Isomursu, M., & Spasojevic, M. (2007). Metaphors for the Mobile Internet. *Journal of Knowledge*. *Technology & Policy*, *20*(4), 259–268. doi:10.1007/s12130-007-9033-5

Kamvar, M., & Baluja, S. (2006). A Large Scale Study of Wireless Search Behavior: Google Mobile Search. In *Proceedings of CHI* (pp. 701-709). New York: ACM.

López-de-Ipiña, D., Vázquez, J. I., & Jamardo, I. (2007). *Simplifying Human to Environment Interaction through NFC Technology. In 1as Jornadas Científicas sobre RFID. Ciudad Real, España*. Touch Computing.

Meloan, S. (2003). Toward a Global "Internet of Things". Sun Developer Network (SDN). Available at: http://java.sun.com/developer/technicalArticles/Ecommerce/rfid/.

Metcalfe, R. (1995). Metcalfe's law: A network becomes more valuable as it reaches more users. *InfoWorld*, *17*(53), 2.

Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1994). Augmented Reality: A class of displays on the reality-virtuality continuum. In *Proceedings of Telemanipulator and Telepresence Technologies* (pp. 282-292). Boston: SPIE.

Ministry for Foreign Affairs of Finland - Department for Communication and Culture/Unit for Public Diplomacy. (2009) *Virtual Finland – Your Window on Finland*. Retrieved February 5, 2009, from http://finland.fi/.

NTT DoCoMo. (2007). *Audio Barcode*. Available at: http://www.nttdocomo.com/technologies/future/audio/index.html.

NTT DoCoMo. (2010). *Osaifu-Keitai*. Available at: http://www.nttdocomo.com/services/osaifu/index.html.

O'Neill, E., Thompson, P., Garzonis, S., & Warr, A. (2007). Reach Out and Touch: Using NFC and 2D Barcodes for Service Discovery and Interaction with Mobile Devices. In LaMarca, A. (Eds.), *PERVASIVE 2007, LNCS 4480* (pp. 19–36). Berlin, Heidelberg: Springer-Verlag.

Ramachandran, V. S., & Blakeslee, S. (1998). *Phantoms in the brain*. London: Fourth Estate.

Reijnveld, K., de Looze, M., Krause, F., & Desmet, P. (2003). Measuring the Emotions Elicited by Office Chairs. In *Proceedings of the International Conference on Designing Pleasurable Products and Interfaces* (pp. 6-10). New York: ACM.

Rekimoto, J., & Ayatsuka, Y. (2000). CyberCode: designing augmented reality environments with visual tags. In *Proceedings of DARE 2000 on Designing Augmented Reality Environments* (pp. 1-10). New York: ACM.

Riekki, J., Salminen, T., & Alakärppä, I. (2006). Requesting Pervasive Services by Touching RFID Tags. *IEEE Pervasive Computing / IEEE Computer Society [and] IEEE Communications Society*, *5*(1), 40–46. doi:10.1109/MPRV.2006.12

Robinson, M., & Clore, G. (2002). Belief and feeling: Evidence for an accessibility model of emotional self-report. *Psychological Bulletin*, *128*(6), 934–960. doi:10.1037/0033-2909.128.6.934

Rukzio, E., Schmidt, A., & Hussmann, H. (2004). Physical Posters as Gateways to Context-aware Services for Mobile Devices, In *Sixth IEEE Workshop on Mobile Computing Systems and Applications (WMCSA 2004)* (pp. 10-19). Washington DC: IEEE Computer Society.

Swindells, C., Inkpen, K. M., Dill, J. C., & Tory, M. (2002). That one there! Pointing to establish device identity. In *Proceedings of the 15th Annual ACM Symposium on User interface Software and Technology* (pp. 151-160). New York: ACM.

Times, N. F. C. (2010). *Sony Faces an Uncertain Market for its FeliCa Technology*. Available at: http://www.nfctimes.com/news/chart-article-contactless-e-money-japan-felica-chips.

Välkkynen, P., Niemelä, M., & Tuomisto, T. (2006a). Evaluating Touching and Pointing with a Mobile Terminal for Physical Browsing. In *Proceedings of NordiCHI* (pp. 28–37). New York: ACM. doi:10.1145/1182475.1182479

Välkkynen, P., Tuomisto, T., & Korhonen, I. (2006b). Suggestions for Visualising Physical Hyperlinks. In Proceedings of Pervasive Mobile Interaction Devices Workshop (pp. 245-254). Berlin, Heidelberg: Springer.

Want, R., Fishkin, K. P., Gujar, A., & Harrison, B. L. (1999). Bridging physical and virtual worlds with electronic tags. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: the CHI is the Limit* (pp. 370-377). New York: ACM.

Weiser, M. (1991). The Computer for the 21st Century. *Scientific American*, *265*(3), 94–104. doi:10.1038/scientificamerican0991-94

Chapter 15
What does Mobile Mean?

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ABSTRACT

This article presents a perspective on what it really means to be mobile - why being mobile is different. It looks at the technological and physical implications, but really considers the broader issues: the social implications, the impact that data on the move can have on people, and the use of mobile devices as sensors that can drive intelligent, contextual systems that provide a much more effective experience for the user than existing systems do.

MOBILE DEVICES AND MOBILITY

When we talk about mobile computing, what do we really mean? There are many devices that claim to be for mobile computing, ranging from laptops through tablets and personal digital assistants (PDAs) to mobile phones. Some of the larger 'laptops' require quite impressive feats of strength from their owners, requiring them to carry awkward, bulky and sometimes heavy loads: in return they offer tremendous computing power and an experience not dissimilar to sitting at a highly-specified desktop machine. These do provide great functionality to their owners; they essentially give them their office, wherever they happen to be—they allow one to move locations, but really require one sets them in a specific location and then work with them. They are more *migratory* than mobile, allowing one to move to a new location, and then work from there for a reasonable period. Tablet PC's are more portable than this—but they still have a relatively large form factor so that carrying them is a significant action: not an issue when stock-taking, or collecting data in the field, but a problem for activities in which interacting with the device is not a major focus of the task. The relatively new ultra-portable netbooks and mini-laptops offer much increased portability, some being pocket-sized, especially if you are of the age where wearing cargo pants is

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common—they trade reduced power and display size for their compact dimensions, but this allows them to be taken to more places and used in occasional moments. Ideal for when a users' task is not based on the technology, but having sporadic access to it is useful, they are finding roles in supporting travellers on planes and trains, journalists in the field, and photographers on safari. The smaller screen height when open also presents less of a social barrier to visual communication with other parties, making them seem somewhat more acceptable for use in meetings and other such settings (at least, this is my impression based only on personal experience, observation, and discussion with other users). Other devices are much more portable: the PDA offers pocket sized assistance with notes, reminders, documents and support, but has recently been superseded by the latest generation of smart mobile phones, that offer all the capabilities of the PDA coupled with integrated data connectivity and voice communications as well. As phones become every more powerful, they are increasingly provided with more and more applications to increase their functionality: indeed, Apple's AppStore, which is an e-commerce site for Apple and 3rd party add-on software for the iPhone, is used as one of the strong selling points of the device itself.

However, all these characterisations of these devices are technology-centric: they define mobile in terms of how portable the devices are: the more portable the device, the more mobile. And hence this has defined the way mobile applications are created; they are created for small, portable devices and designed to the limitations of such devices. However, my contention is that the real issue is not the 'mobility' of the devices, but the mobility of their users. Mobile computing is not, in my view, about computing on small portable devices; instead, it is about computing for users who are not in a single location, but are moving around. They may be migratory, moving from one place to another but spending much of their time in a known location, or they may be much more active, being truly mobile and out and about, moving from location to location far more frequently, and computing whilst on the go as well as when at their destinations.

For example, the European-funded Mobilearn project looked at the issues involved in mobile learning. It developed a context-aware architecture (Beale & Lonsdale, 2004; Lonsdale et al., 2004) that utilised location, user interest, and previous activities to determine the information and activities that the user would most likely want next, and provided that information to them. The intention was to make the usage experience as seamless as possible, so that the user rarely had to interact directly with the device in order to move through material or navigate an information structure, but would instead be presented with the right information at the right time. The idea was that this would provide for a less intrusive but more personalised and appropriate learning experience than other approaches (Syvanen, Beale, Sharples, Ahonen, & Lonsdale, 2005), and in general, this proved successful though was constrained to the specific domains for which it had been designed (guidance around a museum, first aid, art gallery).

When we start to consider users and being mobile, rather than the technology, other interaction opportunities become apparent. For example, there is a growing trend in e-science to allow end-users to participate in information collection, allowing them to provide immediate information on things from wherever the user happens to be, via a smartphone or similar. Whilst the device does need to be small and portable, this is not a requirement of the data gathering but rather that the user needs to have it on him/her at the time, and so the mobility is inherent in the user. Examples of this include on-the-spot weather information collection, reports of bird and other natural phenomena sightings, and so on. This approach provides a modern corollary to the Mass Observation approach to collecting social and other information from ordinary individuals that was originally carried in Britain in the 1930's (e.g., (Madge & Harrisson, 1939) and http://www.massobs.org.uk/index.htm) but which potentially allows a much wider and/or specialised audience to be reached, which opens up enormous potential for qualitative and quantitative research, not just in the social sciences but in any domain in which widespread information gathering could be useful.

PATTERNS OF MOBILE USE

The conceptualisation of mobile as being primarily about the user and not the device has an impact on how we design systems: instead of focusing our attention on the physical constraints of the device, we focus instead on the notion of user movement and consider how we should design for that.

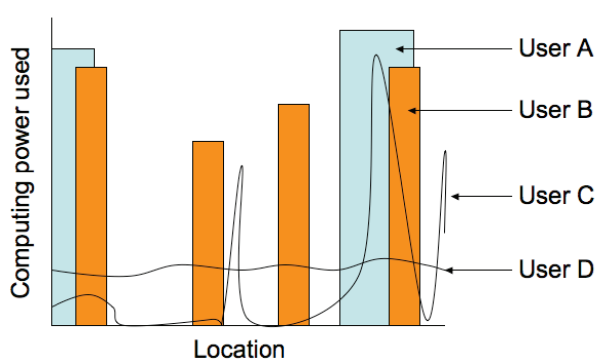
By examining the movement and computing patterns of users, we can identify some common patterns of 'mobile' usage, as shown in Figure 1.

User A represents a user who works at two fixed locations (often, his/her office and home). User B is what I have earlier termed 'migratory'—such users move from place to place, which can vary, and work when at those locations, but not in between. User C has a much more sporadic usage pattern, but this is much less related to his/her current location: at certain places, he/she does certain things, but is also involved in ongoing activities for some of the time whilst on the move: this may represent the usage pattern of someone who works in certain places but also browses the web and watches YouTube whilst on the move between locations. User D represents the other end of the scale from User A: someone who is constantly undertaking activities, no matter where he/she is: this is typical of the Facebook addict, or Twitterer. Of course, this figure is diagrammatic, and the levels of activity can vary hugely—and there are many profiles that can also be added to this picture, but I feel it captures four user stereotypes quite well: these can be characterised as User A being the 'Modern Worker'; User B is 'Migratory'; User C is the 'Nomadic'; and User D is the 'Twitterer'.

IMPLICATIONS FOR DESIGN AND RESEARCH

Clearly, these users will have different requirements for their systems: offering full office-style applications to Nomads and Twitterers is inappropriate, whereas the Modern Worker certainly needs that. The need to design applications within a wider social context is not new (Beale, 2008; Cherns, 1976), but the economics of software development have pushed organisations into porting existing applications to the mobile device: whilst these will work for certain users, it is becoming clearer that the early adopters of the latest and most powerful smartphone technologies are more likely

Figure 1. Diagrammatic patterns of 'mobile' use (shading under Users A and B is only to identify them)



to be Twitterers than they are Modern Workers. For example, a recent report by Rubicon (Rubicon, 2008) on the iPhone surveys 460 users in the US and shows that reading email is the most used function, followed by managing text messages, browsing the internet (which they do much more than on their previous phone), listening to music, managing calendar and contacts, and writing email. 28% of users say they carry their iPhone instead of a notebook computer; about half of the are under 30 and technologically-aware. This pattern of activity is clearly focussed on frequent communication and data access, and given their increased bills, they are using their phones for much more of the time as well.

From a design perspective, the more neglected user groups have been the Twitterers and the Nomads in the sense that many of the applications that they use have still been created assuming that they will be sat in front of a screen. Whilst many of these are available in mobile versions, they still tend to assume that the application is the focus of the user's attention, which makes it very hard to use when the user is actually moving (Sears & Zha, 2003). For these groups, we need to further distinguish between use when mobile that is incidental, and activity that is related to the mobility. In the former category, we have applications such as Facebook, Twitter, and, perhaps more common at present, playing games, browsing the internet and reading blogs—many of these activities are designed to fill in time. Some are just for entertainment, some are part of an ongoing process of digital media consumption to stay up to date. Other activities are more specifically work-related—Blackberry users are used to dealing with their email whilst out and about, making them more efficient and more current in their dealings with colleagues and customers and clients, and many other smartphone users are getting the same easy access to mobile email now. One of the potentially most effective uses for e-learning may well come from the mobile sector, when on-the-spot training can be provided to users who have an immediate and pressing need for it: being motivated, they will be much more receptive to learning and retaining it. Even for education at school ages, mobile systems for learning have the potential to support experiential learning, and can be aware of the previous knowledge and interests of individuals, and so guide and support them through the most appropriate information or activity.

But some of the more fascinating systems are those that are directly related to being out and about. One obvious one is microblogging, whether through bespoke software or through mobile or web interfaces to standard systems, in which the blog posts directly reflect the often immediate experiences and reflections of the user, presenting an almost immediate view of their location, their ongoing activity, and so on. Geotagged photography also falls into this category. Other applications specifically related to mobility include location-aware systems, often information ones such as 'find me the nearest restaurant/petrol station/etc.', and data recording ones such as customer recording, signature capture, and so on.

If we consider the iPhone again, looking at the top ten applications downloaded in 2008 (Kumparak, 2008)—the Apple iTunes store has an up-to-date Top 10 as well—we can see that there is a real demand for applications to be used almost anywhere, anytime: they comprise games, communications (social networking or messaging), and location-based information systems. This further supports the earlier demographic survey evidence, suggesting that iPhone users tend to be Twitterers or Nomads.

To my mind, however, one of the most interesting areas of development is in applications that are driven by the mobility of their users, and in some cases may not require much, or any, direct interaction. Aka-Aki, in Germany, provides notification of possible new friends by scanning Bluetooth-enabled devices and matching the unique identifiers to social networking profiles, and highlighting potential people of interest. Other systems measure key factors about their owner's current physical state, location and inferred activity for health and performance monitoring purposes, aiding their user to get fit or keeping a watching brief that they are not becoming ill (e.g., for diabetics) or needing assistance (e.g., for the elderly or infirm).

Newer applications (or research concepts, at least) recognise the importance of transits between locations as being important as well; for example, in London a smartphone could relatively easily determine that you were travelling in a car, and automatically pay the congestion charge for you when you entered the charging zone. More complex systems could monitor your car usage and provide discounts on your insurance premium based on the fact that you mostly drove only in daylight, on roads regarded as safe, and within the speed limit. Such monitoring and information sharing has a host of ethical, legal and user acceptance issues to overcome, and it may well be that we as a society decide that we do not want many of these changes: but some could be of great benefit to us with little or no effort on our own part.

SUMMARY

I have presented a case for mobility being considered in the widest possible sense, with the focus being more usefully on the mobility of the user and not of the device. This has clear implications for considering different types of mobile user, and for each of those types there are issues to be addressed in application design that, especially towards the more mobile user end, are considerable and challenging. Issues such as where the user's focus is, whether they need to interact with their device or whether the act of moving provides the interaction itself are of great research potential. Concepts such as activity at a location, or between locations, provide us with new avenues to explore: the world of mobile interaction appears to be even richer than we originally thought.

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REFERENCES

Beale, R. (2008). (accepted). Socially-aware design: the 'Slanty' approach. [IJSKD]. *International Journal of Sociotechnology and Knowledge Development*.

Beale, R., & Lonsdale, P. (2004). *Mobile context aware systems: The intelligence to support tasks and effectively utilise resources.* Paper presented at the Mobile Human-Computer Interaction - Mobile HCI 2004, Glasgow.

Cherns, A. (1976). The Principles of Sociotechnical Design. *Human Relations*, *29*(8), 783–792. doi:10.1177/001872677602900806

Kumparak, G. (2008). Apple announces Top 10 iPhone App downloads of 2008. Retrieved 3rd December, 2008, from http://www.mobilecrunch.com/2008/12/02/apple-announces-top-10-iphone-app-downloads-of-2008/

Lonsdale, P., Barber, C., Sharples, M., Byrne, W., Arvanitis, T., Brundell, P., et al. (2004). *Context awareness for MOBIlearn: creating an engaging learning experience in an art museum.* Paper presented at the Proceedings of MLEARN, Odescalchi Castle, Lake Bracciano, Rome, Italy.

Madge, C., & Harrisson, T. (1939). *Britain by Mass-observation: The Book*. Penguin Books.

Rubicon. (2008). The Apple iPhone: Successes and Challenges for the Mobile Industry. Retrieved 5th January, 2009, from http://rubiconconsulting.com/downloads/whitepapers/Rubicon-iPhone_User_Survey.pdf

Sears, A., & Zha, Y. (2003). Data Entry for Mobile Devices Using Soft Keyboards: Understanding the Effects of Keyboard Size and User Tasks. *International Journal of Human-Computer Interaction PU - Lawrence Erlbaum Associates*. *Inc.*, *16*(2), 163–184.

Syvanen, A., Beale, R., Sharples, M., Ahonen, M., & Lonsdale, P. (2005, November 28-30th). *Supporting Pervasive Learning Environments: Adaptability and Context Awareness in Mobile Learning (poster)*. Paper presented at the IEEE International Workshop on Wireless and Mobile Technologies in Education (WMTE 2005), Tokushima, Japan.

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Chapter 16
ICT for Consumers or Human Beings:
What's the Difference?

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ABSTRACT

The large scale deployment of mobile applications inevitably impacts upon our culture as a whole and affects more intimately our daily lives. Not all of these effects are desirable. In a market economy, ethical issues are not the most important drivers in the development of technology. In this chapter, the authors ask whether the mobile human-computer interaction community could take an active role in discussing ethical issues. In so doing as a community we could focus our attention on developing technology for 'human beings' rather than fine tuning our emerging gadgets.

INTRODUCTION

The research paradigm of human-computer interaction (HCI), despite its brief history, has established itself as representing the human point-of-view in terms of the research and development of digital technology. However, what 'human' means is far from clear in this context. The history of HCI shows that the paradigm aims to combine computing, behavioural studies and design (see e.g. Myer, 1998). The contribution of behavioural studies has entailed the adoption of empirical methods and the approach of the behavioural sciences, psychology in particular.

Exploiting psychological methods in HCI studies certainly reveals important issues for a community intent on developing highly usable products. HCI, as a paradigm, therefore seems to have a mainly instrumental purpose in terms of producing usable and ultimately best selling

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products. Nonetheless, to use the term 'human' forces one to take a broader view of human beings than simply a consideration of his or her cognitive capacity. Psychological studies may reveal how a product should look, sound, or feel, yet these kinds of practical design concerns, we argue, tell us very little about the more complicated, ethical issues involved.

Social issues, in particular, are beyond the scope of traditional HCI studies. Even as human-sounding a strategy as user centred design, may turn against the construction of a better world for human beings: As discussed by Halttunen, Maksimainen and Pirhonen (2010), the construction of human society is inevitably a reciprocal process between individuals and the society. HCI – due to its history – is fundamentally individualistic. The individualistic approach is extremely clear in mobile HCI, which mostly focuses on the development of consumer products. The underlying rationale is usually to make new products desirable for potential customers. Little attention is paid to the social impact of any potential success for the business. For instance, the idea and vision of a portable telephone in a pocket must have sounded great twenty years ago. However, now when the vision has been implemented, we can easily observe that it did not only help individuals to use the telephone, but changed our society in many ways. This impact in our culture was hardly part of the vision.

In this paper, we challenge people, who are involved in the research and development of mobile HCI, to take an active role in the discussion of the inevitable ethical problems resulting from the rapid penetration of mobile applications. Some of the ethical examples raised in this paper may appear far-fetched in terms of the mobile HCI tradition. However, we think that the mobile HCI community cannot afford to shy away from or wash their hands of these difficult ethical issues. As long as we are part of the structure which develops a mobile computing culture; we are also responsible for the results.

What follows is a discussion of a number of topics which we feel deserve more attention from the mobile HCI community. Most of them, if not all, could be categorised under the heading of 'health', not only physical health, but also mental and social aspects of well being. The term 'welfare' also feels appropriate and we take this to include a broad variety of positive qualities important to consider when we are trying to construct a better future.

ROASTING YOUR BRAINS

It is not headline news to report that mobile phones, when used in their traditional handset form adversely affect human brains. The health risks associated with this form of radiation are highly controversial, and there is no sign of this debate being resolved in the near future. At present it is difficult for a consumer to find relevant information about the risks, while commercial interests are so evident in both the research and reporting of research in the area. In a recent analysis (Marino & Carubba, 2009) it was found that vast majority of the EMF (electro magnetic field) health risk reports have been wholly or partially funded by mobile phone industry. It is hardly surprising, that when a mobile phone manufacturer is funding a health risk study, the published results never indicate any potential danger. One thing we can say for sure is that currently no one really knows how severe the risk is.

What is the role of the mobile technology designer in terms of possible health risks? A good example of what the role should *not* be was highlighted in a brief interview about ten years ago. In those days, most of the mobile phones had a visible aerial on the top of the device. It was known that the radiation is strongest in the immediate proximity of the aerial. A phone designer was asked, whether the aerial could be situated at the bottom of the device, thus markedly increasing the distance between the aerial and the brain. The designer responded that an aerial pointing down was out of question – it would look so stupid that no one would buy it.

The example above illustrates that design matters, sometimes in a very concrete way, in terms of our welfare. The designer could have taken an active role and started to talk openly about the health risks. It might even have resulted in commercial success, if the message had been skilfully communicated.

BEING CONNECTED TO WORK: WITH CHAINS?

Being constantly connected to digital communication channels via small, portable devices is somewhat of a double edged sword. From the point of view of the employers' short term benefits; it might sound ideal that almost half of US employees do at least some work from home, via digital networks. Quite often, the opportunity to be connected to your work is presented as an opportunity to flexibly share time between your work life and your private life. On the other hand, however, if 70% of Blackberry and PDA owners check their work related emails at the weekends, suspicions are evoked as to whether it is a question of reciprocal flexibility anymore. Even more suspicious is the recent observation that 22% of employees claim that they are expected to be reachable through e-mail outside working hours. (Madden & Jones, 2008).

During the last two years, the sad news of France Télécom has received a lot of publicity. From the introduction of mobile email in January 2008, at least 46 employees have committed suicide (New York Times, 2010). Even if the causal relationship between the suicide wave and 24/7 email access is probably impossible to show, at least one top executive of the company has publicly concluded that such a relationship exists. Even if this is, from scientific perspective, still merely speculation, the case at least challenges us to critically consider the social and mental impact of the mainstream trends in the penetration of mobile technologies. We do not believe that the developers' aim is to increase peoples' stress levels or to disturb family life by binding people to invisible networks, from which they cannot free themselves. But perhaps we simply developed the technology with an inadequate understanding of human nature.

WIDGET-ASSISTED FAMILY LIFE

We are constantly being reminded that our culture is rapidly changing due to our exploitation of mobile devices. Indeed, the change has been salient in everyday family life. We have been given the impression, that when everyone has a mobile device in their pocket, communication among family members is fluent and immediate. Parents welcome tiny widgets which enable effortless control of their offspring.

What about family life and the relationships between family members then? If mobile technology has enhanced communication in families, it should have also strengthened family ties. Some people argue that this is the case (see for example a recent study by Kennedy et al., 2008). In particular, it is argued that long distance family communication is easier with the help of mobile devices and the internet. Mobile devices we are told also make it possible to keep in touch despite the hectic rhythm of life. However, the same study reveals that families, in which digital communication devices are heavily used, are less likely to have their meals together. The same group of families also reported being less satisfied with their leisure time.

With almost 100% mobile phone penetration it is now extremely easy to contact a family member. However, the changes in terms of how people live their daily lives deserve a closer, critical look. Is it really the case that mobile phones have helped support communication in our hectic lives, or are mobile devices actually one of the main reasons for the busy lifestyle? A few years ago, Finnish boys went out after school to play football or ice-hockey together. At the moment, they rush home to chat via the internet or update their Facebook profile, and are unable to agree with their friends what to do next – the communication plans do not seem to be extendable beyond the current minute of internet use. If they get fed up with chatting, they text their friends and ask if they would like to do something (and rarely succeed in getting anyone to come out of their house to play). At the same time, obesity as well as back and neck complaints among adolescents have increased rapidly (see e.g. Alexander & Currie, 2004; Hakala et al., 2006). Mobile devices, do however, it could be argued enable 'mobility', and support the 'instant-life-style' making it possible to contact anyone any time. The lack of meals together indicates the same phenomenon; even that one single time, e.g. dinner time, cannot be agreed in advance. Instead of proper meals, we eat unhealthy snacks, with well publicised consequences. In terms of communication, the value of family meals should not be underestimated (see an overwhelming collection of research reports about shared meals and their impact in physical and social health by Mayfield, 2007). The potential for constant contact and communication may not always be beneficial for either parent or child. Research by Weisskirch, (2009) found that a greater frequency of parental calls to their children led to less adolescent truthfulness.

Perhaps then technology has a role to play in freeing up families from mundane tasks allowing them to spend more time together? In a vision of the near future, Little, Sillence and Briggs (2009) described a scenario in which a trip to the supermarket is supported by the use of a biometric payment system, radio frequency identification tags on household products and a fridge, cupboard and waste bin that monitor and communicate seamlessly with the shopper's PDA creating a shopping list of items needed. Whilst at one level this might seem like a good use of technology, speeding up transactions and increasing convenience, the authors note that the increased functionality of such a system is in conflict with the subtle social interactions that sustain family bonds. For example, the shopper receiving a message on their PDA alerting them to the fact that the household had run out of biscuits, alcohol and condoms would potentially damage the trust and privacy balance within the family. On the other hand, the idea of using technology to free time from mundane tasks to something else is not new. The marketing of household appliances has always alluded to easier everyday life. However, there is evidence that the ownership of household appliances does not lead to less time spent on household work, sometimes quite the opposite (Bittman, Rice & Wajcman, 2004). *

The vision of a highly automated shopping experience with the support of mobile devices can be easily associated with the early notions of human-computer interaction by Card, Moran and Newell (1983). In their framework, the machine and its human operator were supposed to constitute a seamless whole performing a task. In other words, the role of the human operator ('user') could be characterised as being part of the productive machinery. In the vision of high-tech shopping, the 'task' has been broken down to its constituents and described as a process chart. I.e., shopping is paralleled with industrial process. This kind of approach reveals how completely inappropriate the engineering perspective is to conceptualise real life. Is our everyday life, even at home, simply a set of tasks to be performed?

Effective internet access is seen today as almost a civil right. For instance, in Finland it has been compulsory for telecoms providers to offer reasonably priced broadband for all households and enterprises from July this year. If it is so important to arrange internet access for all, it is worth having a closer look at what people do with it. With regard to families, a recent study by Symantec (2009) concerning the internet searches carried out by children is very informative. The three most popular keywords in internet searches among children are, curiously, “Youtube”, “Facebook” and “Google”. The next most popular ones, in all age groups (<8, 8-12, 13-18) are “sex” and “porn”. Internet-critical people are often blamed for techno phobia and moralism. Perhaps, there are grounds for research based criticism as well. Discussion of this kind should be carried out before arguing that we all, from toddler to granny, need mobile internet in our pockets to access the resources of the information highway.

GROWING OLD? NO PROBLEM, WE HAVE A TECHNICAL SOLUTION FOR YOU

The population is ageing. Improvements in mortality and a falling birth rate mean that in the UK the fastest growing age group in the population are those aged 80 years and older (National Statistics, 2008). Consequently supporting independent living is high on the agenda for many designers and technology providers. It is also on the minds of everyday citizens, consider this typical scenario: A concerned son buys a mobile phone as a present for his elderly parent. The parent is instructed that the phone is to help them feel safe and more secure (although of course it is also a form of family tracking). The son then reports feeling frustrated that his mum always has the phone turned off. She reminds him that it was only for emergencies anyway and ‘why should I have to always be contactable?’ This example highlights the distinction between keeping a friendly eye on a loved one and something potentially more sinister – the idea of tracking and surveillance. Some ‘surveillance’ systems are intended to monitor the physical well being of elderly people with a view to supporting independent living. Blood pressure and pulse for example can be monitored and recorded remotely. Such systems, however give rise to the notion of ‘Big Brother’ and place constraints upon personal freedom and autonomy. The system will know immediately if the monitored person has drunk or eaten something forbidden or has stayed up to watch their favourite film and thus has had insufficient sleep.

Similar issues arise when considering location based services (LBS) or devices. These tracking devices monitor the elderly inside and outside of the home environment and can potentially protect against ‘wandering’ as well as measuring and encourage mobility. Can the person being monitored decide when to turn the device on and off? Should people have to be able to account for every minute of their day? Journeys to the shops, the doctors or outings to the library etc form an important part of older people’s daily activities. In turn this makes up an integral part of the storytelling that occurs between friends and family either face to face or during the weekly phone call with long distance relatives. The conversation ‘You’ll never guess where I went last Tuesday’ would be rendered redundant if the family had access to the tracking details. It is this kind of social implication which is still not being fully considered by designers of LBS. The HCI models on which designers can draw are slowly beginning to go beyond the straightforward issues of usability to include individual factors such as personal privacy. There is however some way to go before the subtler, social issues highlighted in the scenario above are given the weight that they deserve.

The provision of monitoring systems may be accompanied by a reduction of direct contact with relatives, friends and care personnel (Abascal & Nicolle, 2005). At what point does monitoring become surveillance and to what extent are we (accidentally or otherwise) removing the need for human contact? Yes people want to maintain independent lives in their own homes but on the other hand they don’t want to be looked after by a robot’ (Monk et al, 2004). How are these systems attending to the elderly person’s emotional and social wellbeing? Twenty years ago a community warden scheme supported older peoples’ independent living. A call from the warden’s home through an intercom (like) system twice a day provided social contact, reassurance and an opportunity to exchange information. The warden typically lived five minutes walk away and could pop around if there was a problem or alert the relevant caregivers.

CREATING A HEALTHY CONNECTED SOCIETY?

Mobile and ubiquitous computing have huge implications for healthcare. One can envisage systems that act, not simply to store health information, but to continuously monitor and communicate health status, coupled with intelligent environments that can respond immediately to this information. Restaurants and supermarkets that work seamlessly with mobile applications to check the food on offer against known allergies, buildings that adjust temperature and lighting in accordance with known medical conditions and hospitals that are primed with up-to-date information the moment the patient arrives.

Here is an excerpt from a scenario used by Little & Briggs (2008) in their work on trust and privacy issues in ubiquitous computing. *Built into Bob's PDA are a number of personalised agents that can pass information seamlessly to relevant recipients. As Bob is epileptic his health agent monitors his health and can alert people if he needs help. One lunchtime Bob trips and falls to the ground. When he fails to respond to his PDA alert the health agent takes over and contacts the emergency services. The paramedics are able to assess Bob and upload all his medical information direct to the hospital via their hand held devices. Meanwhile other agents built in to Bob's PDA take control of his diary, cancelling appointments and informing his wife of the situation.*

This scenario highlights rapid communication of health status and health history between interested parties but exchanging information in this way raises important ethical implications about disclosure (Stanford, 2002). Participants responding to this scenario (Little & Briggs, 2008) were concerned about increasing social isolation, dehumanisation and bystander apathy – surely there is no need to rush to the assistance of someone who has had a fall if the paramedics have already been alerted? What is the value of the human word, thought or deed in that situation?

GlucoMON™ is an automated, long-range wireless blood glucose data monitoring and transmittal system. A child's blood glucose results are automatically transmitted via email or SMS to other family members. The promotional video for this product shows a child being reminder by an older friend to test her blood sugar levels. The results are then transmitted to her mother's mobile phone. The mother then calls her daughter's school and asks them to increase the amount of snack food her child has at break time. What would happen if the mother could not get through to the school? Whilst such devices appear to do the reassuring for us, knowing that the school had developed a culture in which the child's diabetes was an understood and accepted part of everyday life would perhaps provide a broader form of reassurance for parents?

PUTTING THE RECORD STRAIGHT

We do not oppose mobile technology in principle. Mobile technology, like most technologies can be used for good or bad. What we do oppose, however, is using 'human-computer interaction' as a way of simply wrapping up purely commercial motivations into a more acceptable human-looking package. The phenomenon is familiar in all areas of HCI, but the rapid growth of mobile technology has made it all the more salient in this context.

One of the most traditional virtues in science is its exact and precise use of concepts. We doubt, therefore whether the term 'human computer interaction' is precise enough to illustrate the range of activities which fall under that heading. Instead of 'human', which is clearly too encompassing, if not misleading, the current trends in research could be better expressed using different, more appropriate wording. For instance, in studies which focus on the observable behaviour of the user, the more appropriate term would be 'user'. Or, if the over-all aim of the research and development is purely to create best selling products, why not use the term 'consumer' instead of 'human'? Thus the use of the term 'human' could be reserved for endeavours in which the underlying motivation arguably could be the construction of a better world in terms of our understanding of humanity. In a 'human' approach, the interests, needs and wants of an individual should never be separated from the common. Therefore in the pursuit of better societies, the scope of mobile HCI should not be restricted to that of computer scientists and psychologists.

There is a lot of good work being carried out in the field of mobile HCI. Mobile devices, for example, really have provided new means of communication for the deaf. Blind people may also benefit a great deal from a vast array of devices designed to help them survive in a world which has primarily been constructed for the sighted person. Indeed some people have been saved from dangerous situations, e.g. remote mountainsides, with the help of mobile phone. The list of these more positive examples is endless. On the other hand, it can be argued that mobile ICT has been one of the foremost catalysts of the dark side of post-modern way of life: isolating people from each other and binding them all to the more hectic rhythm of life (Halttunen et al., 2010).

Someone has designed all the devices which we now have in active use. So in effect the designers and practitioners of today are creating all of our tomorrows. As scientists and human beings we should be open and explicit making our motives transparent. This would provide the best starting point for creating technology which does not conflict with our human values.

REFERENCES

Abascal, J., & Nicolle, C. (2005). Moving towards inclusive design guidelines for socially and ethically aware HCI. *Interacting with Computers*, *17*(5), 484–505. doi:10.1016/j.intcom.2005.03.002

Alexander, L. M., & Currie, C. (2004). Young people's computer use: implications for health education. *Health Education*, *104*(4), 254–261. doi:10.1108/09654280410546745

Bittman, M., Rice, J. M., & Wajcman, J. (2004). Appliances and their impact: the ownership of domestic technology and time spent on household work. *The British Journal of Sociology*, *55*(3), 401–423. doi:10.1111/j.1468-4446.2004.00026.x

Card, S. K., Moran, T. P., & Newell, A. (1983). *The psychology of human-computer interaction*. Hillsdale, N.J.: Lawrence Erlbaum Associates.

Hakala, P. T., Rimpelä, A. H., Saarni, L. A., & Salminen, J. J. (2006). Frequent computer-related activities increase the risk of neck-shoulder and low back pain in adolescents. *European Journal of Public Health*, *16*(5), 536–541. doi:10.1093/eurpub/ckl025

Halttunen, V., Maksimainen, J., & Pirhonen, A. (2010). Less, slower, better. Do information society visions have healthy alternatives? In Suomi, R. & Ilveskoski, I. (eds.) *Proceedings of the Third International Conference on Well-being in the Information Society (WIS 2010).* TUCS General Publication no. 56, University of Turku, 77-88.

Kennedy, T. L. M., Smith, A., Wells, A. T., & Wellman, B. (2008)). *Networked families. A report of Pew Internet & American Life Project*, October 19. Retrieved (4/11/2008) from http://www.pewinternet.org/pdfs/PIP_Networked_Family.pdf

Little, L., & Briggs, P. (2008). *Ubiquitous Healthcare do we want it?* Presented at BCS British HCI Group Conference, Liverpool, UK 1-5th September.

Little, L., Sillence, E., & Briggs, P. (2009). *Ubiquitous systems and the family: Thoughts about the networked home.* In the proceedings of the Fifth Symposium on Usable Privacy and Security (SOUPS), Mountain View, California, USA, 15-17 July 2009.

Madden, M., & Jones, S. (2008). *Networked workers*. A report of Pew Internet & American Life Project, September 24. Retrieved (4/11/2008) from http://www.pewinternet.org/pdfs/PIP_Networked_Workers_FINAL.pdf

Marino, A., & Carrubba, S. (2009). The effects of mobile-phone electromagnetic fields on brain electrical activity: A critical analysis of the literature. *Electromagnetic Biology and Medicine*, *28*(3), 250–274.

Mayfield, B. (2007). *Selected References: Family Meals*. Purdue University, Center for Families. Retrieved (4/11/2008) from http://www.cfs.purdue.edu/CFF/documents/promoting_meals/mealtimereferences.pdf

Monk, A., Brant, J., Wright, P., & Robinson, J. (2004). *CUHTec: the Centre for Usable Home Technology.* In CHI '04 extended abstracts on Human factors in computing systems. Vienna, Austria, 1073-1074

Myers, B. A. (1998). A brief history of human-computer interaction technology. *Interaction*, *5*(2), 44–54. doi:10.1145/274430.274436

National Statistics. (2008). *More pensioners than under-16's for first time ever*. Retrieved (3/11/08) from http://www.statistics.gov.uk/cci/nugget.asp?ID=949.

Reuters. (2009). *French exec blames email for staff stress*. Retrieved (24/9/2010) from http://www.reuters.com/article/idUSTRE58N6ES20090925.

Stanford, V. (2002). Pervasive health care applications face tough security challenges. *Pervasive Computing*, *1*(2), 8–12. doi:10.1109/MPRV.2002.1012332

The New York Times. (2010). *France Télécom Needs 'Radical Change' After Suicides,* Report Says. Retrieved (27/9/2010) from http://www.nytimes.com/2010/03/09/technology/09telecom.html?_r=1&scp=3&sq=&st=nyt.

Weisskirch, R. (2009). Parenting by Cell Phone: Parental Monitoring of Adolescents and Family Relations. *Journal of Youth and Adolescence*, *38*(8), 1123–1139. doi:10.1007/s10964-008-9374-8

Chapter 17
Empowering People Rather Than Connecting Them

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ABSTRACT

This article discusses the consequences for the fundamentals of interaction design given the introduction of mobile devices with increased sensing capability. Location-aware systems are discussed as one example of the possibilities. The article provides eight challenges to the mobile HCI research community, and makes suggestions for how the International Journal of Mobile HCI could contribute to the field.

INTRODUCTION

The history of mobile interaction has been largely about creating smaller and smaller devices with more and more computing power, faster connections and better displays. Now, increasingly, mobile phones are being better equipped with more sensing capability via physical sensors, and they are accessing further information from the Internet via sources which can be viewed as 'virtual sensors'. These developments give users the chance to create embodied interaction loops in a range of novel ways. In this article I try to summarise my perspective on the fundamentals of interaction design and the challenges we face, and which I believe we need to address with our research and development effort in the coming years.

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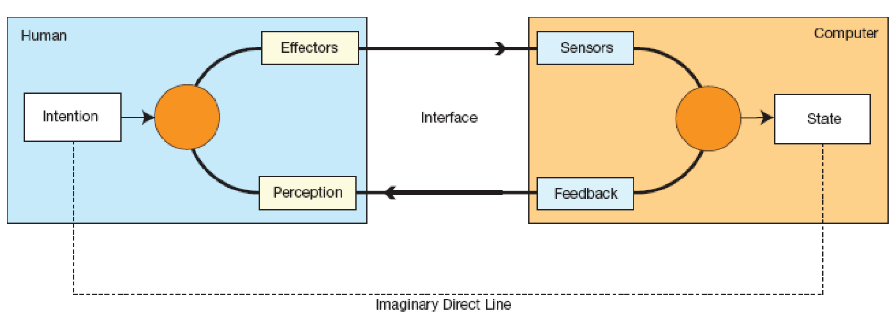
INTERACTION AS CLOSED-LOOP DESIGN

In this article, one of the basic assumptions about the fundamentals of interaction is that a user's behaviour is about them controlling their perceptions (Powers, 1973). We view the closed loop between user and phone as a dynamic system, where designers can alter the feedback mechanisms in

Figure 1.



the phone, and where, to an extent, the human user can adapt, in order to create and appropriate closed-loop behaviour. (See Figure 1).

There is already a wide variety of sensing and display technologies that can be used to construct the physical aspects of a human-computer interface, and much recent research has been dedicated to expanding the sensing and display capabilities of typical devices. Rich sensors, from accelerometers, smart clothing and GPS units, to pressure sensors, create the potential for whole new ways of interacting with computational devices in a range of contexts. Each of these has different information capacities, noise properties, delays, power demands, frequency responses, and other modality-specific characteristics. Sensors will continue to get cheaper and smaller, and new ones will create as yet unimagined interaction possibilities. Building interfaces that make use of possibly high-dimensional, noisy, intermittently available senses to create usable communication media is a significant challenge for the current HCI framework. We need general frameworks which are not tied to specific sensing or display devices, but generalise to wider classes of devices.

The display in any human-controlled control system is to provide the user with information needed to exercise control, i.e. to predict the consequences of control alternatives, to evaluate the current status and plan future control actions, or better understand the consequences of recent actions. Current examples of basic feedback loops include: Visual, audio, or vibrotactile display of the states of phone, or of distant events, people or systems.

In a mobile context users are subject to significant levels of disturbances and tend to have a lower attention span, leading to fragmentary or *intermittent* interaction. Because of this, in many cases it can be advisable to use *modality scheduling*, where the order of presentation of information in different feedback channels can be controlled as a function of the context, and the user's control behaviour. Perception is commonly seen as process of receiving information from the world, which is typically followed by cognitive processes and then action. However, in reality, perception is tangled up with specific possibilities of action, so perception is not mediated by action-neutral models. Inner states are 'action-centred'. Gibson called this detecting 'affordances'. Such affordances are nothing other than the possibility for use, interpretation and action offered by the local environment to a specific type of embodied agent.

Perception is not passive reception of information—it is geared to tracking possibilities for action. Traditional actions on a mobile phone consisted of button pushing, but in a modern phone the action might also include gesturing with the phone, tapping the phone, walking or driving to a new location, changing the phone's compass bearing. Some of these are essentially discrete actions, but many others are actions which are spread out over time, and which may be difficult to classify consistently. This perspective changes the design of feedback for users, the software engineering platforms devices are developed on, and has implications for the users' models of how to engage with their mobile devices.

It also changes the notion of the sort of services users can be offered. One can imagine 'Apps stores' offering customers new sensory perception abilities (e.g. a 'mother-in-law early warning system' which provides feedback when the mother-in-law is within four minutes of your current location, or a 'my friends are in the pub' sensory input, which is activated when more than two of your close social network contacts are co-located in a pub), which could then be combined with actuation modules which generated particular behaviours, such as changing your visibility status, when initiated. Frameworks which make it easy for end users to combine multiple sensor readings, and possibly integrating them with other information from the Internet, allows the creation of 'virtual sensors' which offer a new service. These can then be shared with other users, many of whom will have little technical skill or interest, but who can profit from the work of others.

This approach can be summed up as *empower the users—don't dictate*! Give users more options, and create opportunities to build control loops combining different groups of output and input channels. Let the users create meaningful interactions, and let groups of users put information and structure into the world, creating the conditions for their future interactions. As discussed at length in (Clark 2008), humans are the ultimate examples of beings which are suited to create and adapt to new ecological niches. There are also some interesting objective measures of empowerment as the maximum information flow the agent can direct into its future sensoric input via the environment. It is a measure of control suggested by (Klyubin, Polani & Nehaniv 2006), building on work of Powers (1973), and is the information-theoretic capacity of an agent's actuation channel. As Klyubin *et al* say, an agent which maximises empowerment, is continuously striving for more options, which lead to more potential for control or influence as if to the motto *"All else being equal—keep your options open"*.

Once people's behaviour starts to be shaped by the properties of these novel sensory-action loops we can expect to see interesting novel, but hard to predict developments in the way people move and behave in our cities. In this issue, Pirhonen and Sillence note the effect of the mobile phone use on the behaviour of young Finnish boys. The flexibility provided by the mobile phone allowed them to defer decisions on what to do next, and led to less frequent games of ice hockey. Once people add extra sensory perceptions to their mobile devices which are a function of their behaviour, location and proximity to others in their social network, we will see interesting and unpredictable new developments in such situations. Maybe it becomes enough for three boys to start heading towards the ice hockey for others to be alerted to this and join them?

We will see an increasing level of conscious and unconscious offloading of information into the environment, which might be for our own use, or for others'. This is *stigmergy*—indirect communication between agents via the environment (which in our case includes the digital environment) without targeting a specific recipient. The academic work in this field is used to explain nest building and foraging in social insects, but it is also a vital step in the creation of cultural instruments such as language. Maybe the three boys had not actually originally intended to play another game of ice hockey, but as they formed a core of a potential game, others might be attracted to that area, and a game would emerge in a self-organised manner.

We might see a more general move in interaction design away from our simplistic 'command-and-control' systems towards a metaphor which is more like dancing, with a natural ebb and flow of control between the user, their mobile device and the broader environment. In such *negotiated interaction* systems, the control changes fluidly as the context determines. The user and the computational system work together to negotiate their interactions and communicate their intentions in a fluid, dynamic manner (Williamson, 2006). Timed, informative feedback shares the load between both sides, and the interactions occur at multiple time-scales. We are currently developing such prototypes in a collaboration between Glasgow and Swansea Universities in a joint research project in Negotiated Interaction.

This change of perspective makes us consider whether we should maybe view the interaction more as we do with animals? Here we would think of a rider on a horse, rather than someone giving a human butler instructions. The rider 'reads' the horse, and the horse reads the rider's intentions via body language, gait, general behaviour, pulling on reins etc. The human and horse each have something to bring into the interaction, and are aware of different constraints, and there will be a varying level of control, depending on these constraints. In their paper on the 'H-metaphor' Flemisch et al. (2003) discussed the loose/tight reined approach to cooperative control in detail, in the context of cockpit automation. This metaphor seems very appropriate for the world of mobile interaction, where increased sensory interaction can provide the device a sense of context, but where this is subject to significant uncertainty.

LOCATION-BASED INTERACTION

A clear example of the potential benefits of offloading information into the environment is that of location-based interaction, where content and services are placed in the environment for the user to access as needed, in a context-dependent fashion. While there is already a lot of work in this area (Fröhlich et al. 2007), Mobile Spatial Interaction (MSI) feels very much like where the world-wide web was in 1992, when the first browsers came out. The huge potential can be seen, but there is still a long way to go, and we need to couple location with an ability to use bearing and projection information (Strachan & Murray-Smith, 2009). Without the ability to point from your current location in multiple directions, and at different distances, the location-based service options remain fairly limited (see Figures 2 and 3).

Figure 2. User 1 is 'the cursor' while User 2 has the ability to point at different locations by changing their bearing and the distance they are pointing

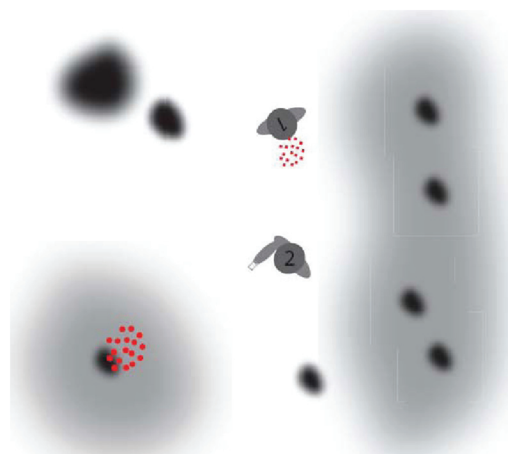


Figure 3. A user interacting with digital content and services in his physical garden

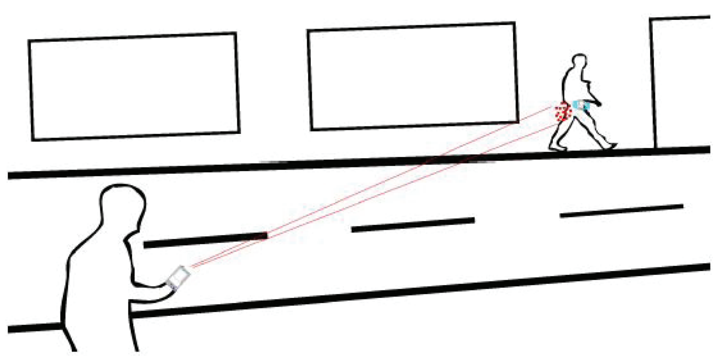
As an example of where this technology might take us, we include an illustrative mobile use-case scenario: On the left of his garden footpath the user has recorded the location of a number of work-related virtual objects and on the right, leisure objects. When he leaves for work in the morning he wants to pick up e-mail for that day and any new voicemails. Stepping out of the house, he queries the area where he has stored his work objects by pointing at them. His location is detected using GPS, his bearing via a magnetometer. He feels, via tactile feedback, that he is pointing at the 'work' area of his garden, and he probes around this context, finds the email and gauges the amount of new mail by force-feedback, and grabs them from that location with a gesture, feeling a satisfying clunk as they transfer to his device. He then pulls in an upbeat music recipe from the leisure context on the right and heads for his train. Approaching the station, he points in the direction of his train for an update on any travel delays, with a pulsing vibration indicating the time to the next train. At the end of the day he comes home again and decides to leave his work behind him, so he locates again his work context by the footpath and drops his email there, effectively redirecting all work-related emails until the next morning when he can pick them up again. He then probes the leisure area, detecting its specific haptic feedback, feels his usual news podcast there but decides to leave it, and instead takes a relaxing playlist for the evening ahead, goes inside, and grabs a beer. (See Figure 4.)

How will MSI cultures evolve? Will it be a top-down 'designed' approach, with major infrastructure investment by content providers and operators, or will it be a bottom-up approach where users create local content and services which are of value to them personally, and where they share this with others, shaping the evolution of their behaviours and the content they interact with in space and time? We would, as with other mobile technologies, expect to see variations in evolution, given same technology but varying local cultural and physical constraints. Will cities sponsor local content to guide people to specific locations? This could be the standard tourism scenario, but it might also be used by the police, where they could try to shape behaviour in the real world by sponsoring content and service availability which would attract young people away from areas where there had been disruptive behaviour, towards areas where the police felt things were more controllable? Will retailers give away content with gradients designed to attract people closer to their 'bricks and mortar' shops? Will operators provide location-specific functionality?

CHALLENGES

The preceding sections have outlined some of the broad issues in the evolution of novel forms of interaction in the world of sensor enriched mobile

Figure 4. Geosocial networking will bring embodied interaction into the world of social networks



devices. This section is an attempt to highlight some of the interesting research challenges we need to solve in order to make progress.

1. **The Midas touch:** How do we control the interpretation of our phone's sensor readings? How do we 'declutch' certain modes? The information flow from the sensors will need be interpreted differently in different contexts. This requires excellent models to automatically infer likely intention given overt behaviour, and we need subtle feedback to the user for them to infer current mode and consequences of action. This is a major, fundamental area which will recur everywhere in mobile multimodal interaction.
2. **Inference, learning and adaptation:** Understanding the data generated by mobile users: To survive in mobile service provision, companies will need the skills to create models, infer latent variables, such as context and goals, and be able to negotiate these interpretations with the users. Interpretation of context, of music content, of emotional aspects of behaviour and the meaning of interactions within social networks.
3. **Uncertainty:** Every interaction involves uncertainty. An interface should be honest—it must work with the uncertainty and not just filter it out blindly, as is the norm today. Increasing computational power makes this *ad hoc* approach less defendable. The quality of control of a system depends on its feedback. The feedback must reflect the uncertainty of system beliefs. Appropriate use of uncertain feedback can lead to smoother interaction, with user behaviour regularised appropriately (e.g. Körding & Wolpert, 2004).
4. **Physical simulation for interaction design:** Physical simulation based models for real-time synthesis for audio and haptic rendering. The model for this could be the development of the tools within the computer-generated film industry, where complex physical models are now controlled by artists with little need for them to understand the underlying physical models. In mobile software engineering, we therefore need to be enabling interaction designers to create dynamics, the way animators create films. This is likely to be done via standard parameterised primitives, using a range of physical metaphors, with accompanying vibration and audio feedback profiles. The quality of output is open-ended - the models can progressively improve as computational power and models improve, and as better sensing and displays evolve. This will then lead to the evolution of richer cultures of linking such models to abstract data structures.
5. **Real-time mobile Operating Systems:** For a sense of flowing, embodied control, we will need mobile devices with real-time architectures, with hard real-time guarantees. This will involve tight loops from sensing to actuation on device (including fast vibrotactile and audio responses, which are not subject to random delays due to multi-thread operating systems, as in current popular platforms). It will also need guaranteed low-latency round-trip-times over the wireless network for interaction between people at a distance. This would lead to a major rethink of mobile operating systems requirements.
6. **Power implications of control & inference loops:** This issue combines aspects of the 'midas touch' challenge, and the real-time mobile challenge, with hardware and software design and the choice of interaction metaphors. Without appropriate hardware and algorithms for intelligent allocation of limited processing power, none of these techniques will be used in everyday mobile devices.
7. **Aesthetic-utilitarian trade-off:** Will interactions be so rewarding people enjoy working hard to 'master' them? E.g. In Mobile

Spatial interaction, can we provide feedback gradients as elegant as a Zen garden? Will well-designed multimodal interaction make the device feel as rich as a fine musical instrument?

8. **Dancing or commanding?** Can we create metaphors which users can accept which explicitly support interaction which consists of a smooth ebb and flow of control between human and machine, rather than a dialogue of instructions and responses? Your phone can actively engage with you at a range of conceptual levels and timescales. On a scale from autistic to spookily mindreading, how alive to your wishes do you want your phone feel?

OUTLOOK FOR THE INTERNATIONAL JOURNAL OF MOBILE HCI:

How could the International Journal of Mobile HCI contribute to progress towards the challenges outlined above?

I think we need theoretical frameworks which can handle the sensing, modelling and inference which will be such a vital aspect of modern mobile interaction, and an openness for interaction design which breaks the 'discrete-event' mould.

We will also need to make sensor interpretation and signal processing developments which enable truly engaging context aware interaction, and we should respect and publish the research in this area, rather than viewing it as the 'technical engineering details' which are hidden at the back of a user study. Without appropriate sensing and intelligent power management, none of the futuristic goals can be realised in practice. Many of the most interesting applications of the inference technology might end up being used at very low levels, in order to sense and respond rapidly to perceived changes in intention.

Furthermore, when we work with such highly instrumented devices, we should use the sensors not just for interaction design, but also for instrumented usability analysis, when we do our scientific studies. Standard mobile phones now have sensing and storage abilities which allow us to log significant amounts of data, including location, activity levels, behaviour, and voice characteristics during normal use, and to use this to better understand the effects of design decisions on user behaviour, especially if multiple members of a social network are instrumented. This allows users to go into more realistic environments, but we sense more of the activities and at a finer grained level than before. We can use automated behaviour or context detection to initiate experimental interventions, regaining some level of experimental control, with the ecologically appropriate conditions (Roto et al. 2004, Oulasvirta et al. 2005). Researchers will be faced with demands for increased levels of objective data and more explicit behavioural metrics to augment and complement the more traditional subjective feedback, and the research community needs to explore, calibrate and standardize the use of such metrics.

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REFERENCES

Clark, A. (2008). *Supersizing the mind: Embodiment*. Oxford: Action, and Cognitive Extension. doi:10.1093/acprof:oso/9780195333213.001.0001

Flemisch, O., Adams, A., Conway, S. R., Goodrich, K. H., Palmer, M. T., & Schutte, P. C. (2003). *The H-Metaphor as a Guideline for Vehicle Automation and Interaction*. NASA/TM—2003-212672.

Fröhlich, P., Simon, R., & Baillie, L. (2009, April). Mobile Spatial Interaction. *Personal and Ubiquitous Computing*, *13*(4). doi:10.1007/s00779-008-0208-1

Jagacinski, R. J., & Flach, J. M. (2003). *Control theory for humans: quantitative approaches to modelling performance*. Mahwah, NJ: L. Erlbaum Associates.

Klyubin, A. S., Polani, D., & Nehaniv, C. L. (2005, September). Empowerment: A Universal Agent-Centric Measure of Control. I*n Proceedings of the 2005 IEEE Congress on Evolutionary Computation, 1*, 128-135. IEEE Press.

Körding, K., & Wolpert, D. (2004). Bayesian integration in sensorimotor learning. *Nature*, *427*, 244–247. doi:10.1038/nature02169

Oulasvirta, A., Tamminen, S., Roto, V., & Kuorelahti, J. (2005). Interaction in 4-second bursts: The fragmented nature of attentional resources in mobile HCI. *Proceedings of CHI 2005* (pp. 919-928). New York: ACM Press.

Powers, W. T. (1973). *Behavior: The Control of Perception*. Aldine de Gruyter.

Roto, V. O., Haikarainen, A., Lehmuskallio, T., & Nyyssönen, T. (2004). *Examining mobile phone use in the wild with quasi-experimentation*. HIIT Technical Report 2004-1.

Strachan, S., & Murray-Smith, R. (2009). Bearing-based selection in mobile spatial interaction. *Personal and Ubiquitous Computing*, *13*(4), 265–280. doi:10.1007/s00779-008-0205-4

Williamson, J. (2006). *Continuous Uncertain Interaction.* PhD thesis, Dept. Computing Science, University of Glasgow.

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Chapter 18
Mobile Internet:
Past, Present, and the Future

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ABSTRACT

The Mobile Internet is no longer a new phenomenon; the first mobile devices supporting Web access were introduced over 10 years ago. During the past 10 years many user studies have been conducted that have generated insights into mobile Internet use. The number of mobile Internet users has increased and the focus of the studies has switched from the user interface to user experiences. Mobile phones are regarded as personal devices: the current possibility of gathering more contextual information and linking that to the Internet creates totally new challenges for user experience and design.

INTRODUCTION

When the mobile Internet was launched in the late 90s it was claimed to be the Internet in your pocket. With hindsight, it is easy to say that this metaphor was not justified, as it did not take the user perception of the Internet into consideration. The huge Wireless Application Protocol (WAP) hype and hangover following the hype have been widely reported (for example, Pannanen (2000), Sokela (2002), and in a 2000 Znet article). This disappointment after such high expectations made it impossible to take WAP seriously in later years. WAP had become merely a joke, albeit many network operators kept on developing services on the WAP protocol (Kaikkonen 2005), and made revenue on these services as increasing numbers of users used these services. For user experience experts it became clear that the technology and protocol behind a service do not really matter to users; what is more important is what you can do with the services. The success of iMode in Japan is well known, but it is rarely mentioned that other Japanese operators, like KDDI, built

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their successful mobile Internet offering on the WAP protocol.

Was WAP a waste of time and effort? The question in itself is not very interesting—it is more interesting to ask what we learned from the first years of WAP. Are these lessons sufficiently valuable that we can consider WAP as a useful—and necessary—step along the path to effectively offering Web access on mobiles?

It does not make sense to ask if we should still have WAP or other mobile-tailored Web support on mobile devices; instead, we should be asking *when do we need mobile-tailored content on mobile devices and when is full Internet content needed*?

DID WE LEARN ANYTHING FROM WAP THAT WE CAN USE IN THE FUTURE?

During the first years of WAP, many researchers published papers related to user interface (UI) design and usability—for example, Buchanan *et al.* (2001), Chittaro and Dal Cin (2002), Kim *et al.* (2002), Kaikkonen and Roto (2003), and Hyvärinen *et al*. (2005), amongst many others. In addition to technology and protocol information, such papers also contain generic information related to the usability of, and design for, small screens and spotty networks; this generic information can certainly inform the future design and evaluation of any services targeted at small screens.

Another obvious lesson is not related to user interface design or usability, but rather to how important it is to take user expectations and mental models into consideration. The disappointment portrayed by the media in early 2000 reflected the mismatch between the message and user perception. In the midst of the hype, analysis of the reasons for the hype took second place to market messages. The companies developing mobile technologies are not, however, entirely to blame; critical public reviews were, in general, pretty rare. The public message on the mobile Internet in Europe and North America failed to take into consideration the perception and mental models of users. The situation in Japan and South Korea shows that the problem was not entirely related to network and device limitations, but was, instead, more complex. When the mobile Internet became available in Japan, the Internet penetration was fairly low (13.4% in 1998) and mobile phone penetration high (57.7% in 1998); as a result, most users did not have a clear perception as to the Internet per se, and so the local operators were able to advertise the mobile Internet by highlighting its benefits. At the same time, Western operators and technology developers continued advertising WAP with gimmicky technical terms. These lessons are not unique to WAP, but they clearly show that you should know your audience, its perceptions and values, and match your message to these!

WHAT IS THE MOBILE INTERNET?

The Mobile Internet can be described in many different ways. To illustrate its diversity, I have chosen 4 studies on mobile Internet use, all of which were published during 2008. The description of the mobile Internet in these papers gives a good impression of how differently the topic can be approached. Cui and Roto (2008) studied mobile Web usage and seem to define use of the Web on mobiles as viewing Web pages with mobile browsers; this covers both mobile-tailored and full Web content. Hinman *et al.* (2008) compare mobile and PC Web use in the context of a PC deprivation study. In this study, the use of the mobile Web is mainly related to full Web site use on mobiles. Taylor *et al.* (2008) seem to perceive the mobile Web as mostly providing more relevant, mobile-tailored services.

The fourth definition of the mobile Web combines all three of the previous approaches: Kaikkonen (2008) defines the mobile Web as any access to the Internet via a mobile device- this approach is rather presenting *Internet access* *on mobiles* than *Mobile Internet*. The different alternatives for using and accessing the Web on mobiles today can be seen in Figure 1. Web access from mobiles can be divided to *browser-accessed* and *client-accessed*. The difference is very clear from the user's perspective. For browser-accessed approaches, there are two alternatives; a site can be either identical to that which the user accesses via a desktop computer or the content can be tailored for a mobile platform. Client-access means that applications connect to a service to fetch specific pieces of data from the Web: different approaches support different usage situations, and therefore one service can be accessed multiple ways.

Full Web on Mobile Phones

Full Web sites are sites developed with standard HTML for desktop computer use. The content on a mobile browser is (with some technical limitations) the same as that which the user sees when browsing the site on a desktop computer. Most mobile browsers do not support all audio and video formats; this means that a user may not be able to listen to background music or view video clips on sites. In some cases full Web site design is optimized for a specific browser, commonly Internet Explorer. The layout of such sites may, therefore, look awkward on mobile (or other) browsers to a user who is familiar with the site on a specific browser on a desktop computer.

Full Web content on mobile devices is not really a new thing; it has been possible to access full Web content on mobiles for as long as it has been possible to access mobile-tailored content; for example, the Nokia Communicator provided a Web browser with HTML support as early as the late 90s. Kaasinen *et al*. (2000) demonstrated ways to render Web content to fit the screen of a mobile phone, and Roto and Kaikkonen (2003) analyzed the problems users have when full pages are rendered to a narrow layout inside mobile browsers. Currently the narrow layout is no longer the only solution; as mobile phone screens have become bigger; more devices are able to show the Web site layout in a comparable manner to the layout seen on a desktop computer. Figure 2A shows how one service, *Share on Ovi* (a full Web page), looks on a mobile device. I will explain the other figures in the following sections.

Lately, increasing numbers of companies have started to take mobile browsers into consideration when building their full Web sites. The question now is '*how do you best create Web sites that fit both desktop computers and mobile devices?*'. For example, Yahoo! has defined guidelines to

Figure 1. Landscape of the mobile Internet

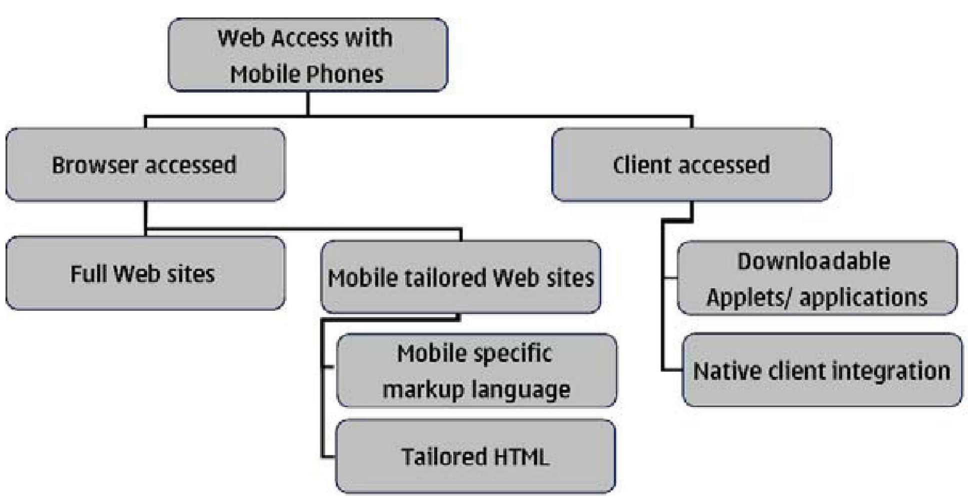
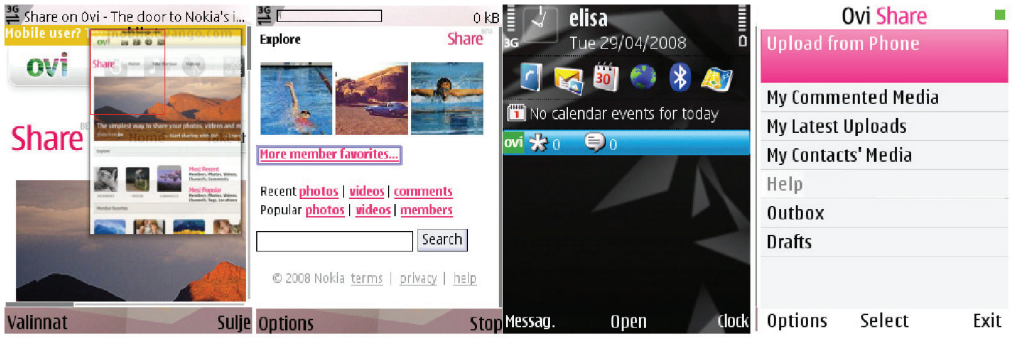


Figure 2. Different views of the same service on mobile devices



A B C D

help developers to build full Web sites that also work well on mobile browsers (Sounders and Theurer 2008).

Mobile-Tailored Browser Access

Tailoring Web content for mobile phones can be done in different ways, as Figure 1 shows. Users can obviously access Internet content with a mobile browser, and open websites that are tailored for mobile phones. That is not, however, the only way to tailor Web content to mobiles: users can have an applications or applets that access Internet content without opening a browser. Figures 2 B-D show how the *Share on Ovi* service can look on mobile devices: Figure 2B shows the mobile-tailored browser view. It does not really matter to users if the mobile tailoring has been done with a markup language designed for mobile devices (e.g., HDML, WML, cHTML, or XHTML) or standard HTML. What is important is that the content and UI is tailored to suit the mobile use.

Client Based Access

The other way of tailoring Internet content for mobile consumption is to develop applications that access the Internet. Figure 2C shows how service content can be visible on a phone's home screen, and 2D is an example of a downloadable application that can access an online service. Phone applications can support the upload or download of content to and from the Internet. The Web access can either be an integrated functionality in the phone's native applications (such as the calendar, photo gallery, music player, or phone idle screen) or it can be a stand alone application downloaded from the Web. These downloadable applications can access specific data from a phone; the applications connect to a specific site for a specific information query or task. For example, they may be used for uploading photos to a photo blog or downloading a game to a mobile phone.

WHAT DO PEOPLE DO WHEN BROWSING ON MOBILES?

Mobile browsing has become more common in recent years. Strategy Analytics (2008) estimates that the global number of mobile Internet users will exceed 400 million users by the end of 2008. The growth of the user base has influenced the topics of recently published papers. The number of papers that focus on analyzing empirical data on user behavior has increased. In previous years, the papers focused on how to make the user interface easy and consistent; now the technology is mature, studies are tending to focus on what people do and why.

Taylor *et al.* (2008) studied 11 mobile Internet early adopters in the U.S. They used user feedback to create a framework that could help in classification of user motivation in relation to mobile browsing. Taylor *et al.* tried to understand users by classifying their motivations, behavior, and physical settings. *Motivations* are divided into two subcategories—*utilitarian* and *hedonic*; although the division was not originally invented by Kim *et al*., they base their use of this classification on a paper by Kim *et al*. (2002) who studied the use contexts of, and usability problems with, the mobile Internet. *Behavioral* aspects were divided into *info seeking*, *action support*, and *info exchange*. The *Physical* setting is a list of locations or activities, such as 'home', 'work', or 'walking'. Based on this classification, Taylor *et al.* aim to provide tools for more effectively building user scenarios to help product/service creation. Their work focuses on creating tools for future work; as such, it does not provide extensive information on the frequency of different motivations (though so called utilitarian motivations seem to be more common in their study) or behaviors.

Cui and Roto (2008) combined the results from multiple studies published between 2004 and 2007. They analyzed the mobile Web use of 47 people in 6 cities (and countries). The users were familiar with mobile Web use; they were mostly male and could be considered early adopters of technology. Based on contextual inquiries, Cui and Roto found that the mobile Web is often used in stationary, rather than truly mobile, settings. People browse both when alone and in social situations, but browsing sessions are for fairly short periods of time. The length of browsing sessions depends on network access type; people browse for longer when they have WLAN access than when they have cellular network access. According to Cui and Roto, the cost associated with the different network access types is the main reason for this difference. Cui and Roto divide user activities when browsing on mobile devices into to 3 categories: information seeking; communication; and content object handling. All these can be done for utilitarian or entertainment purposes. The most common activity when browsing was related to communication, and being aware of social networks (via email mostly). Based on their study, Cui and Roto observed that mobile Web use sometimes changes people's daily chores and behavior; for example, people choose routes that have better network connections.

Hinman *et al.* (2008) adopted a very different approach in their study; they studied 8 Internet users in the U.S.; all users were familiar with both mobile and full Web access. For four days, users were allowed to use the Internet only on their mobiles; the usage data was then analyzed together with their 'natural' usage data that had been recorded prior to the deprivation study. Hinman and her colleagues found that users' PC-based Internet browsing experience substantially influenced their perceptions of the Internet. Even when using a mobile browser, users' usage motivation was in line with their desktop computer use—the feeling of being connected was more important than the actual tasks done online. During the deprivation period, users tried to follow, on their mobile device, the same Internet usage patterns they had developed using their desktop computer, but found it difficult and were unhappy about the situation. A feeling of disconnectedness from social networks was one of the strong feelings reported by users. It was clear that desktop computer usage patterns did not work on mobile devices. Based on their study, Hinman *et al.* draw the metaphorical conclusion that PC-based Internet browsing is like scuba diving, and the mobile-based Internet experience is like snorkeling. Internet browsing on a desktop computer is like scuba diving because it is immersive; it invites exploration and discovery, and it supports multitasking. The mobile Internet experience is like snorkeling because attention is divided, and it is difficult to get totally immersed.

Based on my experience, this metaphor describes well the experience of users that use both desktop computers and mobile phones to access the Internet. The same experience was described by one user in an unpublished media sharing pilot, when she was describing her flow experience (Flow is an experience theory by Mihaly Csikszentmihalyi (1990, 1998)), namely:

When analyzing my service use and my experiences, I realized that in PC use it was easier and faster to go to flow state. Mobile application is good for uploading photos, but (lack of) speed of the data transfer distracts the flow experience. [Pilot user commenting on flow experience on mobile and PC Web].

WHAT DID I LEARN ABOUT MOBILE INTERNET USE?

In 2007 I conducted a survey-based study of smart phone users' mobile Internet experiences (Kaikkonen 2008). Three hundred and ninety mobile Internet users from various countries responded to the survey, and from these respondents I chose 23 people for in-depth interviews. Interviews were held in Hong Kong, London, and New York during May- June 2007.

Like in other studies described in this article, most of the online survey respondents (80%) were male. It was not surprising that these male users were typically engineers, technical IT professionals, or in managerial/analytical positions. More surprising, was that most females were teachers or worked in healthcare; only 6 women had a technical background. Overall, a large proportion of the survey respondents came from Asia; additionally, the majority of the *female* respondents were Asian. Having many non-technical females amongst the Asian users made Asian responses different overall from the responses received from other continents; Asians were using more mobile-tailored Web and, rather than being early adopters, they could be described to represent early mass. Asian users were most excited about the future possibility of browsing the full Web on mobile devices. European and North American respondents typically had technical backgrounds; they could be described as representing early adopters of technology. European and North American respondents browsed more full Web sites and had downloaded applications that connect to the Internet. European and North American users saw the future of the mobile Internet as being based on application-integrated use of Internet services.

How does Mobile and Full Web Use Differ on Mobile Devices?

All the survey respondents owned a device with a browser capable of accessing both full Web content and mobile-tailored content. Many of the respondents did take advantage of this capability; almost 70% of the respondents browsed both full Web and mobile-tailored Web sites (very often, operator WAP portals). Rarely did a respondent report only browsing full Web sites: only 14% of the respondents mentioned exclusively browsing sites that were available only as full Web sites. Browsing restricted to mobile-tailored sites was more common; 32% of respondents mentioned only browsing sites that are mobile-tailored. The use of downloadable applications, widgets, and native application-integrated solutions was not very common; 7% of the respondents mentioned use of applications that access the Web.

Users in different countries accessed the Web in different ways: most respondents from Hong Kong browsed only mobile-tailored sites—typically, the WAP portal of their mobile operator. Overall, Asian users browsed fewer full Web sites than Europeans and North Americans; 23% of Asian respondents only browsed mobile-tailored sites compared to only 10% and 2% of North American and European respondents, respectively. The interviews clarified the reasons behind the behavior: although users everywhere *perceived* that cost is an issue in terms of mobile Internet use, the interviewees in Hong Kong were especially conscious of the perceived difference in cost between accessing full Web and mobile-tailored Web sites from their mobile devices. Operators in Hong Kong had packaged their phone plans in such way that the use of the operator mobile portal was part of the phone plan; users paid the same fee whether or not they used the portal but additional costs were incurred to access other Web sites. As a result, only users that had WLAN support on their phones browsed full Web sites—typically when at a WLAN hotspot.

The respondents of the online survey were asked to list up to 5 recent Web sites they had accessed via their mobile browser. Collectively, respondents identified 999 Web addresses: half of these sites were available only as full Web versions; 25% of the addresses led to sites that were clearly mobile-tailored, and the rest to sites available both in full Web and mobile-tailored formats, such as Google and Yahoo! More users reported browsing mobile-tailored than full Web sites, but there was more diversity with regards full Web sites; many users browsing mobile-tailored sites reported accessing the same operator portals. Users who reported accessing only mobile-tailored sites listed just 1 or 2 Web addresses, whereas respondents who also browsed the full Web on mobile devices reported having viewed at least 4 sites.

When the Web sites viewed, and corresponding motivations of the users in the survey, were divided using the categorization by Cui and Roto (2008)—i.e., *information seeking*, *communication*, and *content object handling*—we observed that 60% of the respondents mentioned accessing sites that supported clear information search motivations—e.g., the use of search engines, news sites, and news areas of operator portals. *Communication* (mostly Web-based email) was mentioned by 20% of the respondents, and object handling, like adding text or photos to a blog, was mentioned by 30% of the respondents.

Computer vs. Mobile Device

Most respondents to our survey accessed the Internet with both a desktop computer and a mobile phone. Some of the Web sites they browsed are the same on both platforms. Although some user activities were the same no matter how they accessed a site, there were also differences. When seeking information, users generally read news and searched information based on keywords in search engines; on mobile devices they read smaller amounts of text and browsed for a shorter period of time. Users also read email on both mobile and desktop computers; on mobile devices, however, users read more emails than they wrote. Users also avoided reading very long emails on mobile phones if they were not essential; if they needed to write an email on a mobile phone, their responses were typically shorter than on a desktop computer. That said, although the responses were short on mobile devices, they were no less important than the longer ones written on a desktop computer. Many respondents reported that they followed blogs and discussion group conversations on mobile devices. Writing to, and active participation in, social sites was less common on mobile devices than on desktop computers. One could assume that this is mainly due to the small screen and numeric keyboard but although these do influence behavior, our interviews revealed more reasons: mobile Web sessions were shorter and more prone to interruptions than sessions on a desktop computer, so the latter was considered more appropriate for participating actively in social sites where one needs more time and peace.

Based on the interviews, we observed that there were some activities where mobile phones were linked to the Web via a desktop computer; some users perceived this to represent Internet use on a mobile device. Mobile imaging is one such case: picture viewing usually happened on the mobile phone from the phone's photo gallery; people shared photos by sending them as MMS messages or by transferring the photos to a desktop computer and either uploading them to a photo service or sending them as an email attachment:

Mobile photos I sync them to my computer, I MMS them to people, on occasion, maybe two or three times in a month, maybe not that often. Because *there aren't so many people you'll send it to, so it doesn't actually get through. I have some that I have uploaded to Flickr as well [Interviewee from London].*

Mobile Tailored Solutions for Web Access

Hinman *et al.* (2008) applied a diving metaphor to Web browsing. They said that browsing on a desktop computer is like scuba diving, and browsing on a mobile device is like snorkeling. As we have just shown, there are different ways to use the Internet on mobile devices, and in the same way there are different ways of snorkeling. Based on my experience with Internet use on mobile devices, I would extend Hinman *et als*' metaphor: I see full Web browsing on mobile devices as free diving, browsing mobile-tailored Web sites on mobile devices as snorkeling with occasional deeper dives, and Internet use via mobile applications as snorkeling in a swimming pool.

Why Full Web Access on Mobile Devices is Like Free Diving

When browsing the full Web on mobile devices, users looked for specific information that was only available in a full Web version, or users were not aware of a mobile-tailored solution. Full Web site browsing on a mobile device is like free diving because information needs are specific, and users know where to find the information; no matter how deep within a site structure the information is located, a user dives directly to it. Very often the depth of the information is more profound than when browsing on mobile-tailored sites. Information needs are often time critical, and usually the context in which information is being sought does not allow the use of a desktop computer: there is either no desktop computer available, the social context does not allow the use of a desktop computer, or the user knows he/she will be changing location during the information search. The motivation for use is less related to killing time than when browsing mobile-tailored sites:

I used Google at school, with my classmate. I had to look for school information. Because I can't use a normal PC browser at school so I use my mobile, it's so normal for me. I think it's so positive, cos it's very useful to have Internet always with me! [Web survey respondent];

Also I will use it at home. When I'm home I won't just go to my room and sit on my PC all the time, you know parents don't like that. They think I'm a good girl, as I'm not on PC all the time. They do not know I browse with my phone.[Interviewee from Hong Kong].

Why Browsing Mobile-Tailored Web Sites is Like Snorkeling with Occasional Deeper Dives

Browsing mobile-tailored sites is like snorkeling near the surface with occasional deeper dives because mobile-tailored site browsing is often related to killing time or browsing interesting information. When a user sees something interesting when browsing, he/she delves deeper into the information, but usually returns to the surface (for example, the home page of the portal) to browse for the next interesting topic; sometimes the next cue is caught when a user is viewing the deeper information, but that is less common. Sometimes a user just needs to quickly access specific information, like timetables or weather information:

The last service I used was the BBC Traffic News WAP site (I used the "Services" browser for this). I was on my own, just got in the car and about to drive off - checking for congestion etc on my route. I use this a lot - very useful to me! The experience was good - in a way a WAP site rather than a full Website is better for information like this; it gives me the information I need, quickly. [Web survey respondent];

Most of the time I use Hutchison portal, easy to access, easy to link to system and it is cheap. Yesterday I was in a bus and you know Hong Kong is always traffic congested, when I was waiting for the bus to move, I searched the Web, news, I even watched TV. [Interviewee from Hong Kong].

Why Internet Use via Mobile Applications Is Like Snorkeling in a Swimming Pool

Internet use via mobile applications is not yet very common, but it is likely to become more popular. It can be likened to snorkeling in a swimming pool because it is only possible to do specific tasks related to the application: the user often cannot browse outside the specific information source or service. The common use cases reported were related to time- and situation-critical activities—e.g., uploading photos to photo sharing sites and checking time-critical information. Often these situations were related to social activities, either with a group of friends physically present or with friends present online:

I was using Widsets- I was in a bar with some friends. We needed to get some facts I knew I could find quickly. I think it was a fairly typical use case, now with Widsets my mobile browsing has diminishing. The whole thing worked ok (turned out I was right! [Web survey respondent];

I used VOX during lunch break- it enables me to blog from anywhere I want. I love using mobile technology. I had a great experience. [Web survey respondent].

HOW MOBILE IS MOBILE WEB USE?

People can browse the Internet on their mobile devices in any context and situation, but our online survey revealed that the most common place was when at home alone. The study conducted by Cui and Roto (2008) revealed the same pattern in relation to location, but in their study social use was as common as solitary use. Home was a place where many respondents typically had desktop-based Internet access, but there were situations when it was just more convenient to browse on a mobile device. This issue came up both in our online survey and during the interviews. People browsed on mobile devices in places where desktop computer use was not possible, such as on their living room sofa. In general, with one exception, any Web activity could happen on mobile devices at home; the exception being that blog updates and photo sharing on mobile devices happened less frequently at home than other online activities.

Even though it was common for people to use the mobile Web at home, it was also common for users to browse the mobile Web from mobile devices while traversing multiple locations during one usage session. In these situations, people specifically chose to use the mobile Internet *because* they knew they would change location during the task:

I used it [mobile browser] to check the weather; I was at work on the way back home. I used a mobile because I could use it while I was leaving the building. The situation was absolutely normal for me. I use Mobile Web browsing since about 5 years, beginning with black&white wap pages. [Web survey respondent].

Using the mobile Internet was also common when people were on the move. When using public transportation, people often need to sit and wait either for, or in, their transportation (e.g., a train or bus); the mobile Internet is good way to 'kill time' and create private space in public environments:

I used Web browser on my N93 during my traveling to/from school by mass transport (tram, underground). I check RSS feeds, browse main Web servers about politics, economy, mobile phones, tech etc. I am connected through 3G cellular network. In school or at home i usually use

Wi-Fi. The Web browser in N93 is superb, Web pages look same as on desktop and that's very important. [Web survey respondent].

Work and office usage typically happened either during breaks (e.g., lunch and coffee breaks) or as a secondary task when a user's desktop computer was occupied for work-related activities.

Even though the mobile Internet could be used in any social context, users were often alone when browsing on a mobile device; this included when they were at home, moving around, and in work situations. When reporting on their most recent usage situations, people in both the online survey and in the interviews said that, when approached by a person, they stopped browsing and started interacting with the person. There were two reasons for this: the mobile device was regarded as a personal device, and mobile phone use was not seen as polite in most social situations. Interviewees did not consider the situations when they were surrounded by strangers in public places as 'social situations'.

Social usage happened at school, in cafés and pubs, and even outside. In these situations, the mobile Internet was typically used to verify something that came up during discussion:

Browser is pretty important for me. I use it a lot. Like when I went out to eat with my friends, I used it to view reviews of the restaurant before we made decision where to go [Interviewee from New York].

WHAT ISSUES WILL THERE BE IN MOBILE BROWSING IN THE FUTURE?

Cost has been known to be an issue from the early days of WAP; "Wait and Pay" was, in fact, one popular interpretation of the acronym. Roto *et al.* (2006) demonstrated the extent to which cost influences mobile browsing user experiences: perception of cost and lack of control affect user behavior and interaction with a system. Users often perceive that the mobile data traffic cost is high, but it is also hard for the users to understand, follow, and control how the cost is generated! Users try to maximize the benefit while they minimize the cost; perception of the billing model—whether right or wrong—influences their usage. To facilitate mobile Internet adoption to other than early adopters, flat fee data should be more commonly available for users and cost generation should be transparent. This is not a new concept, nor is it related only to the mobile Internet. Gourville and Soman (2002) pointed out that cost awareness and transparency are the main elements influencing consumption behavior in general. People are more likely to use a product or service when they are aware of the cost and they know how it is generated. Today, users are very often not aware of the actual cost of their typical browsing—never mind situations when they are traveling and roaming in foreign networks. When downloading a game to a mobile phone, users may be informed about the cost of the game, but not the cost of the data transfer. For global stores, it may actually be impossible to provide this information because there are so many different billing models. In some cases, users are informed about the size of the game, but it may be difficult for a user to calculate how much it will cost to download 3MB of data to his/her phone. The cost issue needs to be handled as more 'always connected' devices come to market—otherwise users may get very unpleasant surprises when they receive their phone bills. Since they cannot predict and control the cost, many users today solve the problem simply by not using services any more.

Another barrier for mobile Internet use is battery life. Users keep their mobile phones with them for communication purposes; they want to make sure they can make or receive calls or text messages in critical situations. If there is a risk of running out of battery, users start controlling their service use. The situation with respect to battery life is not getting significantly better; display sizes are growing, and larger displays consume more battery life than smaller ones. Some of the newer devices are built with the idea of being online "all the time". When such a device is connected to a network—irrespective of whether the connection is via WLAN or 3G—battery life is being consumed. If the connection is not good, a device will run out of battery power even faster. In my work I have observed that there seems to be differences between countries and operators with respect to battery life; across different operator networks, users exhibiting similar service usage patterns report very different experiences with respect to battery life: users of one network can report that they can use their devices for a whole day without charging the battery, where users of other network report that they need to charge their devices more than once during the day. It would be beneficial for user experience researchers to co-operate with technical researchers to investigate this area; if the network configuration can influence battery life expectancy, it would be very useful to have good data in this regard.

In relation to these two barriers to usage—cost and battery life—the mobile technology industry seems to be overly optimistic about how users will behave and adopt the technology. I would encourage researchers and developers, as well as business professionals, to evaluate their perceptions and be careful not to get too excited.

The studies discussed in this article do not consider device design in general, but the design of a device does influence usage patterns. Although screen size and keyboard did not surface explicitly in studies as issues influencing usage patterns, it is clear that they do exert influence on interaction. Many new mobile devices have touch screens and are designed to support information scanning and point–and-click interaction. Norman (2007) has noted that good Internet search engines have encouraged users return to engage in "command based" browsing. The challenge is not only, therefore, how best to design services that work both for touch screens and non-touch screens, but also increasingly how best to design services that simultaneously support mobile device- and desktop computer-based access—especially when the devices support such different interactions.

Application integrated services were only familiar to a small number of users in 2007- 2008, but this approach may be increasing for mobile devices. As mentioned earlier, European and North American early adopters believe that is the path to take. Social networking service access is already possible on mobile devices; when that becomes more common, it will potentially change the level of awareness of our social networks. For many years I have discussed a particular concern with users: they have seen positive aspects related to services that allow them to be more connected with their friends, to know where their friends are, and what they are doing, but they have also, however, expressed an occasional need for privacy, even from their closest friends. Of course it is always possible to turn a service off, but people do not want to have to later explain to friends why they were not available at a particular time: users comment that they already have to explain too often why they did not answer their phone or immediately respond to text messages. Users also distinguish between friends they have on their mobile phones and friends on social network services; they do not necessarily want to give hundreds of online 'friends' access to their very personal mobile device (e.g., phone).

Since we carry mobile devices with us all the time, it is possible to gather information about the environment we are in. This potentially automatically generated/collected data is richer for mobile devices than would be possible for data gathered by a stationary device. With current mobile devices, it is possible to upload the information in real time; it is also much easier to link together contextual information, information about (and on) a device, and services information to create data pools that were not previously possible. This information could be used for good or bad; it can potentially harm people, even (or especially) if they do not know about it. In many countries children start to use mobile phones and online services at a very early age—so young that they have no idea about the potential risks and, because mobile devices are perceived as personal devices, parents may not know all the things children do on their mobiles.

As technology researchers and developers, we need to think about, and evaluate, the potential side effects on people's lives of the systems we create. We should do whatever we can to decrease the negative influence without sacrificing the positive.

REFERENCES

Buchanan, G., Farrant, S., Jones, M., Thimbleby, H., Marsden, G., & Pazzani, M. (2001). Improving Mobile Internet Usability. *WWW10,* May 1-5, 2001, Hong Kong, China.

Chittaro, L., & Dal Cin, P. (2002). Evaluating Interface Design Choices on WAP Phones: Navigation and Selection. *Personal and Ubiquitous Computing*, *6*, 237–244. doi:10.1007/s007790200023

Csíkszentmihályi, M. (1990). *Flow: The Psychology of Optimal Experience*. New York: Harper and Row.

Csíkszentmihályi, M. (1998). *Finding Flow: The Psychology of Engagement With Everyday Life*. Basic Books.

Cui, Y., & Roto, V. (2008). How People Use the Web on Mobile Devices. *In Proceedings of World Wide Web Conference*, Beijing, China.

Gourville, J., & Dilip Soman, D. (2002). *Pricing and the Psychology of Consumption. Business Review September 2002 R0209G*www.hbr.org.

Hinman, R., Spasojevic, M., & Isomursu, P. (2008). They call it "surfing" for a reason: Identifying mobile Internet needs through PC deprivation. *Proc. of CHI 2008*, Florence, Italy, April 2008.

Hyvärinen, T., Kaikkonen, A., & Hiltunen, M. (2005). *2005*. Salzburg, Austria: Placing Links in Mobile Banking Application. In Proceedings of MobileHCI.

Kaasinen, E., Aaltonen, M., Kolari, J., Melakoski, S., & Laakko, T. (2000): Two approaches to bringing Internet services to WAP devices. Proceedings of the 9th international World Wide Web conference on Computer networks (2000) 231-246.

Kaikkonen, A. (2006). *2005- full paper. JIT July 2006*. Usability Problems in Today's Mobile Internet Portals. In Proceedings of Mobility.

Kaikkonen, A. (2008). Full or Tailored Mobile Web- Where and How do People Browse on Their Mobiles? *In Proceedings of Mobility 2008 conference* Yilan,Taiwan September 2008.

Kaikkonen, A., & Roto, V. (2003). Navigating in a Mobile XHTML Application. In *Proceedings of CHI2003.*

Kim, H., Kim, J., Lee, Y., Chae, M., & Choi, Y. (2002) An Empirical Study of the Use Contexts and Usability Problems in Mobile Internet. *In Proc. of 35th Hawaii international Conference on System Sciences 2002*, (pp. 1-10).

Manktelow, N. (2000). One wireless viewpoint: 'WAP is crap' In http://news.zdnet.com/2100-9595_22-108667.html?legacy=zdnn

Norman, D. (2007). The next UI breakthrough: command lines. *Interactions* XIV.3 - May / June, 2007

Paananen, V-M., Kolari, J., & Veistola P. (2000). *WAP ja Mobiili tulevaisuus*. Gummerus Jyväskylä 2000.

Roto, V., Geisler, R., Kaikkonen, A., Popescu, A., & Vartiainen, E. (2006). *Mobile Browsing User Experience and Data Traffic Costs*. Workshop paper in MobEA IV - Empowering the Mobile Web, workshop in WWW2006

Roto, V., & Kaikkonen, A. (2003). Perception of Narrow Web Pages on a Mobile Phone. *In proceedings of HFT 2003*

Sokala, H. (2002). *Maailma taskussa- kuinka matkapuhelimella tienattiin ja tuhottiin miljardeja.* Otava, Keuruu 2002.

Sounders, S., & Theurer, T. (2008). *High Performance Web Sites 14 rules for faster-loading pages Yahoo guidelines*, http://www.techpresentations.org/High_Performance_Web_Pages

Strategy Analytics (2008). *Mobile Internet: Global Market Forecast.*

Taylor, C. A., Anicello, O., Somohano, S., Samuels, N., Whitaker, L., & Ramey, J. A. (2008). A Framework for Understanding Mobile Internet Motivations and Behaviors. *Proc. of CHI 2008*, Florence, Italy, April 2008

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Chapter 19
Novel Technologies and Interaction Paradigms in Mobile HCI

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ABSTRACT

In this chapter the authors argue that it is time for the mobile HCI community to think beyond the traditional screen-keyboard-mouse paradigm and explore the many possibilities that mobility, mobile platforms, and people on the move offer. They present a collection of ideas aiming to encourage HCI researchers to explore how up-and-coming mobile technologies can inspire new interaction models, alternative I/O methods, and data collection methods. In particular, they discuss potential applications for gesture- as well as sound-based technologies. The range of possible applications designed to make life easier for specified user populations is limited, they maintain, only by their imagination to understand novel problem spaces, to mix, match and expand on existing methods as well as to invent, test, and validate new methods.

INTRODUCTION

The continuing emergence of new technologies and creative, innovative ways of employing existing mobile tools for new purposes and a wide range of audiences highlights a need for understanding how to maximize the potential benefits these may offer. Indeed, the need to explore different approaches and techniques for generating user requirements and evaluating mobile and wearable devices has been recognized for some time (e.g. Lumsden & Brewster, 2003; Benyon, Höök & Nigay, 2010; Lindgaard & Narasimhan, 2009). Progress is being made in many areas of human

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endeavor to embrace new technologies especially in the mobile arena. The recent mobile HCI literature shows how such new technologies could be deployed in a variety of application domains; it also demonstrates how different technologies may be combined and how existing technologies may be adapted to suit mobile devices and people. In this chapter, we discuss mainly technologies that rely on sensory modalities other than, or in addition to, human vision, and those that go beyond the traditional keyboard-screen paradigm. We explore the techniques currently applied in user research and show wherever suitable how evolving mobile products reported are evaluated. In many recent papers, innovative technological approaches and solutions to known user-related problems have only been considered or proposed, with no user-based studies reported as yet. One may regard these ideas as novel approaches to requirements gathering where technological and human sensory and motor capabilities and boundaries are explored 'in the wild'. That is, in some cases it is still unclear how the evolving technologies discussed may be useful in future applications. In other papers, small pilot studies with a limited number of participants have been published. Since some of the technologies are still at a very early stage of development, it is not surprising that few studies report results of fully fledged user-based studies. We include all kinds of studies here, as we find the ideas behind proposed or preliminary prototype applications often very inspiring and thought-provoking, allowing us to speculate on potential future mobile applications.

The next section discusses a range of recently published gesture-based approaches employed in mobile devices. It presents how some techniques invented in the gaming industry has been, and could be, used in other areas such as in medicine, particularly in rehabilitation. We review two studies concerning wearable gesture-based technologies that can be used with 'eyes busy', and one study that frees up mobile touch screen real estate by using the casing itself as an interaction mechanism. We take the risk of going out on a limb by imagining how some of the ideas underlying these novel approaches could be applied to other domains. It is followed by a discussion of some context- and location-aware technologies that, although many issues are still to be overcome, suggest some innovative applications. Next, we review some of the literature on sound-based interaction, both non-vocal sounds and speech. Interesting progress is being made in terms of substituting visual information such as graphs and geographical maps with sound as well as sound being used to help blind and visually impaired people navigate their environment. One recent application using natural language to present information about graphs allowing users to interrogate the graph content is described in some detail. We then offer some thoughts on the challenges of collecting data in usability evaluations of mobile devices and conclude that, although we agree with other authors that new evaluation paradigms are needed in mobile HCI, the HCI community must be very careful not to deny both laboratory-based and field-based usability studies their rightful place in the mobile domain.

GESTURE-BASED INTERACTION

The common element in all gesture-based approaches is that they rely on some kind of motion detection or motion tracking that is then 'translated' into vocabulary or reciprocal movements that are meaningful to the particular application when used in the appropriate context. Although gestures have been considered as an interaction technique in HCI since the late 1980s, gesture based interfaces began to make its way into popular culture via Hollywood in 2002 with the release of the film "Minority Report" in which the lead character interacted with screens by pointing and manipulating objects with gestures. These interfaces are now a Hollywood standard in science-fiction films such as Iron Man 2, but these types of systems are now making their way into living rooms as household favourites as well as being considered for more serious purposes such as in simulations for medical education (e.g. Gallo & de Pietro, 2009) and rehabilitation (de Graaf, 2010). In many instances, gesture-based interactions are combined with other input/output mechanisms, for example, speech synthesizers and speech recognition (Turunen, Hakilinen, et al., 2009), gross motor movements (Hudson, Harrison, et al., 2010), or finer motor movements such as bending or twisting the mobile device (Scott, Brown & Molloy, 2009).

In the entertainment/gaming sphere Nintendo's Wii began with motion controllers and gesture-based interaction; it is now the market leader for selling the console as a family entertainment unit. Sony's new "Move", motion controller for the PlayStation 3 will use advanced motion sensors and the PlayStation®Eye Camera to mimic every movement on-screen. The PlayStation 3 monitors where the controller is moving; it projects a user's image onto the TV screen, and replaces the controller on the image of the screen with the object it is to mimic such as a sword or gun. The system is considerably more sophisticated than Nintendo's original version (Kien, 2010). Microsoft's Kinect controller is designed for the Xbox360 console that employs a camera and gesture recognition to let players use their bodies to run, shoot or almost anything else that their in-game avatars do. The system contains a camera and a microphone with sensors that can be mounted onto a television; it recognizes facial expressions along with body motions and speech. This system is unique in that the user does not need to hold a controller, enabling them to concentrate entirely on mimicking the actions of throwing, dancing, shooting, and so on. These products are all scheduled to be released in late fall 2010. However, despite strong reviews none of them work quite as seamlessly as the interfaces in the Hollywood films yet.

Uses for technologies involving gestures are being explored in domains that, although using a game metaphor, are devoted to other purposes. De Graff (2010), for example, proposes application of a Kinect-type device that could even be used in a patient's home environment for physical rehabilitation of patients with various injuries. The mobile devices can be programmed to measure performance via game scores, thereby introducing a sense of competitiveness to the exercises and encouraging the patient to keep going just a little longer in any one session (Burke et al., 2009). The sense of competitiveness need not involve other players; the sheer joy of seeing improvements via those indirect game scores could well act as an important motivator, even when exercising in isolation. In turn, this could shorten the duration of rehabilitation as well as reducing the need for physiotherapy, thereby saving resources as well as helping people to get back to work faster or for elderly folks to remain independent longer. Kien (2010) explored using the gaming metaphor as a learning tool where a learner would be immersed in an environment by using the whole body to interact while learning. One can imagine that this kind of application could stimulate a sense of achievement in children with academic learning disabilities whose need to succeed is just as important as for children without such disabilities. It could also be used for children who are physically hyperactive, perhaps with an attention deficit disorder who need a healthy outlet for their surplus energy.

Another use of the Wiimote mobile device is in virtual reality-enhanced diagnostic and therapeutic medicine (Gallo & de Pietro, 2009). Following a thorough analysis of the most frequently occurring tasks in medical data inspection and an overview of the major weaknesses of the Wiimote, Gallo and de Pietro identified five necessary 3D interaction techniques that could be implemented with that technology. These were pointing, orientation, translation, zooming, and cropping. Pointing enables the user to select a precise point in a set of visualized data; rotation enables users to visualize the 3D object from all possible points of view; translation refers to the ability to move the object in the 3D space; zooming in/out enables better focus of the data, and cropping enables users to cut off and look inside the image, for example, two or three vertebrae from a human spine. With little tweaking, these techniques could equally be applied to both learning games and rehabilitation games. In terms of learning, they could be used to stimulate hand-eye coordination, which can be a problem for people with certain visual impairments, as well as to strengthen the muscles in the hand, wrist, and forearm, which invariably will atrophy while the patient is wearing a cast while healing a bone fracture.

Several innovative uses of gestures have been proposed for interaction with small mobile devices such as mobile phones and MP3 players. Hudson and his colleagues (2010), for example, report a study involving a category of what they refer to as 'inexact and inattentive interactions'. With their 'Whack Gestures' technique, common interactions are handled with gross motor movements such as firmly striking the device with an open palm or heel of the hand moving towards the waist, where the device is worn at the waist, for example, in a holder attached to a belt. The authors attempt to overcome the important problem of accidental activation of the device by unintended jostling or bumping that can lead to false positives, by requiring the user to perform a sequence of several movements to signal intended activation of the device. At present, the whack vocabulary is quite limited. However, rather than focusing on the ease of learning the vocabulary and carrying out the correct movements associated with these, as would be the typical HCI approach to formative testing of early prototypes, the preliminary user-based study aimed to assess the effectiveness of the proof-of-concept implementation. The 11 participants were shown how to attach the device correctly before going about their normal routine while wearing the device for two hours each, yielding data for 22 hours of use. Thus, there were no set tasks, no questions to answer, and no routes or procedures to follow. The data analysis focused on identifying the frequency of occurrence of false positives of which they found only one per 12 hours of this in-the-wild usage, assessed on six of the 11 participants. No false positives were found among the remaining five participants. In addition, the recognizers correctly classified 100% of the known framing gestures. The short sequences of gestures are easy to learn, and, to the extent that these early results may be indicative of the system's performance, the accuracy levels appear to be impressive.

Relying on rather finer movements, the 'Gesture Watch' (Kim, He, et al., 2007; Lee & Starner, 2009), a wrist-mounted mobile gesture interface worn on the non-dominant hand, allows non-contact hand gestures above the wrist to control mobile devices. Much in the same fashion as the Whack Gestures technology, the Gesture Watch requires the user to perform three interactive movements to avoid accidental activation. First, the sensors must be triggered, then the command gesture must be performed, and finally, the sensors must be de-activated. As in the Whack Gestures study, the results of a small pilot study are reported. It included a sample of four participants testing multiple tactile patterns in two sessions. Data from a total of 384 trials were thus collected. The level of performance accuracy was 85.98% in the first, and 89.45% in the second session. Given the high accuracy rates for both the Whack Gestures and the Watch Gesture devices, one may speculate that the range of movements (commands/vocabulary) could quite readily be increased. So, the Whack Gestures could perhaps be employed in situations in which movement is unrestricted but hands/fingers or eyes are 'busy/unavailable'. Similarly, the Gesture Watch could be used in situations that are unsuitable for wearing a mobile device on a belt. First responders to a large disaster, for example, typically wear heavy suits, gas masks or Head-Up Displays (HUDs), making it difficult or impossible to handle a device requiring fine movements. Both technologies could be explored in that context.

Using force sensing as an input mechanism (Scott et al., 2009) is another method that relies on rather small movements. In this case, the sensing of physical forces is applied by the user's hands bending or twisting the case of a mobile device that itself does not need to be more flexible than a normal mobile phone to detect the meaningful hand movements. Force applied to the casing is mechanically transmitted through it and parts attached to it. Because of this, force sensors do not need to be located at the external surface of the device, and device cases "can be made with fewer holes for physical switches, which can facilitate more robust, more easily manufactured, and smaller form factor devices" (p. 136). Although several force gestures are possible, the paper concentrates on the implementation of technology that allows bending and twisting movements. The authors implemented the two force-based shortcut interactions on an Ultra Mobile PC (UMPC), where the bend action is used to indicate 'page down', and the twist action is used to change the foreground application (as 'alt-tab' in Windows). Both provide suitable visual feedback to the respective movement that mimic real-life interaction with a window or document. Thus, for page-down, the visual feedback looks like bending a book and flicking through the pages. The right-hand page seems to flip up and over to the left hand side. Of the 20 participants included in the user-based study, 10 were assigned to a 'bend', and 10 to a 'twist' condition. The study employed a familiarization phase, a training phase after which the device was calibrated to each participant's preferred amount of force applied to initiate the target action, and a test phase. In the test phase, which was based on Fitts' Law, the user had to move a force cursor as quickly as possible to a special-coloured target and then hold the force cursor inside the target for two seconds. The number of targets in a block varied randomly from two to eight, and blocks were repeated in three cycles in which each number of targets was attempted once, resulting in 210 target acquisition attempts for each participant. Targets varied in width and in distance from the starting point. The 'bend' action appeared to be easier than the 'twist' action in the sense that participants' acquisition time was significantly shorter than in the twist condition and it did not change between the first and the third cycle whereas acquisition time was significantly lower in the third- than in the first cycle in the twist condition. In addition, and contrary to the predictions of Fitts' Law, acquisition time decreased in both conditions as distance increased, with the closest targets being most difficult to acquire. One major benefit of this type of approach is obviously the saving of screen real estate, giving more space to the actual application.

The final study in this genre of gesture-based interaction concerns a completely non-visual interface that repurposes a touch screen as a 'talking' touch-sensitive surface, called 'Slide Rule' (Kane, Bigham, & Wobbrock, 2008). Like the studies above, it also requires somewhat finer movements as well as integrating speech. Users navigate through lists of items by scanning their fingers down the device surface; gestures are used to interact with on-screen objects. It uses a set of four interactive gestures. The one-finger scan is used to browse lists, for example, of phone numbers; users can select items on the screen with the second-finger tap. They use a multi-directional flick gesture to flip between pages of items or a currently playing song, and an L-select gesture to browse hierarchical information, for example the hierarchy of artists and songs in a MP3 player. As it provides speech output, this kind of technology could be suitable for blind people as well as for people with hand tremor or people who have problems with fine-motor hand-eye coordination. The paper reports a pilot study in which eight blind users were interviewed to identify usability issues with mobile devices and touch screens. Results were used to inform the design of the Slide Rule system. A new sample of 10 blind individuals took part in the evaluation in which each performed three tasks in each of five trials, namely (1) placing a phone call, (2) reading an email message, and (3) playing a song. Two devices were used in the carefully designed within-subject experiment: Slide Rule and Pocket PC with MSP. Findings showed that task-completion times were shorter with Slide Rule but that participants made more errors per trial than with the Pocket PC; most errors were made with the playing a song-task. Despite of this poorer performance, seven of the 10 participants preferred Slide Rule to the Pocket PC, suggesting that the most preferred device may not be the one with which one is most 'successful'. Similar results have also been found in numerous other studies (see e.g. Tractinsky & Zmiri, 2006; Diefenbach & Hassenzahl, 2008; 2009, study 2; De Angeli et al., 2006; Mahlke, 2006). One issue these studies raise is the subjective trade-off between performance and preference. In HCI, we take it for granted that people are motivated to perform well with whatever technology, device, or application we offer, and that this motivation will override their preferences. With a little more experience than was possible to obtain during the Slide Rule experiment, one would expect performance to improve anyway. Thus, if people are motivated to persevere with a slightly more difficult task on a device they enjoy using, one may question the wisdom of always insisting on excellent user performance in usability tests. We believe that the HCI community needs to be more sensitive to preferences, at least when designing software that is not aiming to support critical work tasks.

As the abovementioned studies show, gesture-based technologies, particularly the mobile aspects of these technologies, are giving rise to a fascinating variety of innovative interactions. These range from tracking full body movements to detecting very slight hand-, or even finger gestures, and from relying on hefty whacks to gentle stroking gestures for reliable and accurate detection. Compared to the traditional keyboard-mouse paradigm, this genre of interactive technologies would appear to open a whole new interactive world. The status of each approach outlined above suggests that the exploration of possibilities that gesture-based technologies offer have barely begun to be explored. This is evidenced by the observation that most of the studies had only pilot-tested the relevant technology, with fully fledged user studies still in the planning stage. It is especially noteworthy that evaluation of all the user-based studies adhered to traditional experimental paradigms. Apparently, the need for novel approaches to evaluation of mobile technologies is not really relevant while the technologies are still in the incubator as seems to be the case with gesture-based technologies.

While the development of gesture-based technologies and applications are very exciting in their own right, other technologies and innovative uses of these are worth exploring. In the following sections, we address issues associated with location-aware technologies, sound based technologies, and large emergency management technologies.

CONTEXT- AND LOCATION-BASED INTERACTION

Navigating one's environment unhindered is extremely difficult for people who are completely or partially blind. Research into sensory substitution using technology has made impressive advances in recent years. It is now known, for example, that a certain part of the occipital cortex is activated when objects are recognized by vision or touch (Amedi et al., 2007), and that one sensory capacity can substitute for another. Thus, for example, as with the Slide Rule technology described to above, sound can substitute vision (e.g. Meijer, 1992) because 'we see with the brain, not with the eyes' (Bach-y-Rita et al., 2003). Certain smart phones can translate visual images, for example, signs, into sound via built-in cameras that interact with specialized image-to-sound software (e.g. Nokia 3650). Other systems comprising head-mounted cameras placed in eye glasses connected to a laptop and worn in a backpack (e.g. the vOICe system, www.artificialvision.com) perform similar sensory substitutions by providing some kind of sound output indicating changes in density in the environment. However, while these are beginning to enable visually impaired and blind people to navigate their environment more independently, they cannot yet provide instant feedback on important environmental cues that people need such as an upcoming curb. Global Positioning Systems (GPS) are becoming very accurate, but noise can introduce error margins between one and 10 meters, suggesting that they cannot reliably provide timely warnings either. The same is true in dense cityscapes and inside buildings.

Getting a little closer to Weiser's (1991) original vision of people interacting seamlessly with multiple computers embedded in their environment, one could explore the possibility of tagging objects in the environment with sound, even speech, capabilities that are activated when a person carrying the necessary equipment approaches. We do not know what kinds of objects should provide such augmented reality, how far in advance they should identify themselves, whether such tags would be socially and psychologically acceptable, or if they would confuse more than to assist a blind person attempting to navigate their environment. Alternatively, one could provide built-in intelligence into the white cane and use it as a sensory interface to the environment via vibration, sound, or a mixture of both. This kind of multimodal research is in its infancy but technologies are beginning to emerge as discussed below.

The sensing and representation of context is a very challenging area of research in location-aware mobile applications. Some early examples of context-aware mobile systems include several tour-guides (e.g. Abowd et al., 1997; Feiner et al., 1997; Cheverst et al., 2000) and mobile games (Drozd et al., 2006) that combine mobile computers with various positioning systems, including the most popular of these, the GPS (see Strachnan et al., 2009 for a review), introduced already in the late 1980s. One disadvantage of many of these systems is that they are limited to outdoor environments, and that they provide limited contextual information during navigation. More recently, it has become possible to use currently available infrastructure to develop portable, affordable context- aware devices to support high quality, exact navigation, for example, enabling blind people to detect the status of traffic lights (Angin, Bhargave & Helal, 2010). Some of these existing systems consist of a digital camera and a portable PC that analyzes video frames captured by the camera (Charette & Nashahibi, 2009). One drawback of these is that they are rather cumbersome to use because of their dependence on hardware for image- and video processing. To overcome this drawback, Angin et al. (2010) proposes a two-tier open, extensible architecture comprising a mobile Navigation and Awareness Server (mNAS) and a cloud Navigation and Awareness Server (cNAS). The mNAS could be any smart phone, and the cNAS is simply the web services platform. The mNAS has an integrated GPX receiver; it is responsible for local navigation, local obstacle detection and avoidance, and interacting with the user as well as with the cloud side. It is envisaged to "provide location data to cNAS, which will perform the desired location-specific functionality and communicate the desired information as well as relevant context information and warnings of potential hazards in contact back to mNAS" (p. 397). The architecture, which is still in the conceptualization stage, is described in the paper.

Another approach in this genre of technologies is by enabling medical implants to interact with other technologies. Rasmussen and his colleagues (2009) describe an access control mechanism for implantable medical devices based on ultrasonic distance-bounding that enables an implanted medical device to grant access to its resources only to those devices that are in its close proximity. They are investigating the use of the technology to enable a treating physician or, in an emergency, a paramedic access to a patient's pacemaker. The paper describes how this is done, but for our purposes here, we might think about extending the notion of a beeping backpack or a vibrating white cane with an implant into the occipital cortex or worn in a cap of a blind person. Bone-conducting technologies are already being explored in the context of managing major disasters, as discussed later. One finding in the neuropsychological literature is that a loss of vision does not result in the permanent inactivation of the visual cortex, regardless as to the age of onset. Recent neuroimaging studies provide evidence suggesting that functional activity in visual brain areas persists in blind individuals when performing non-visual cognitive tasks such as Braille reading, listening to words, or sensory discrimination of auditory or tactile stimuli (Burton et al., 2002a, b; Sadato, Okada, Honda, & Yonekura, 2002). Such results suggest that remaining sensory modalities have the capability of being modified or activated through cortical reorganization after severe visual deprivation. Such an approach would preserve the privacy of the person and also save the environment from yet another sound source. The challenges in this technology genre thus includes technical, psychological, and social issues, but the potential benefits are very exciting. Next, we turn to sound-basded technologies.

SOUND-BASED INTERACTIONS

Continuing the thread of using sound to support navigation, studies in sound-based interaction both with computers and with the physical environment using mobile devices to aid navigation have been published since the early 1990s (e.g. Flowers & Hauer, 1992; Choudhurry et al., 2004). To date, most of this research has involved sonification of statistical data presented in visual graphs (Brown & Brewster, 2003; Flowers, Buhman & Turnage, 2005; Rigas & Alty, 2005) or in geographical maps (Zhao et al., 2005; 2008), aiming to render visual data accessible to visually impaired and blind audiences. By relying on differences in pitch to denote slope changes and monotonic differences in the data over time (e.g. Flowers & Hauer, 1995), these studies have generally shown that it is relatively easy to perceive pitch- and intensity-coded auditory data with a minimum of training (Flowers et al., 2005; Zhao et al., 2008). Thus, research involving the sonification of graphs enables visually impaired and blind users to perform typical data-inspection tasks such as describing and depicting simple functions, examining the distribution properties of one or more samples, and examining the covariation between two variables. Research into navigation in physical space consists mainly of software installed in portable, mobile devices that can detect obstacles in the immediate surroundings, be that indoors (Simpson et al., 2005; Choudhurry et al., 2004) or outdoors (Trivedi, 2010).

More recently, an evolving tool developed in our lab, iGraph-Lite (Ferres et al., 2007) enables user to interact with simple line graphs using natural language. In its current form, iGraph-Lite relies on key commands and a Text-To-Speech (TTS) engine. It comprises three subsystems: (1) a knowledge representation system that enriches a basic semantic representation of line-, bar- and combination graphs, (2) a Natural Language Generation (NLG) system that produces a static description of a graph, and, (3) an interface that allows users to navigate the full enriched representation of (1) by means of keyboard combinations, much as JAWS or DOLPHIN. iGraph-Lite can therefore be used to generate rich descriptions to accompany graphs through the longdesctag in plain HTML and, if a graph is published with iGraph-Lite's full semantics embedded through exif or a similar tool, the iGraph-Lite navigator can be used to explore the graph at different representational levels. The free plugin can be downloaded from (http://www.inf.udec.cl/~leo/igraph.html#sec3) to a desktop PC or to a mobile device. Users can navigate a graph using a set of spoken commands, which enable them to interrogate the data in various ways. Currently, the command set comprises 18 commands that our user-based studies have shown to be relatively easy to recall. Results have also shown that the kinds of functions iGraph-Lite offers are relevant to people using graphs in their daily work. Adopting a user-centred design methodology (e.g. Preece et al., 2007), iGraph-Lite has thus been tested and revised iteratively in terms of usefulness and usability on both blind and sighted participants. It has been shown to facilitate the construction of a correct and accurate mental model of single-line graphs for both types of audiences (Ferres et al., 2010) provided the information is presented in a sequence that allows the person to visualize the structure and data labels before dealing with the data in the graph. iGraph-Lite avoids the problem of recognizing different accents correctly that speech-based technologies typically face. However, natural language interactions using an unrestricted vocabulary are still some distance away from implementations available to the mass market.

SOME THOUGHTS ON DATA COLLECTION IN MOBILE USABILITY EVALUATIONS

According to Cockton (2008): "usability evaluation measures remain too close to what were originally independent variables in factorial experiments. The basis for genuine usability problems in such variables is not guaranteed, but there has been little progress in finding replacements since HCI's shift from the laboratory to field studies" (p. 287). This widespread view coincides with that of Benyon and his colleagues (2010). We do agree that novel data collection and usability evaluation methods are needed in the mobile arena, but we argue that it is not an 'either-or' (controlled quantitative laboratory studies versus qualitative field studies) situation. In our view, both field- and laboratory studies have a legitimate place in mobile HCI. Indeed, the above review has clearly provided many examples showing that controlled studies are most usefully applied in the very early stages of the evolution of a new technology.

Since Egon Brunswik (1956) proposed that we need to consider the environment carefully in which people work, play, and make decisions as well as studying their tasks and task performance, this has been taken seriously in the Human Factors literature. Along those lines, job shadowing, contextual interviews (Beyer & Holtzblatt, 1998), and other forms of 'direct' observation techniques (Drury, 1995) in the users' context are warmly advocated in the usability literature (e.g. Preece et al., 2007). However, in the world of mobile devices, many of which are used only occasionally, often in situations in which it would be impossible or too intrusive for researchers to be present, these techniques do not work (see e.g. Bennett et al., 2006; Svanæs et al., 2008). Even if target users are readily accessible, it may be impossible to follow them around and observe them unobtrusively in their 'natural environment' to collect the kinds of 'ecologically valid' data that Brunswik so eloquently advocated. In addition, the recording of observations presents an obvious challenge. Video recording of mobile device usage capturing button presses and screen shots are difficult to employ without disturbing normal usage patterns, and video data can be difficult to analyze post hoc because there are likely to be gaps in the recording due to screen blockages and the like.

Potential solutions to the problem of collecting observation-based data are reported in the literature, but many of these suffer from obvious limitations. For example, it is difficult to imagine using a wireless camera that clips onto a mobile device being used in outdoor situations. In one reasonably widespread approach, the user under observation wears a backpack containing the necessary recording equipment (Roto et al., 2004). While this is less intrusive than the wireless clip-on camera, it is still bothersome and quite heavy. The solution suggested by Reichl and his colleagues (2007) in which the user wears a hat equipped with the several cameras, microphones, and battery packs, is certainly less obtrusive and lends itself well to outdoor observations. However, none of these solutions would be acceptable, for example, when attempting to collect usage data over a longer period of time and involving, say, highly mobile business executives.

One possibility for collecting field data unobtrusively is to beam software directly onto mobile devices (Lindgaard & Narasimhan, 2007). The purpose of our study was to these predict which features should be bundled for specific target user audiences. In order to avoid sensitive privacy- or business issues, data logging was limited to recording time-stamped feature activation and de-activation. At the end of each day, users uploaded their data logs to a server. Apart from the data analysis of the logs, which provided useful information as such, these data logs also served to spark the user's memory of what they were doing at the time as divulged in weekly interviews. The method, which we called Strategic User Needs Analysis (SUNA), enabled us accurately to predict, and subsequently verify, different usage patterns of two types of executives whose job descriptions were very similar. Electronic data logging can thus be a very practical, objective method of gathering indirect observational data which, combined with other methods, can contribute to a more complete picture of people's usage patterns in their natural environments.

The popular 'Think Aloud' technique, or verbal protocol tracing, is typically applied to investigating problem solving approaches (Ericsson & Simon, 1984) where the researcher seeks to uncover mental processes either during or after task performance (Bainbridge, 1995). Concurrent verbalizations in which the test person verbalizes their thoughts and performs a task simultaneously, are difficult to carry out in natural mobile environments, although this has been done with a researcher walking next to a user with an audio recorder (Treen, 2008). However, it is a less-than-perfect option and far from 'natural' even when the test person is accompanied by a researcher and their monologue may seem like a two-way conversation to outsiders. Apart from test user safety issues, the requirement to talk while doing and while mobile would probably be unacceptable to most people. Instead, the researcher could follow the test person at a distance, take snap shots and audio record their own narrative to be replayed later when both are safely back in the lab. This form of retrospective verbalization avoids interrupting the user and also avoids the need to 'translate' one's thoughts into verbal articulation as in Ericsson and Simon's (1984) 'level 2' verbal protocols. Such 'translations;' can easily distort the user's thoughts and actions, yielding inaccurate data. At the same time, electronic data logging, together with the researcher's narrative and snap shots, could serve as memory prompts for the user when interviewed at the end of the test session once they are safely back in the laboratory. Thus, the challenges of collecting data and running usability tests on mobile devices while seeking to preserve ecological validity and a sense of 'naturalness' remain.

CONCLUSION

Traditional usability evaluations on standard screen-keyboard-pointing mobile devices would not focus on whether a user knows how to use the pointing device or how to whack it into activation but rather on the meta-task such as searching for or adding an item to a list. Evidently, new mobile technologies and novel uses of existing technologies that go beyond the traditional keyboard and mouse paradigm demand detailed studies before they can be employed in novel applications. Such studies include investigations of human memory for gesture vocabulary to activate and de-activate the device, correct placement of it, in some cases focusing on the weight of the equipment, as well as of physical interaction with devices and with the environment. Accordingly, many of the above studies reviewed concentrated on identifying movements that are more natural to users, on ways to reduce or avoid false positives, and on the amount of force a user may typically wish to apply to accomplish a particular goal such as turning a page in a document, and so forth. These kinds of research questions can be compared with studies determining the accuracy with which people would use a mouse to point to, or highlight, a particular letter or phrase in a written document. These are hardly tasks that anyone would test these days in traditional GUI environments. The kinds of studies of novel, innovative interaction methods found in the recent literature reviewed here were evidently found to revert to the controlled laboratory experiments originating in 'disembodied cognition' (Benyon et al., 2010) that some researchers argue should be replaced in the mobile arena. Indeed, new paradigms must be invented and adopted to meet the challenges of people multitasking while using mobile devices, the literature reviewed here does suggest that well-designed, tightly controlled experiments still have an important place in the mobile world. This may well change as we learn more about interaction models using different sensory modalities as well as multimodal approaches just as has happened in the GUI world. For now, however, while acquiring this basic level of understanding, we should be very careful not to throw out the proverbial baby with the bath water.

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REFERENCES

Abowd, G., Atkeson, C., Hong, J., Long, S., Kooper, R., & Pinkerton, M. (1997). Cyberguide: A mobile context-aware tour guide. *Wireless Networks*, *3*, 421–433. doi:10.1023/A:1019194325861

Amedi, A., Stern, W. M., Camprodon, J. A., Bermpohl, F., Merabet, L., & Rotman, S. (2007). Shape conveyed by visual-to-auditory sensory substitution activates the lateral occipital complex. *Nature Neuroscience*, *10*, 687–689. doi:10.1038/nn1912

Angin, P., Bhargava, B., & Helal, S. (2010). A mobile-cloud collaburative traffic lights detector for blind navigation.In *Proceedings 11th. international conference on mobile data management*, (pp.296-401).

Bach-y-Rita, P., Tyler, M. E., & Kaczmarek, K. A. (2003). Seeing with the brain. *International Journal of Human-Computer Interaction*, *15*(2), 285–295. doi:10.1207/S15327590IJHC1502_6

Bainbridge, L. (1995). Verbal protocol analysis. In Wilson, J., & Corlett, E. (Eds.), *Evaluation of Human Work: A practical ergonomics methodology* (pp. 161–179). London: Taylor & Francis Ltd.

Bennett, G., Lindgaard, G., Tsuji, B., Connelly, K. H., Siek, K. A., & Khan, S. (2006). Reality testing: HCI challenges in non-traditional environments. *CHI'06 Extended Abstracts,* Montreal, *1679-1682*.

Benyon, D., Höök, K., & Nigay, L. (2010). Spaces of interaction, *Proceedings ACM-BCS visions of computer science conference*. Edinburgh, UK.

Beyer, H., & Holtzblatt, K. (1998). *Contextual design: Defining customer-centred systems*. San Francisco: Morgan Kauffman Publishers.

Brown, L., & Brewster, S. A. (2003). Drawing by ear: Interpreting sonified line graphs, Proceedings ICAD (pp. 15-22).

Brunswik, E. (1956). *Perception and the representative design of psychological experiments* (2nd ed.). Berkeley, CA: University of California Press.

Burke, J. W., McNeill, M. D. J., Charles, D. K., Morrow, P. J., Crosbie, J. H., & Donough, S. M. (2009). Optimising engagement for stroke rehabilitation using serious games. *The Visual Computer*, *25*(12), 1085–1099. doi:10.1007/s00371-009-0387-4

Burton, H., Snyder, A. Z., Conturo, T. E., Akbudak, E., Ollinger, J. M., & Raichle, M. E. (2002a). Adaptive changes in early and late blind: A fMRI study of Braille reading. *Journal of Neurophysiology*, *87*, 589–607.

Burton, H., Snyder, A. Z., Diamond, J., & Raichle, M. E. (2002b). Adaptive changes in early and late blind: A fMRI study of verb generation to heard nouns. *Journal of Neurophysiology*, *88*, 3359–3371. doi:10.1152/jn.00129.2002

Charette, R., & Nashashibi, F. (2009). *Real time visual traffic lights recognition based on spot light detection and adaptive traffic lights templates*. World congress and exhibition on intelligent transport systems and servides (ITS'09).

Cheverst, K., Davies, N., Mktchell, K., Friday, A., & Efstratiou, C. (2000). Developing a context-aware electronic tourist guide: Some issues and experiences. In *Procedings CHI'00*, 17-24.

Choudhurry, M. H., Aguerrevere, D., & Barreto, A. B. (2004). A pocked-PC based navigational aid for blind individuals. In Proceedings IEEE international conference on virtual environments, human-computer interfaces, and measurement systems (VeCIMS),(pp.43-48).

Cockton, G., Woolrych, A., & Lavery, D. (2008). Inspection-based evaluations. In Sears, A., & Jacko, J. (Eds.), *The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications* (2nd ed., pp. 1175–1178). Mahwah, NJ: Lawrence Erlbaum Associates.

De Angeli, A., Sutcliffe, A., & Hartmann, J. 2006. Interaction, usability and aeshtetics: What influences users' preferences? *Proceedings DIS*, 271-280.

De Graaf, A. (2010). *Gaming motion tracking technologies for rehabilitation*, unpublished manuscript University of Twente, NL.

Diefenbach, S., & Hassenzahl, M. (2008). *Give me a reason: Hedonic product choice and justification, Extended Abstracts, CHI 2008, 3051-3056*. Boston: ACM Press.

Diefenbach, S., & Hassenzahl, M. (2009). The beauty dilemma "Beauty is valued but discounted in product choice [Boston: ACM Press.]. *Proceedings CHI*, *2009*, 1419–1426.

Drozd, A., Benfoird, S., Tandavanitj, N., Wright, M., & Chamberlain, A. (2006). Hitchers: Designing for cellular positioning. In *Proceedings 8th. international conference on ubiquitous computing* (Ubicomp), 279-296.

Drury, C. (1995). Methods for direct observation of performance. In Wilson, J., & Corlett, E. (Eds.), *Evaluation of Human Work: A practical ergonomics methodology* (pp. 35–57). London: Taylor & Francis Ltd.

Ericsson, K., & Simon, H. (1984). *Effects of verbalization. Protocol Analysis: Verbal Reports as Data* (pp. 63–107). Boston: The MIT Press.

Feiner, S., MacInture, B., Hollerer, T., & Webster, A. (1997). A touring machine: Prototyping 3D mobile augmented reality systems for exploring the urban environment.In *Proceedings first international symposium on wearable computers*, Digest of papers, 74-81.

Ferres, L., Lindgaard, G., & Sumegi, L. (2010). Evaluating a tool for improving access to complex visual objects, to appear. In *Proceedings ACM ASSETS'10*.

Ferres, L., Verkhogliad, P., Lindgaard, G., Boucher, L., & Chretien, A. (2007). Improving accessibility to statistical graphs: The iGraph-Lite system. *Proceedings ACM ASSETS*, *07*, 67–74.

Flowers, J. H., Buhman, D. C., & Turnage, K. D. (2005). Data sonification from the desktop: Should sound be part of standard data analysis software? *ACM Transactions on Applied Perception*, *2*(4), 467–472. doi:10.1145/1101530.1101544

Flowers, J. H., & Hauer, T. A. (1992). The ear's versus the eye's potential to assess characteristics of numeric data: Are we too viouscentric? *Behavior Research Methods, Instruments, & Computers*, *24*(2), 258–264. doi:10.3758/BF03203504

Flowers, J. H., & Hauer, T. A. (1995). Musical versus graphs: Cross-modal equivalence in perception of time series data. *Human Factors*, *37*(3), 553–569. doi:10.1518/001872095779049264

Gallo, L., & De Pietro, G. (2009). Input devices and interaction techniques for VR-enhanced medicine. In Damiani, D., & Jeong, J. (Eds.), *Multimedia techniques for device and ambient intelligence* (pp. 115–134). Springer Verlag. doi:10.1007/978-0-387-88777-7_5

Hudson, S. E., Harrison, C., Harrison, B. L., & LaMarca, A. (2010). Whack gestures: Inexact and inattentive interaction with mobile devices. *Proceedings ACM TEI*, 109-112.

Kane, S. K., Bigham, J. P., & Wobbrock, J. O. (2008). Slide rule: Making mobile touch screens accessible to blind people using multi-gouch interaction techniques, *Proceedings ASSETS'08*, Halifax.

Kien, T. (2010). *Body movement interaction: An immersive learning game, Masters thesis computer science & Information engineering*. National Central University, Taiwan.

Kim, J., He, J., Lyons, K., & Starner, T. (2007). The gesture watch: A wireless contact-free gesture-based wrist interface. *Proceedings IEEE International symposium on wearable computers*, 15-22.

Lee, S. C., & Starner, T. (2009). Mobile gesture interaction using wearable tactile displays. *Proceedings CHI*, *09*, 3437–3442.

Lindgaard, G., & Narasimhan, S. (2007). Factors influencing feature-usage in work-related communication. *Behaviour & Information Technology*, *27*(2), 153–168. doi:10.1080/01449290601111218

Lindgaard, G., & Narasimhan, S. (2009). Mobile HCI: thinking beyond the screen-keyboard-mouse interaction paradigm. *International Journal of Mobile HCI*, *1*(1), 24–36.

Lumsden, J., & Brewster, S. (2003). A paradigm shift: Alternative interaction techniques for use with mobile and wearable devices. *Proceedings conference of the Centre for advanced studies on collaborative research*, Toronto, Canada, 197-210.

Mahlke, S. 2006. Studying user experience with digital audio players, submitted to *ICEC2006, 5th International Conference on Entertainment Computing*, 20-22 September, Cambridge.

Meijer, P. B. L. (1992). An experimental system for auditory image representations. *IEEE Transactions on Bio-Medical Engineering*, *39*(2), 112–121. doi:10.1109/10.121642

Preece, J., Rogers, Y., & Sharp, H. (2007). *Interaction design: Beyond human-computer interaction*. Hoboken, NJ: John Wiley & Sons Ltd.

Rasmussen, K. B., Castelluccia, C., Heydt-Benjamin, T., & Capkun, S. (2009). Proximity-based access control for implantable medical devices.In *Proceedings, ACM CCS'09*, 410-419

Reichl, P., Schatz, R., Fröhlich, P., Dantcheva, A., & Baillie, L. (2007). The LiLiPUT prototype: A wearable lab environment for user tests of mobile telecommunications applications, Experience report. *Proceedings CHI'07,* San Jose, CA, pp. 1833-1838.

Rigas, D., & Alty, J. (2005). The rising pitch metaphor: An empirical study. *International Journal of Human-Computer Studies*, *62*(1), 1–20. doi:10.1016/j.ijhcs.2004.06.004

Roto, V. Oulasvirta, A., Haikarainen, T. Kuorelathi, J., Lehmuskallio, H. & Nyyssonen, T. (2004). Examining mobile phone use in the wild with quasi-experimentation. *HIIT Technical report*, downloaded from http://www.i-cherubini.it/mauro/blog/2008/10/16/examining-mobile-phone-use-in-the-wild-with-quasi-experimentation/ 12 December, 2008.

Sadato, N., Okada, T., Honda, M., & Yonekura, Y. (2002). Critical period for cross-modal plasticity in blind humans: A functional MRI study. *NeuroImage*, *16*, 389–400. doi:10.1006/nimg.2002.1111

Scott, J., Brown, L. M., & Molloy, M. (2009). Mobile device interaction with force sensing. *Proceedings pervasive computing*. *LNCS*, *5538*, 133–150.

Simpson, R., LoPresti, E., Hayashi, S., Guo, S., Ding, D., & Ammer, W. (2005). A prototype power assist wheelchair that provides for obstacle detection and avoidance for those with visual impairments. *Journal of Neuroengineering and Rehabilitation*, *2*, 2–30. doi:10.1186/1743-0003-2-30

Strachnan, S., & Murray-Smith, R. (2009). Bearing-based selection in mobile spatial interaction. *Personal and Ubiquitous Computing*, *13*, 265–280. doi:10.1007/s00779-008-0205-4

Svanæs, D., Alsos, O. A., & Dahl, Y. (2008). (in press). Usability testing of mobile ICT for clinical settings: Methodological and practical challenges. *International Journal of Medical Informatics*.

Tractinsky, N., & Zmiri, D. (2006). Exploring attributes of skins as potential antecedents of emotion in HCI. In Fishwick, P. (Ed.), *Aesthetic computing* (pp. 405–421). Cambridge, MA: MIT Press.

Treen, C. (2009). *Usability evaluation in the mobile world: Will existing methods suffice?* MA Thesis, Department of Psychology, Carleton University, Ottawa, Canada.

Trivedi, B. (2010). *Sensory hijack: rewiring brains to see with sound*, New Scientist, 2773, August 14, downloaded from http://www.newscientist.com/article/mg20727731.500-sensory-hijack-rewiring-brains-to-see-with-sound.html?full=true, 6 October 2010

Turunen, M., & Hakulinen, J. Hella, J., Rajaniemi, J-P., Melto, A., Mäkinen, E., Rantala, J., Heimonen, T., Laivo, T., Soronen, H., Hansen, M., Valkama, P., Miettinen, T. & Raisamo, R.,(n.d.). Multimodal interaction with speech, gestures, and haptic feedback in a media center application, *Proceedings INTERACT'09*, 836-837.

Weiser, M. (1991). The computer for the 21st century. *Scientific American*, *265*(11), 94–104. doi:10.1038/scientificamerican0991-94

Zhao, H., Plaisant, C., & Shneiderman, B. (2005). "I hear the pattern" – interactive sonification of geographical data patterns. *Proceedings CHI*, *05*, 1905–1908.

Zhao, H., Plaisant, C., Shneiderman, B., & Lazar, J. (2008). Data sonification for users with visual impairment: A case study with georeferenced data. *ACM Transactions on Computer-Human Interaction*, *15*(1), 4–28.

Chapter 20
Designing Mobile Phones for Children:
Is there a Difference?

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ABSTRACT

The mobile phone is one of the most ubiquitous technologies in the developed world. In a market dominated by adults and older teenagers, one group of users that is relatively new to the mobile phone market is children. When children use mobile phones their needs are sometimes complicated by, or conflict with, the needs of their parents or primary care givers. As the laptop is being redesigned to make it accessible to children, it is worthwhile to ask the question 'Do children need a different sort of mobile phone than their parents?' By considering data about the use and usage of mobile phones, research on designing special children's technologies, and research on the needs of children as mobile phone users, this paper presents the argument that the mobile phone needs a design re-think if it is to meet the needs of children.

INTRODUCTION

To assist the reader in parsing this paper, the terms children, young teens, older teens, and adults are used to describe different user groups. These terms are not used exclusively—thus an older teen can also be considered an adult and a younger teen can be considered a child—but in general, the four terms are used to demonstrate an age line in which children are more likely to be under 11, young teens might be 11-14, older teens might be 14-19 and adults would be 18+. As users of mobile technology, these four groups have different approaches, different needs, and different use patterns.

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The mobile phone is an example of a mobile technology that is, as described by Naismith, Lonsdale, Vavoula, & Sharples, (2004) 'portable, movable, and personal'. In addition, as the mobile phone is networked it also allows information sharing and communication. Because the mobile phone has so many attributes it can theoretically offer the user a chance to work, play or connect in different places, to work, play or connect whilst on the move, and, while doing both these things, the mobile phone allows the user to change his or her behaviour as a result of the features embedded in the technology.

The features embedded in most mobile phones are many and varied and it is not uncommon for users to only interact with a subset of these features. By looking at the use and usage of mobile phones, and focusing down to consider use and usage with children, this paper will make the argument that, contrary to popular belief, the features and functionalities of the mobile phone, although well used by adults and older teens, are not as suited to purpose for use with children as has hitherto been assumed.

This argument is built as follows: in this introductory section of the paper, data from several reports of usage of mobile technologies and mobile phones with children is presented, and then research studies that have looked at children's use of these technologies are examined. The case is then made that the mobile phone is in need of a design makeover for it to be useful to children and young teenagers. Using evidence from a small focus group with children, mobile phone use in the UK, in 2008, is summarized. Taking a user centered approach to this design problem, I then propose several key features for mobile phones for children.

THE UPTAKE OF MOBILE PHONES

In 2004, Prensky suggested there were more than 1.5 billion phones in the word, a figure that is more than three times the number of personal computers in the world at that same time (Prensky, 2004). Four years on, even conservative reports would expect there to be over 2 billion mobile phones worldwide and it is interesting to note that, in discussions of how to breach the digital divide, the mobile phone is lauded as the single most influential piece of technology (Kamssu, 2005).

Whilst the first mobile phones were used only by adults—the car phone was the leader in this domain—as time has moved along, the age of first use of mobile phone technology has dropped. Thus, whilst older teenagers have long been considered primary users of mobile phone technologies, more and more studies report significant uptake of mobile phone technology in younger teens and children.

Children are significant users of mobile technology in all forms. They are primary consumers of mobile games consoles, mobile media players and mobile phones. In the Western world it is common for children as young as six and seven to own at least one mobile device with most children in the age group 11 to 13 having at least two, and invariably three mobile devices, most usually a mobile phone, a handheld games console and a media player.

The general age at which children acquire mobile technology is falling. Previously the age that most children got their first mobile phone in the UK was 13/14, now it is understood to be 10/11. The games console market has recently adjusted for younger children with the Nintendo DS being very popular with children aged 5, 6 and 7, and mobile media players, once the technology of adults, are now common childhood accessories with around 40% of children aged 12 and 13 having personal ownership of an iPod or similar device (Hart, 2007, National Opinion Poll, 2001).

Statistics on mobile phone use by children and teenagers vary and inevitably these statistics lose their currency very rapidly. Many studies only focus on older teenagers but some include older and younger teens; others can be reliably compared across situations and spaces and many show that children are 'catching up' with their older siblings. In 2000, a study by Statistics Norway reported that 26% of 11/12 year olds had mobile phones (Vaage, 2000), in this same country, a study by Ling, (2000) reported that 60% of 13 year olds had mobile phones, perhaps adding some weight to the 'folk' belief that many children get their first mobile phone as they reach their teenage years. This 'folk' belief might have been true in 2000 but more recent statistics paint a different picture. One study indicated that in January 2001, half of all 7 to 16 year-olds in the UK were mobile phone owners (National Opinion Poll, 2001). A 2003 study reported that 28% of younger teenagers owned a mobile (Aoki & Downes, 2003), and in the same year it was estimated that up to a whopping 90% of UK secondary school students (11-16) had a mobile phone (Selwyn, 2003). Similar figures are reported in other developed areas; in Japan, for instance, a national survey of mobile phone communications conducted by Video Research, (2002) found that the overall penetration of mobile phones in Japan was 73.7% with ownership by students age 12 and older up at 75.7%. In 2005, the Wireless World Survey of mobile phone use reported that more than a third of all children aged 5-9 (more than a million) now have a mobile phone and the average age at which a British child gets his or her first mobile phone is now 8 (Wireless World Forum, 2005).

Given the inevitable lag associated with most of these figures, it appears clear that in 2008, the uptake of mobile phones by younger children is bound to be rising—comments in the popular press and anecdotal evidence suggest that children as young as 6 and 7 are now becoming regular users of mobile phones.

THE TECHNOLOGY OF THE MOBILE PHONE

Mobile phones come in all shapes and sizes and have multiple functionalities. There seems to be almost nothing that cannot be added to a mobile phone and as more and more functions are added the possibilities and power embedded in the mobile device change the way they can be used and the way their usefulness is perceived..

It is common to classify mobile phones according to their features. An entry level phone will normally have functions for making voice calls, for sending and receiving text messages, for some customization of the display screen and ring tone, and for profile setting (silent/general etc). This sort of phone will likely also offer the possibility to delete and reorganize messages, create a contact list, and to see missed calls. It might have a calculator, some simple games, a simple organizer for events (calendar), and a clock with an alarm and in most cases a stop watch.

More sophisticated phones offer camera functions (still and video), extra connectivity (Bluetooth/infrared), media player/storage, more sophisticated games, a more graphic interface, internet services, and radio. At the top of the range mobile phones also provide office document compatibility, GPS and navigation, the potential for the use of customizable applications, web and video calling, and easy email functions.

Whereas mobile phones pack a whole lot of features into the technology, the user is often constrained by the service provider. Some service providers limit the connectivity allowed with their packages—the use of services, even if they can be provided, are often rationed due to the cost of the service, for instance, the use of the Internet can be an expensive choice on many pay as you go tariffs.

Opinions of the use and usefulness of mobile phones vary. The mobile phone is simultaneously lauded as a great device and reviled as a destructive irritation. In their book, Perpetual Contact, Katz & Aakhus, (2001) write, '*it [the mobile phone] is a technology that has been given credit for—inter alia—saving lives, organizing terrorist efforts, and overthrowing dictators*.' Some commentators focus on the possible health risks (Burgess, 2002), whilst others, who are unconvinced about the general benefits of mobile phones, recount some of the more irritating social behaviors associated with mobile phone use (Monk, Carroll, Parker, & Blythe, 2004).

My own view of mobile phone technology is generally positive. As a keen mobile user myself, I encourage my own children to use their mobile devices but, whilst I am a keen supporter of technology for children, I do consider that technologies for children should be designed for their needs.

WHAT CHILDREN USE MOBILE PHONES FOR

Data on the use of mobile phones with children is relatively scarce. Most reports focus on older teenagers and young adults but there are a handful of studies that have considered younger ages. That mobile phones are a first choice for communication between friends and synchronization of events was evidenced in Livingstone & Bober, (2004)—who reported that, compared to email and synchronous chat, the mobile phone was the preferred choice of children aged 9 -16, as a voice device for seeking advice, and as a text device for flirting, setting up meetings, and killing time. The use of texting, by this age group, to arrange meetings is also reported in Axup & Bidwell, (2005).

Most of the other studies of use are currently looking at older ages. Taylor & Harper, (2002) described the gift-giving nature of mobile phone ownership as users (teenagers 16-19 in this case) collected, shared and stored memories with their mobile phone devices; one girl in this study rather eloquently summarized this behaviour saying she had ‘so many little memories’. Other activities reported in this 2002 study included exchanging phones, sharing messages and photos, and saying goodnight to one another by text.

Most of the studies on teen behaviour serve to highlight how teenagers behave differently from adults and thus it could be assumed that these studies might also inform us about how children might evolve towards teenage use patterns. It is, however, more the case that children and adults are the extreme cases and there is a normal distribution of use that peaks with teenage behaviour. As an example of older teens being the peak users, a study of Japanese youths showed that Japanese teens send twice as many texts than twenty to thirty year olds, (Yoshii et al., 2002), and a study that compared adult and older teenage use by Smith, Rogers, & Brady, (2003) showed that, across teenagers and adults, the younger the user, the more contacts they had in their phone. This does not necessarily transcend to the child / teen divide as younger children will typically have fewer contacts than older teens and will make fewer texts.

Some behaviors of younger people might be associated with place and context. One context that is very familiar to children and teens is school and so, mobile phone behaviors by these groups, reflect this context. In a thorough ethnographic study that used focus groups, scrapbooks, questionnaires, observations, and diaries by Carroll, Howard, Vetere, Peck, & Murphy (2002) with teens aged 16-20; participants reported that the phone brought to them a ‘freedom from constraints of time and place’, and a ‘fashion item’. These respondents reported texting together as a group in school in dull classes, and playing games under the table in the classroom when they were bored.

The ‘value’ of the phone as a symbol of identity is a common theme in many research studies, Berg, Taylor, & Harper (2003) allude to this in their paper on the design of mobile technologies for teenagers, also highlighting the two aspects of connectedness and solidarity that are enabled by mobile phone technology. There is certainly a lot that can be said about identity and mobile phone use for these older users, it is less clear, however, how much identity matters to younger children and so this particular aspect of mobile phone use is not especially discussed in this article.

ADULT VIEWS ON MOBILE PHONES AND CHILDREN

As alluded to in the earlier sections of this article, there is a general ongoing debate about the suitability of mobile phones for all young users and this is especially true for children. Individuals tend to polarize on one of the two sides of the debate. Many adults are unhappy for their children to have phones at too early an age fearing that the child will lose the phone, be bullied for it, that it will be too expensive, or that it is simply a technological evil. Others take the view that the phone is a necessity for their children, seeing the phone as a security feature and an always on connection and wanting their children to benefit from the technology of the moment.

Both of these views have support and opposition in the research press. The general idea that children cannot be trusted, that they will lose, sell, break, abuse, or otherwise misuse mobile technology was considered in a recent study in which 216 mobile devices were given out to a range of participants in a learning project. Despite over 55% of the participants being under 19, and with 35 of them being homeless, this group of users showed great sense in using the technology and, contrary to the views of the adults overseeing the project, and their rather glum predictions, only 6 of the 216 devices got stolen (less than 3%) and only one was damaged. In addition, in this study, only one participant had to be told off for incorrect use of the technology (Attewell, 2004), It is worth noting that, at the outset of the project reported in this article, the researchers took a sensible line of explaining the technologies, agreeing a 'contract' and then trusting (but also in part monitoring0 use.

Mobile phone theft is difficult to measure and quantify as it relies on self report, on thefts being reported and on honesty in reporting theft (which may be confused with loss or sale). In one survey of 15,000 11-16 year old mobile phone users in deprived areas of the UK, it was claimed that as many as 12% of those surveyed had had a mobile phone stolen; a rather more representative MORI poll in 2001 of 5000 13-16 year olds reported that less than 5% had had a phone stolen (Harrington & Mayhew, 2001). It is easy to see why some people may see mobile phone theft as a greater problem than it might really be.

Many parents feel 'comfortable' knowing their child can call them easily if they are needed (but this is only the case if the child has a) credit, b) the appropriate number stored, and c) battery). This always connected behaviour has some tensions in addition to the obvious flaws in the overall assumption. There is clearly a very fine line between being in touch with a child and the child being surveilled. There seems to be a dangerous trend towards 'tracking' children that is not borne of any real sense but comes from a misunderstanding of the risks associated with life (Furedi, 2001, Rayner, 1999). Aitken, (2001) reports the almost constant parental surveillance of children even up to their early teenage years while they are out. With modern phones now having GPS and way-finding services, together with the rather more sinister ability of parents to 'track' their children, some commentators, in particular Williams, Jones, Fleuriot, & Wood (2005), have identified a concern for children's general understanding of the spaces and places they inhabit in an electronically mapped out world

An alternative (and in my own mind, a much healthier) view is to see the phone as providing freedom for, and giving control to, the child. Fotel & Thomsen (2004) discuss the role of mobile phones in facilitating the discussions between parents and children about where, and how far, the child can go. During a workshop on this topic, the authors established that in most cases children were only allowed 'freedom' if they had their mobile phones on them.

CHILDREN NEED PHONES THAT ARE DESIGNED FOR THEM

The argument therefore, in this article is that, given the variations of use, the physical and social differences, and the particular needs of parents and children, children (and in this case the term is used to more specifically refer to those 11 and under) need different technologies than adults and young teens. As Colbert, (2005) writes '[there is a need].. to identify different user groups, and outline their distinctive characteristics. These characteristics reflect differences in the kinds of task that each group performs, the contexts in which they perform these tasks, and the qualities of use that they value. Having characterized distinct groups, it is then possible for design to target one group or another.'

The counter argument to the suggestion that children need special designs for phones is that they don't need differently designed technologies, that technology can be created to suit all, and that the current range of phones are well designed for the tasks that children want to carry out. There is considerable evidence for this 'stay as it is and let the children adapt' assumption. In general children use adult versions of television remote controls, they use the same house phone as the other householders; they are able to operate the same controls, the same PC technology and the same music technology as adults. It is certainly the case that these static, generally low risk, mainly simple, technologies can all be easily appropriated and understood by children—that does not imply that the same is true for mobile phone technology which is complex, mobile and which, if used incorrectly, may incur risks to the child.

It is certainly possible to design technology to be almost universally useful. The technologies outlined in the previous paragraph are all designed for almost universal use. Many other technologies exist that are universally usable. Children are able to use mobile phones that are designed for adults. They are able to carry out their functions and are able to learn the features and facilities.

Being able to use something is not, however, the same as making things usable or creating a good user experience. What has happened in the mobile phone industry is that technologies, initially proposed for adults, have been altered in some way for the teenage user based on the general assumption that teenagers are not significantly different from adults and that they have similar needs and characteristics. Thus, there are pink and purple phones, phones with more sophisticated teen friendly games and phones with a greater focus on music technology than the adult population might have required. In addition, some mobile service providers have teen focused packages that make texting easy and cheap and feature tariff systems that particularly suit teen use.

It would be possible for the mobile phone industry to start to focus on children simply by porting down similar modifications as these—these would not require a re-think of the basic technology—phones could be made in bright primary colours (if that was sensible), younger games could be included and service providers could think (and then provide) what children would want.

SPECIAL PHONES FOR CHILDREN—THE CASE FOR

Should children have their own technologies? There is a strong case for children being considered as significantly more different from older teens than older teens are from adults in which case simply modifying phones around the edges is not enough. Children have different needs, goals and motivations than adults (Read, 2005); for instance, they are unlikely to be working, they are unlikely to be financially independent, they are not normally task driven! Their abilities to deal with many of the activities associated with mobile phone use are limited; for example, in many countries, especially those using the English language!, many children have difficulties in spelling (Treiman & Bourassa, 2000), and these difficulties have been shown to be problematic in interfaces requiring text input as shown in Read, (2007) and Kano, Read, & Dix, (2006).

The physical size of children can adversely affect their interaction with adult sized technologies—input and output technologies are generally considered to need adaptation for children as described in the ETSI guidelines for interactive technologies for children found in Clarke (2005) and in the discussion of interactive systems design by Brouwer-Janse et al., (1997),

The cognitive abilities of children differ from those of adults (Piaget, 1970); they have different ways of processing information, their memories are different and their experiences and analogies are not the same as the experiences and analogies that adults hold. As an example, many of the icons on traditional mobile phone interfaces refer specifically to adult, office applications; for example, the filing cabinets, the clocks and the spanners. In addition, the structure of menus in many mobile phones has no good mapping to children's organizational metaphors.

Eliciting Designs for Children

It is beyond the scope of this article to contribute a complete design solution for mobile phones for children—that would take extended study. Indeed, to gather complete ideas, a study comprising design activities with children, (Druin, 1999, Read et al., 2002), and interviews and surveys with children and adults (Read, MacFarlane, & Gregory, 2004), would be needed. In addition parents would want to also have a say on what their children's technologies should look like - a method for including adults in the design of children's technologies is recounted in Pardo, Vetere, & Howard, (2005). As well as eliciting ideas for new features, an extended study of use with current phones would be useful.

Recognizing these limitations, but rather than being able to offer no new insights and anxious to open up the debate on how mobile phone technologies might look for children in the future, I carried out a short focus group study to discover current practice and this was used, together with the information gained from the study of the literature, to inform some early design ideas

What Children Do with their Phones

Given the shortage of empirical data about mobile phone use with children and early teens, a small focus group study was carried out with seven children aged ten (3), twelve (2) and thirteen (2). These children were asked to reflect on their own, and their friends typical behaviors with their mobile phones and specifically were encouraged to recount the 'order' in which they (and their friends) appropriated the different mobile phone features.

On getting a new phone, the first thing almost everyone did was to customize the look of the phone, add / allocate ring tones and then add a few contacts. The first contacts added were generally family and tended to be the people who were with them when the phone was first used. At this point they would also ring some of their friends using landline numbers (still common in the UK but becoming less and less common in other countries) and ask their friends to add their new mobile numbers to their contacts. Soon after first use, many added music where possible, and experimented with the camera. Girls, in particular, tended to fairly early on add birthdays and events to their phone diaries.

After that—the users would settle into some regular use of the phone. If it was on a pay and go system they would add credit, would work out how to charge the phone battery and would then start to carry the phone with them. Almost without exception, the focus group of children reported that they, and their friends, spent the first six to twelve months of their mobile phone ownership forgetting things. They would forget to charge up, forget to take the phone out with them, forget to turn the phone on, or forget to get credit. Eventually, as phone owning became more of a habit they would generally take the phone to school and use it to listen to music or use as a watch. For these children the mobile phone was not really used as a phone at all in school—it would be turned to silent and most reported that they would forget to turn it off silent even once they had left school

These students reported that the phone as a time keeper was its primary role; one said 'If you ask someone the time—they get their phone out and have a look'. They also reported that stealing phones was not really an issue anymore as everyone they knew had one. They reported that most phone users never used the camera at school—mainly as a result of camera use being discouraged by the school authorities.

The concerns that parents have about their children needing to be in contact are especially interesting when it comes to phone behaviors. Amongst the cohort of children represented in this focus group, most would be expected to have around five or six numbers on their phones at age 10 with this number doubling every two years…. What was interesting to report was that most of the children did not know their own mobile numbers but also, although they had one or both parents numbers in their phones, they did not know(i.e. couldn't recount) the numbers of their parent's mobile phones, not did they know a work number where the parent could be found if needed.

Texting was generally less popular than research reports would have us believe. One child reported 'I don't like texting—you don't know if they have got it.', this despite many service providers making it very easy and almost cost free to text. On investigating texting further it became apparent that many children in this study (who were UK children) didn't text because they had anxieties about spelling things wrong. Others felt texting took too long and remarked that they made too many mistakes.

WHAT COULD BE DIFFERENT?

Despite the mobile phone being so popular with young users, it clearly has several limitations. The design ideas presented here address some of the most serious, and the most common problems.

1. The issue of 'out of battery'. The phone could have a preset message time—maybe about 6pm that says—'put me on charge now' this would encourage children to charge the phone up and would also take advantage of daytime charging (rather than overnight charging) which is a habit children should be discouraged from adopting as it is environmentally damaging (with the transformer being on all night).
2. With every charge the child might get one free voice call to their nominated safe number. This would normally be a parent's mobile or a house phone. This would improve the safety of the phone and overcome the 'out of charge' problem.
3. To assist children in learning phone numbers, especially important if the phone is stolen or lost, suppliers could include a learning mobile phone numbers facility on the phone. For each phone number learned from the phone list, the child might get one free music download.
4. For languages that are known to be problematic, the texting function might include a phonetic spell checker or a phonetic prediction mode that would take children over the hurdle of spelling.
5. As almost all the children reported forgetting to switch their phones to general (from silent) situation aware phones that turn themselves onto sound once they leave school would be a bonus.
6. The phone clock could be made much more visible—it would be good not to have to turn the phone on, or open it, to see the time.

These design ideas are only suggestions based on the short study reported here. Collectively they would remove some of the uncertainty of mobile phone use for parents and children and support the goals of both parties in a more effective way.

CONCLUSION

The argument has been made that, as opposed to the status quo, children might be deserving of mobile phones that are specially designed for them. There is a compelling case for this to happen given that children of ever younger ages are being given, or are asking for, mobile phones and given the assumed (although currently inappropriately so) ideas of parents that by giving their children mobile phones they make them safer.

In this article I have proposed some early design changes that would better suit the needs of the children and their parents but it is clear that much more work needs to be done to elicit needs and understand trends of use with children and new users of mobile technology.

This is an area ripe for research and ready to be studied. Currently I am investigating security privacy and trust in mobile systems for children as young as three—clearly this is an age group who would be unlikely to be users of mobile phones but the needs for security will be transferable for many of the older age children.

Mobile phones offer great benefits—even for children!

REFERENCES

Aitken, S. (2001). *The Geography of Young People: The Morally Contested Spaces of Identity*. London, UK: Routledge.

Aoki, K., & Downes, E. (2003). An analysis of young people's use of and attitudes towards cell phones. *Telematics and Informatics*, *20*(4), 349–364. doi:10.1016/S0736-5853(03)00018-2

Attewell, J. (2004). *Mobile Technologies and Learning*. London: Learning and Skills Development Agency.

Axup, J., & Bidwell, N. J. (2005). *Usability of a Mobile, Group Communication Prototype While Rendezvousing*. Paper presented at the CTS 2005, St Louis, Missouri, USA.

Berg, S., Taylor, A. S., & Harper, R. (2003). *Mobile Phones for the Next Generation: Device Designs for Teenagers.* Paper presented at the CHI 2003, Ft Lauderdale, Florida.

Brouwer-Janse, M. D., Suri, J. F., Yawitz, M., de Vries, G., Fozard, J. L., & Coleman, R. (1997). User Interfaces for Young and Old. *Interaction*, *2*(2), 34–46. doi:10.1145/245129.245133

Burgess, A. (2002). Comparing national responses to perceived health risks from mobile phone masts. *Health Risk & Society*, *2*, 175–188. doi:10.1080/13698570220137051

Carroll, J., Howard, S., Vetere, F., Peck, J., & Murphy, J. (2002). *Just what do the youth of today want? Technology appropriation by young people.* Paper presented at the 35th Hawaii International Conference on System Sciences.

Clarke, A. (2005). *Guidelines for the design and deployment of ICT products and services used by children* ([]. Sophia Antipolis, France: ETSI.]. *ETSI EG*, *202*, 423.

Colbert, M. (2005). Age differences rendezvousing: reminders for side-stepping. *Personal and Ubiquitous Computing*, *9*, 404–412. doi:10.1007/s00779-005-0032-9

Druin, A. (1999). *Cooperative inquiry: Developing new technologies for children with children.* Paper presented at the CHI99.

Fotel, T., & Thomsen, T. U. (2004). The Surveillance of Children's Mobility. *Surveillance & Society*, *1*(4), 535–554.

Furedi, F. (2001). *Paranoid Parenting*. Harmondsworth, UK: Penguin Books Ltd.

Harrington, V., & Mayhew, P. (2001). *Mobile Phone Theft*. London: Home Office Research, Development and Statistics Directorate.

Hart, R. (2007). *My Mobile: UK Children and their Mobile Phones*. Intuitive Media Research Services.

Kamssu, A. J. (2005). Global connectivity through wireless network technology: a possible solution for poor countries. *International Journal of Mobile Communications*, *3*(3), 249–262. doi:10.1504/IJMC.2005.006583

Kano, A., Read, J. C., & Dix, A. (2006). *Children's phrase set for text input method evaluations.* Paper presented at the 4th Nordic Conference on Human-Computer interaction: Oslo, Norway.

Katz, J. E., & Aakhus, M. (Eds.). (2001). *Perpetual contact*. New York: Cambridge University Press.

Ling, R. (2000). *Norwegian teens, mobile telephony and text messages*. Oslo: Telenor Research and Development.

Livingstone, S., & Bober, M. (2004). *UK Children Go Online*. London: LSE.

Monk, A., Carroll, J., Parker, S., & Blythe, M. (2004). Why are mobile phones so annoying? *Behaviour & Information Technology*, *23*(1), 33–41. doi:10.1080/01449290310001638496

Naismith, L., Lonsdale, P., Vavoula, G., & Sharples, M. (2004). *Literature Review in Mobile Technologies and Learning*. Bristol: FutureLab.

National Opinion Poll. (2001). Half of 7–16s have a mobile phone, *NOP Research Group Internet Surveys,* (Vol. 29 January).

Pardo, S., Vetere, F., & Howard, S. (2005). *Broadening Stakeholder Involvement in UCD: Designers Perspectives on Child Centred Design.* Paper presented at the OZCHI 2005, Canberra, Australia.

Piaget, J. (1970). *Science of Education and the psychology of the child*. New York: Orion Press.

Prensky, M. (2004). *What Can You Learn from a Cell Phone? – Almost Anything*. Available: www.marcprensky.com/writing/Prensky-What_Can_You_Learn_From_a_Cell_Phone-FINAL.pdf, [2008, 12th November].

Rayner, J. (1999). 'Why this NSPCC advert is harmful to children'. *The Observer,* 12.

Read, J. C. (2005). The ABC of CCI. *Interfaces*, *62*, 8–9.

Read, J. C. (2007). A study of the usability of handwriting recognition for text entry by children. *Interacting with Computers*, *19*(1), 57–69. doi:10.1016/j.intcom.2006.08.009

Read, J. C., Gregory, P., MacFarlane, S. J., McManus, B., Gray, P., & Patel, R. (2002). *An Investigation of Participatory Design with Children - Informant, Balanced and Facilitated Design.* Paper presented at the Interaction Design and Children, Eindhoven.

Read, J. C., MacFarlane, S. J., & Gregory, A. G. (2004). *Requirements for the Design of a Handwriting Recognition Based Writing interface for Children.* Paper presented at the Interaction Design and Children 2004, Maryland, US.

Selwyn, N. (2003). Schooling the mobile generation: the future for schools in the mobile-networked society. *British Journal of Education*, *24*(2), 131–144. doi:10.1080/01425690301905

Smith, H., Rogers, Y., & Brady, M. (2003). *Managing one's social network: does age make a difference?* Paper presented at the Interact 2003, Zurich.

Taylor, A. S., & Harper, R. (2002). *Age-old Practices in the "New World": A study of gift giving between teenage mobile phone users.* Paper presented at the CHI 2002, Minneapolis.

Treiman, R., & Bourassa, D. C. (2000). The development of spelling skill. *Topics in Language Disorders*, *20*, 1–18. doi:10.1097/00011363-200020030-00004

Vaage, O. (2000). *Mediabruks undersøkelse*. Oslo: Statistics Norway.

Video Research. (2002). *Mobile Phone Usage Situation*. Tokyo: Video Research.

Williams, M., Jones, O., Fleuriot, C., & Wood, L. (2005). *Children and emerging wireless technologies: investigating the potential for spatial practice.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems, Portland, Oregon, USA.

Wireless World Forum. (2005). *Survey of Mobile Phone Use*.

Yoshii, H., Matsuda, M., Habuchi, C., Dobashi, S., Iwata, K., & Kin, N. (2002). *Keitai Denwa Riyou no Shinka to sono Eikyou*. Tokyo: Mobile Communications Kenkyuukai.

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Chapter 21
SatNav or SatNag?
A Case Study Analysis of Evolving HCI Issues for In-Car Computing

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ABSTRACT

A wide range of in-car computing systems are either already in existence or under development which aim to improve the safety, efficiency and the comfort/pleasure of the driving experience. Several unique forces act on the design process for this technology which must be understood by HCI researchers. In particular, this is an area in which safety concerns dominate perspectives. In this position paper, I have used a case study system (vehicle navigation) to illustrate the evolution of some key HCI design issues that have arisen in the last twenty years as this in-car technology has matured. Fundamentally, I argue that, whilst HCI research has had an influence on current designs for vehicle navigation systems, this has not always been in a wholly positive direction. Future research must take a holistic viewpoint and consider the full range of impacts that in-car computing systems can have on the driving task.

INTRODUCTION

In-car computing systems provide information of relevance to the driving task (e.g. navigation, traffic and travel) or aim to support/replace the driver in fundamental vehicle control tasks (e.g. collision avoidance, lane keeping). In addition, a range of systems provide information and services related to other salient goals, for instance, to enhance working productivity (e.g. email/Internet access) or for comfort/entertainment purposes.

The single contextual design factor that differentiates this area from any other within mobile HCI work is the safety impact. Paul Green makes

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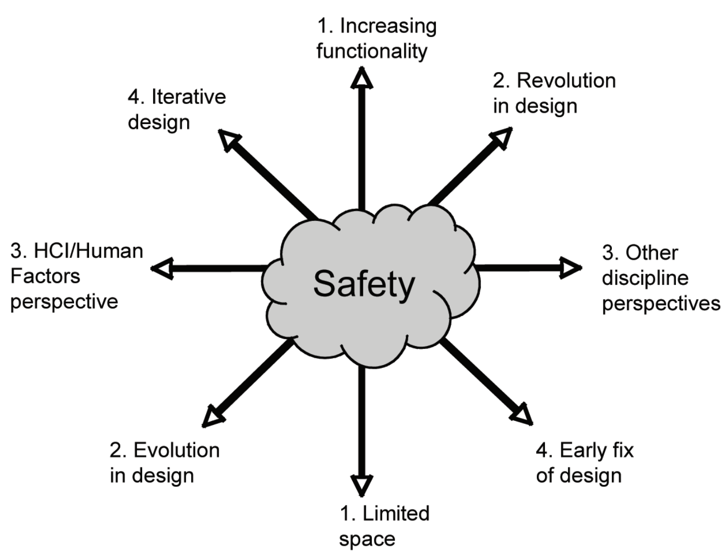
this point eloquently when he notes that he "knows of no-one who has ever been killed as a consequence of operating a computer at a desk, but the loss of life associated with crashes arising from normal motor vehicle operation is huge" (Green, 2008, p.702). Every year, approximately 1.2 million people die in road traffic collisions (WHO, 2004), and, in the vast majority of cases human error is the primary contributing factor (Dewar and Olson, 2002).

In some respects, safety can be seen as a cloud (or mist) that hangs over the automobile industry and impacts on many design decisions. Figure 1 illustrates a range of tensions which exist within the design process for in-car computing. These have been informed by my experience of working closely with vehicle designers and engineers. They are also influenced by recent work we conducted at Nottingham in which ten industry experts were interviewed regarding their perspectives on HCI and Human Factors research and the development of in-car computing systems (Irune and Burnett, 2008). Whilst several other tensions will inevitably arise (e.g. cost versus functionality), I believe these particular tensions to be specific to in-car computing and HCI issues. Importantly, HCI research must recognise such tensions in their development of methods, tools and interface solutions.

- **Tension 1:** A contextual factor of considerable importance for in-car computing is space. A vehicle has limited 'real estate' and drivers/passengers must sit in relatively constrained postures, often for considerable periods of time. Pressures act to increase functionality within the vehicle, yet the space available for controls and displays does not generally change. This factor has had a considerable impact on the nature of user-interfaces developed for vehicles, in particular, the current trend for menu-based interfaces, together with touchscreen or rotary controller input devices.
- **Tension 2:** Designers often seek innovation in their work. However, the automobile industry can be particularly conservative, such that there is often a focus on evolution, rather than revolution, in design. Novel designs are developed, but these

Figure 1. Typical tensions existing in the design process for in-car computing systems



largely build upon previous solutions and the lessons learned in feedback activities.

- **Tension 3:** The complexity of issues involved in designing a car requires a diverse range of professionals to collaborate on important design decisions (e.g. where a touchscreen should be located in a vehicle). Such people may have a strong human-centred view (e.g. HCI/Human Factors practitioners), but may well be driven by other competing perspectives (e.g. stylists, engineers, marketing, and so on). Consequently, design decisions for vehicles must typically be supported by 'hard' data, often quantifiable and based on research with strong 'believability' (or face validity). Such data particularly assists HCI practitioners to argue a case to the wide range of stakeholders involved in the design process who may have competing viewpoints.
- **Tension 4:** A final difficulty occurs because of the need for fixing (or freezing) aspects of vehicle design early in the design process, particularly relating to hardware decisions (e.g. the number of buttons on a panel). This creates a conflict with the HCI philosophy of a continuing cycle of iterative design and evaluation.

As noted by myself (Burnett, 2008) and others (see, for example, Walker, Stanton and Young, 2001), the key HCI design issues for in-car computing systems orientate around two diverse needs. For certain systems (e.g. those providing email access), there is a fundamental desire to avoid driver *overload* (divided attention, high levels of mental workload and stress, etc.). Conversely, for other systems (e.g. adaptive cruise control) research aims to minimise the likelihood or consequences of *underload* due to the automation of core driving tasks (reduced situation awareness, negative behavioural adaptation, de-skilling, etc.).

CASE STUDY ANALYSIS

The remainder of this paper will focus on the evolving HCI issues for a specific case study system, that is, vehicle navigation. This is an in-car computing technology with which I have been involved in a large number of research studies in the last 15 years, commencing with my own PhD work (Burnett, 1998). Relationships with the four tensions described above and the concepts of overload and underload will be described, where appropriate.

Navigation systems within vehicles aim to support drivers in the strategic and tactical components (planning and following routes respectively) of the driving and navigating task. They have become increasingly popular in recent years, across many countries, as costs have reduced and the technology has matured.

There is a considerable literature focusing on human-centred design issues for vehicle navigation systems. As such, this technology serves as an interesting case study in the consideration of HCI issues for in-vehicle computing. Much of the work in the area has emerged from the Human Factors/Ergonomics discipline. Indeed, from around 1985 until approximately 2000, the only research papers that can be found on the topic are within Human Factors/Ergonomics journals and conferences. Nevertheless, more recently there have been several prominent papers within the core HCI literature (e.g. Sodnik et al., 2008; Lee, Hoffman and Hayes, 2004). It is not the purpose of this paper to ignite any controversy concerning the scope of Human Factors/ Ergonomics and HCI and their inter-relationships. Suffice to say, this is a design space in which researchers and practitioners from both domains have a critical role to play in the development of systems which are both usable and safe to use.

It is evident that the great majority of research in this area has made very convincing safety arguments, assuming that *overload* is the most likely concern that navigation system designers must be aware of. It is noted that driving is already a complex task (largely using the visual sense) and secondary systems (such as vehicle navigation) will be associated with divided attention and additional information processing (Srinivisan, 1999; Moriarty and Honnery, 2003). Consequently, there is potential for drivers to make fundamental errors whilst engaging with a navigation system, such as failing to observe in time a lead vehicle slowing down or wavering out of lane.

Consequently, there is considerable literature (especially from the 1980s and 1990s) focusing on distraction effects (visual, cognitive and biomechanical) and several influential design guidelines handbooks have been produced, informed by research studies with this focus (e.g. Ross et al., 1995; Campbell, Carney and Kantowitz, 1998). These handbooks provide a wide range of guidance for designers concerning issues as diverse as the choice of modality for interfaces, the content and timing of voice messages, display position, colour combinations, font types/sizes, orientation of map displays, and so on. Obviously, such handbooks can be important source documents for HCI professionals in industry wishing to argue a case for a specific user-interface design.

From my detailed knowledge of these handbooks, and discussions with practitioners within automobile companies, it is clear that many of the current user-interfaces for vehicle navigation systems have been influenced by their content. In particular, many vehicle navigation systems largely aim to make the workload associated with the navigation task low. This is often achieved using simple turn-by-turn instructions given in the auditory modality, combined with predominately arrow-based graphics.

In some respects, this could be argued as a success for HCI/Human Factors research. Studies were conducted (often on public roads) to provide the 'believable' empirical data for guidelines, which, accordingly have informed best practice. Unfortunately, however, as a result of the recent mass uptake of the technology, it has become evident that overload is not necessarily the most important concern. Two key issues relating to *underload* have emerged, which can be considered broadly under the headings of reliability and reliance.

Reliability

Surveys, in conjunction with considerable anecdotal evidence, have demonstrated the problems associated with unreliable guidance information from vehicle navigation systems. The resulting problems have obvious safety implications (e.g. when a driver turns the wrong way down a one-way street) and can have a considerable impact on congestion (e.g. when a lorry gets stuck under a bridge).

Recent work by Forbes (2008) has examined this phenomenon in detail and, in a survey of 872 navigation system owners, established that 85% had received inaccurate guidance. When asked about guidance that was considered dangerous/illegal, 23% of respondents admitted to obeying the instructions on at least one occasion. In addition, there was a clear relationship with age, such that older drivers were more likely to follow the unreliable guidance than their younger counterparts.

From an HCI perspective, it is most interesting to consider here: a) why certain individuals are prone to following such instructions, and b) which characteristics of the user-interface can contribute to the problem. This is an area around which there has been very little research to date. With respect to the former question, Forbes (2008) conducted follow-up detailed diary studies with 30 navigation system users and used the data to hypothesise that, for certain drivers in specific situations, a *trust* explanation could be given. Specifically, there was evidence for overtrust (or complacency), that is, they saw the relevant road sign/cue, but chose to ignore it and favour the navigation instruction. In other contexts, there was evidence that an *attention*-based explanation could be put forward, since drivers did not believe they saw or processed the relevant road sign/cue. In these cases, it is possible that characteristics of the system user-interface disrupted drivers' normal allocation of attention.

Issues concerning reliability will be a rich area for future research and will be relevant to a wide range of in-car computing scenarios (e.g. collision warning and avoidance systems). Whilst it is likely that the reliability of these in-car computing systems will increase with customer demand, it is unlikely that they will ever be 100% reliable. Importantly, research from other application domains (e.g. process control) indicates that people find it particularly difficult to calibrate objective with subjective reliability when systems are close to perfect (Wickens et al., 2004).

Reliance

A further underload issue has emerged from ongoing research in this area and concerns drivers' long-term dependency on navigation systems. Specifically, I have argued with others that current technology automates core aspects of the navigation task, including trip planning (where the user's role is essentially to confirm computer-generated routes) and route following (where users respond to computer-generated filtered instructions) (Adler, 2001; Burnett and Lee, 2005; Reagan and Baldwin, 2006). As a result, drivers are largely passive in the navigation task, and consequently, fail to develop a strong mental representation of the space in which they are travelling, commonly referred to as a cognitive map. Several empirical studies have demonstrated this effect for drivers (Jackson, 1998; Burnett and Lee, 2005). Indeed, there have also been recent studies raising this concern for hand-held pedestrian navigation systems (Young et al., 2008).

A cynical reader at this stage might remark: why does this matter? Surely, it is positive that drivers (and pedestrians) do not have to think too hard about navigating and are able to make "best" use of the technology they have purchased. In response, I would note the following advantages for individuals who possess a well-formed cognitive map of an environment:

- **Enhanced navigational ability:** such people are able to accomplish navigation tasks with few cognitive demands based on their own internal knowledge. Indeed, it should be possible in certain environments (e.g. one's home town) to navigate using automatic processing, that is, with no conscious attention.
- **Increased flexibility in navigation behaviour:** informed individuals have the capacity to choose and then navigate numerous alternative routes to suit particular preferences (e.g. for a scenic versus efficient route), or in response to unanticipated situations (e.g. heavy traffic, poor weather).
- **Social responsibility:** a well-formed cognitive map provides a wider transport efficiency and social function, since it empowers a person to navigate for others, for example, by providing verbal directions as a passenger, pedestrian, or over the phone, sketching maps to send in the post, and so on (Hill, 1987).

This is essentially a complex trade-off problem which has not so far been addressed in research activities. Notably, there is a conflict between the need to design user-interfaces which enable an individual to acquire spatial knowledge (*active* navigation) and those which minimise the demands (or workload) of navigating (*passive* navigation). Figures 2 and 3 are adapted from an original graph by Burnett and Lee (2005) and hypothesise these relationships for an active compared to a passive navigation system.

Figures 2 and 3 make it apparent that, with active navigation methods, task demands are initially high, but as exposure to the environment continues and spatial knowledge develops, de-

Figure 2. Hypothesised relationship between a driver's exposure to an environment and their spatial knowledge when using either an active or passive navigation system

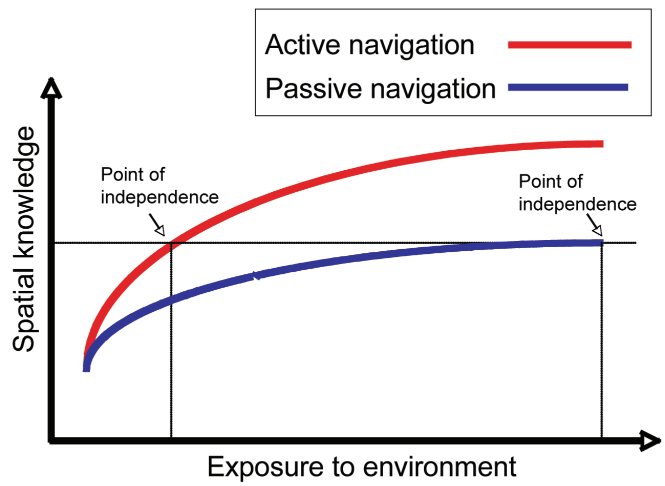
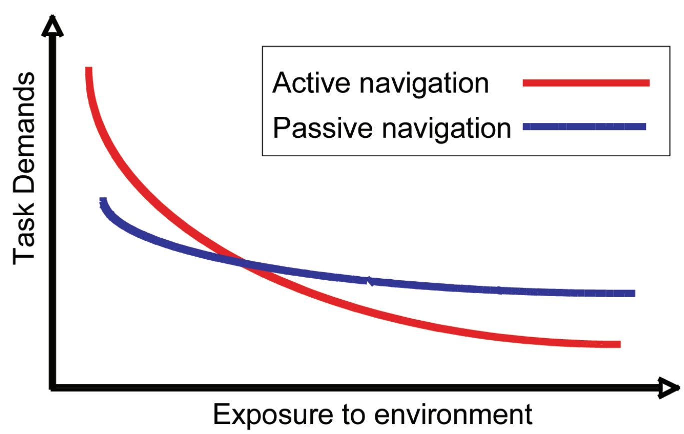


Figure 3. Hypothesised relationship between a driver's exposure to an environment and their task demands (workload) when using either an active or passive navigation system



mands are likely to drop distinctly, such that there is no longer a requirement for the use of external information (what I call the 'point of independence'). In contrast, with passive navigation, whilst task demands are relatively low, spatial knowledge does not develop at the same rate and there is a much longer exposure period where drivers need to use the external information source. Furthermore, it is predicted that task demands do not reach the low levels ultimately achieved when using more active forms of navigation.

Following on from these points, it is argued that future work should consider the design and evaluation of more revolutionary user-interfaces for vehicle navigation systems. Specifically, there are clear merits in developing active, learning-oriented user-interfaces for vehicle navigation systems, as an alternative to the current passive styles. Such interfaces would aim to provide navigation information in a form which ensures that the demands of the navigation task in wholly unfamiliar areas are at an acceptable, low level, whilst aiming to support drivers in the cognitive mapping process. In essence, these interfaces would aspire to move people onwards through the various stages of cognitive map development, ultimately to a level in which they are able to navigate effectively for themselves and others, independent of any external information. Some initial progress was made on this topic in a recent simulator study we conducted at Nottingham which was presented at the ACM Mobile HCI conference (Oliver and Burnett, 2008).

The reliance/dependency issue is also of relevance to a wider range of in-car computing systems, specifically those which provide information relevant to the driving task, or control aspects of driving. As such, these systems offer varying degrees of automation for which there will inevitably be changes to a user's behaviour and/or performance, some of which may be negative. For instance, research studies have shown a tendency for drivers to rely on adaptive cruise control systems (providing both speed and headway control), such that their reaction times are diminished in an emergency braking event (Rudin-Brown and Parker, 2004).

As a final point, I believe it is worth emphasising that in-car computing systems will not be used independently, but in combination with each other. Research studies generally neglect this fact and consider the impact of drivers and passengers interacting with single systems. In reality, for the complex driving situation there will be considerable interaction effects. For instance, a vehicle equipped with a system that automates lateral control of the vehicle is likely to have a significant effect on the tasks that drivers are willing to undertake with other systems, e.g. those providing entertainment or productivity services. How drivers will trade-off the various tasks that occur in future cars will provide a rich vein for research.

CONCLUSION

In this position paper I make two key arguments for in-car computing systems, as an example of mobile HCI in a safety-critical context. Firstly, I propose that there are four key tensions in the design process for this technology which impact on methods, tools and user-interface design practice. Secondly, I express the view that issues of reliability and reliance for in-car computing have a fundamental impact on the overall impact of the technology on driving safety and traffic efficiency. Using vehicle navigation systems as an example, I argue that the styles of user-interface recommended by the research community have actually exacerbated problems. A wide range of research questions emerge from these perspectives which, it is hoped, will stimulate mobile HCI researchers to undertake a variety of novel studies.

REFERENCES

Adler, J. L. (2001). Investigating the learning effects of route guidance and traffic advisories on route choice behaviour. *Transportation Research Part C, Emerging Technologies*, *9*, 1–14. doi:10.1016/S0968-090X(00)00002-4

Burnett, G. E. (1998). *Turn right at the King's Head: Drivers requirements for route guidance information.* Unpublished PhD dissertation (Loughborough University, UK).

Burnett, G. E. (2008). Designing and evaluating in-car user-interfaces. In Lumsden, J. (Ed.), *Handbook of Research on User-Interface Design and Evaluation for Mobile Technology* (*Vol. 1*, pp. 218–236). Hershey, PA: IGI Global.

Burnett, G. E., & Lee, K. (2005). The effect of vehicle navigation systems on the formation of cognitive maps. In Underwood, G. (Ed.), *Traffic and Transport Psychology: Theory and Application* (pp. 407–418). Elsevier. doi:10.1016/B978-008044379-9/50188-6

Campbell, J. L., Carney, C., & Kantowitz, B. H. (1998). *Human Factors design guidelines for advanced traveller information systems (ATIS) and commercial vehicle operations (CVO)*. Report no. FHWA-RD-98-057, Battelle Human Factors Transportation Center, Seattle.

Dewar, R. E., & Olson, P. L. (2002). *Human Factors in traffic safety*. Tucson, AZ: Lawyers and Judges.

Forbes, N. (2008, November). *Investigating end-user behavioural adaptation to in-vehicle navigation systems.* A PhD thesis submitted for examination in School of Computer Science, University of Nottingham.

Green, P. (2007). Motor vehicle driver interfaces. In Jacko, J. A., & Sears, A. (Eds.), *The Human Computer Interaction Handbook* (3rd ed., pp. 701–719). UK: Lawrence-Erlbaum Associates. doi:10.1201/9781410615862.ch35

Hill, M. R. (1987). Asking directions and pedestrian wayfinding. *Man-Environment Systems*, *17*(4), 113–120.

Irune, A., & Burnett, G. E. (2008). *Understanding the integration of human factors methods within the design process for in-car user-interfaces. Internal report CS-2008-08*. UK: School of Computer Science, University of Nottingham.

Lee, J. D., Hoffman, J. D., & Hayes, E. (2004). Collision warning design to mitigate driver distraction. *In CHI04: Proceedings of the SIGCHI conference on Human Factors in computing systems*. NY: ACM.

Moriarty, P., & Honnery, D. (2003). Safety impacts of vehicular information technology. *International Journal of Vehicle Design*, *31*(2), 176–186. doi:10.1504/IJVD.2003.003182

Oliver, K. J., & Burnett, G. E. (2008). Learning-oriented vehicle navigation systems: a preliminary investigation in a driving simulator. *In Proceedings of the 10th international conference on Human-Computer Interaction with mobile devices and services* (pp. 119-126). NY: ACM.

Reagan, I., & Baldwin, C. L. (2006). Facilitating route memory with auditory route guidance systems. *Journal of Environmental Psychology*, *26*, 146155. doi:10.1016/j.jenvp.2006.06.002

Ross, T., Vaughan, G., Engert, A., Peters, H., Burnett, G. E., & May, A. J. (1995). *Human factors guidelines for information presentation by route guidance and navigation systems (DRIVE II V2008 HARDIE, Deliverable 19)*. Loughborough, UK: HUSAT Research Institute.

Rudin-Brown, C. M., & Parker, H. A. (2004). Behavioural adaptation to adaptive cruise control (ACC): implications for preventive strategies. *Transportation Research Part F: Traffic Psychology and Behaviour*, *7*(2), 59–76. doi:10.1016/j.trf.2004.02.001

Sodnik, J., Dicke, C., Tomaic, S., & Billinghurst, M. (2008). A user study of auditory versus visual interfaces for use while driving. *International Journal of Human-Computer Studies*, *66*(5), 318–332. doi:10.1016/j.ijhcs.2007.11.001

Srinivisan, R. (1999). *Overview of some human factors design issues for in-vehicle navigation and route guidance systems*. Transportation Research Record 1694 (paper no. 99-0884), (Washington, DC: National Academy Press).

Walker, G. H., Stanton, N. A., & Young, M. S. (2001). Where is computing driving cars? *International Journal of Human-Computer Interaction*, *13*(2), 203–229. doi:10.1207/S15327590IJHC1302_7

Wickens, C. D. Lee, J. D., Liu, Y., & Becker, S. E. G. (2004). *An Introduction to Human Factors Engineering* (2nd Edition). New Jersey, USA: Pearson.

Young, M., Stanton, N. A., Walker, G. H., Jenkins, D. P., & Smart, W. (2008). Where do we go from here? An assessment of navigation performance using a compass versus a GPS unit. *Cognition Technology and Work*, *10*(3), 231–236. doi:10.1007/s10111-007-0095-7

Chapter 22

Paper Rejected (p>0.05):
An Introduction to the Debate on Appropriateness of Null-Hypothesis Testing

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ABSTRACT

Null-hypothesis statistical testing has been seriously criticised in other domains, to the extent of some advocating a complete ban on publishing p-values. This short position paper aims to introduce the argument to the mobile-HCI research community, who make extensive use of the controversial testing methods.

INTRODUCTION

The approach of statistical analysis using a null-hypothesis testing has been heavily criticised in other domains. Reinvigorated by Cohen and Meehl's seminal papers (Cohen, 1994) (Meehl, 1990) there has been a long running debate in experimental psychology that has led to The American Psychological Association considering, but not going so far as, a complete ban on reporting of p-values (Wilkinson, 1999). While this debate has reached medicine (e.g. (Ioannidis, 2005)), education (e.g. (Cliner, Leech, & Morgan, 2002)), political science (e.g. (Gill, 1999)) and other branches of computer science (e.g. (Demsar, 2008)) for example, it has yet to take root in HCI, despite our inheritance of many methods from experimental psychology. Nor has it had much effect on text books (Cliner, Leech, & Morgan, 2002) from which we and our students typically learn our statistics – a serious problem because many researchers have to teach themselves statistics and one that is compounded because many of the expectations for good practice

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are "actually implicit and arise from the culture of practising statistics rather than being found in books" (Cairns, 2007). This short position paper does not directly contribute anything new to this long running debate as there have been several very eloquent essays within other domains, our aim is to introduce the mobile-HCI community to this discussion and raise awareness of some key papers that discuss the limitations of p-based null-hypothesis statistical testing.

The paper starts with an introduction to the key problems raised in the long discussion in the statistics and experimental psychology domains and moves on to discuss key suggested alternatives - throughout we will make reference to the common use of statistics in mobile HCI work. We feel these issues are relevant to all HCI work but especially relevant to mobile-HCI. Mobiles are used in noisy and complex environments in which the user is often mobile. Experimental design is now, more often than not, reflecting this complex environment to some extent – this makes the studies more complex but also introduces many more potential compounding variables that might bias or simply confuse our results. So the magic formulae of p-testing and ANOVA give us "some degree of reassurance that we are following good scientific practices" (Drummond, 2008). But is this reassurance misplaced or, worse, distorting the investigative nature of science?

KEY PROBLEMS WITH P-BASED STATISTICS

The debate on null-hypothesis testing has identified many "sins" of null-hypothesis significance testing (NHST) and the way that it is normally used in scientific work. Here we look at them as we perceive the severity of the problem in mobile-HCI:

1. Treating NHT as a binary approval of result validity;
2. Confusing strength of p-value results with effect size;
3. Abusing the statistical tests themselves;
4. Making conclusions from non-significant results;
5. Making illogical arguments based on results.

Reviewing recent proceedings of MobileHCI, we are not as guilty as other domains in which null-hypothesis testing has been criticised. However, we tend to be guilty of the first three sins quite widely and we perceive a risk that as publication becomes more competitive, reviewers might push us further along the route of inappropriate statistics.

1. One of the key problems with NHST that has been identified in other domains is the binary treatment of results. The focus on pre-set levels of statistical significance, usually $p<0.05$, leads to simplistic analysis of results: if this level of significance is reached authors tend not to probe deeper as to the reasons and reviewers tend to accept the claims as valid. On the other hand both authors and reviewers are often much more critical of papers where the results do not reach this level of significance, sometimes without probing deeper into the reasons. However, there is nothing magical about 0.05, indeed the fixed level was originally introduced only for convenience so that back-of-the-book tables could be produced in days before computerised stats packages. In mobile-HCI, as with many domains, we very rarely consider what level of significance is required before an experimental result is meaningful: do we need 95% confidence in rejecting the null hypothesis or would 90% do, or do we really need 99.97 for this kind of result? Reviewing recent mobile-HCI papers about half of them do not report the actual p value confirming the binary treatment of this value, our experiments have either achieved this magical number and thus our results are important or they have not and are thus no better than random: clearly a gross simplification.

2. Most statistics books, and people who use statistics for experimental analysis, know quite clearly that you are more likely to get a statistically significant result with more people. What is less clear is that, if there is a statistically significant result in there, then the value of p is inversely related to the number of subjects – the more people you study the smaller the p value will become. What is not strictly related to the p-value is the size of the effect. A study with a large number of users will most likely find a statistically significant effect but that does not mean that the effect is meaningful, large or *scientifically significant* – it may be a trivial difference that would never be noticed in real use never mind have a commercial benefit. However, the smaller the sample the less likely the sample is to be representative of the real population and, thus, "true" (Ioannidis, 2005). Not reporting effect size in some form becomes especially dangerous when linked with our binary thinking of probability.

3. Most statistical procedures (including the standard t-tests and ANOVA) make strong assumptions about the underlying data and are invalid if these assumptions are not met. In particular, they assume the data is taken from an underlying population that is normally distributed. In many psychological tests, e.g. reaction time, it is assumed that the whole population will follow a normal distribution – this is not true for many mobile tasks and experiments. For example, in text entry there is a very wide range of abilities and it is hard to assess the underlying population spread – there are many people with high performance but a long and important tail. There are techniques to overcome this problem (either use of non-parametric tests or adjusting the data, say by using log values for times) but the discussion of parametric checking rarely happens in experimental papers. Furthermore, the distribution in "the population" also differs greatly depending on what the underlying population is expected to be – and we rarely report what underlying population we are studying: again for text entry, is it all mobile users, regular 12-key users, teenagers, twin-thumbers,...? Cairns discusses these and other statistical problems in a review of the use of statistics in British HCI Conference papers (Cairns, 2007).

4. While other domains are more guilty of this than HCI, there is still sometimes a tendency to want to spin a *non-significant result* into a *significant non-result*. This spin negates the whole point of null-hypothesis testing: the authors are trying to use NHST to argue exactly what it is meant to prevent. When we use NHST we are trying to say "the chances of this happening randomly are very low so we have a meaningful difference", the negation is "the chances of this happening randomly are not very low so we have no clear result" and not "the chances of this happening by chance are high, therefore there is no real difference".

5. NHST tests tell us the probability that the observed data occurs by chance given the null-hypothesis is true, usually the probability that we would observe this data given that there is no difference in performance of two systems on a certain measure. This is not the same as the probability that they are the same, nor is 1-p the same as the probability of there being a difference. This is a fairly complex argument involving Baysian probability and modus-tollens validity, we direct the reader to Cohen (Cohen, 1994) for discussion and examples.

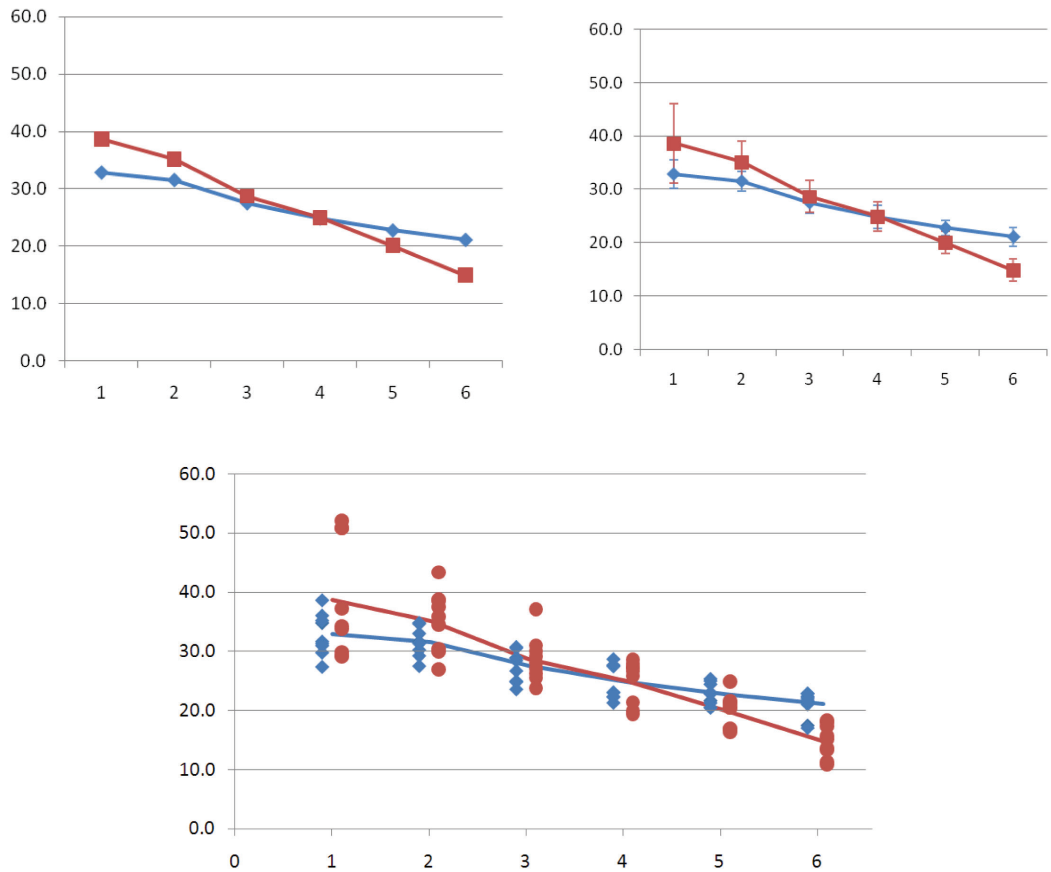
KEY SUGGESTED SOLUTIONS

If there is a single lesson from the discussion of null-hypothesis testing in other domains it is that the size of the effect should be reported in some way – usually along with the p-value results. Effect size tells us how big the observed differences were while p-values indicate how much confidence we should attribute to the basic result. There are two ways of presenting effect size: graphing the results, which to a large extent is normal practice in (mobile-)HCI but could still be standardised somewhat, and using measures of effect size, which are rare in mobile-HCI papers (but also probably less informative than graphs). See (Denis, 2003) for a discussion of this point and an extensive and balanced review of alternatives to null hypothesis testing.

Graphing results is standard procedure in HCI papers and typically shows much more information than straight p-value results (Loftus, 1993) (Wilkinson, 1999): good graphs show trends over time/practice and the size of the difference as well as the range of results. This is good practice and a subject in which the HCI community deserves praise over other domains. However, we are not perfect and the display of error bars on graphs is not as consistent as it should be: sometimes they are not present, sometimes they report a standard deviation, sometimes a standard error or 95% confidence interval, and sometimes the absolute range. By graphing suitable confidence intervals and stating the confidence level of the estimate, alongside point estimates of the population parameter(s), we illustrate visually both the differences between groups and the reliability of the estimates made (i.e. the experimental mean for system A is x and we are 95% confident that the true mean lies between $x\text{-}d_1$ and $x+d_2$). As well as reflecting the range of values, confidence intervals also provide an indication of the sample size as larger samples will tend to result in tighter intervals. Figure 1 shows three graphs of the same data: an artificial experiment comparing two systems over six experimental tasks. The first graph shows the simplest plot of only means, this plot gives the impression that one system is better at the beginning but that performance swaps over around task 4. The second plot adds error bars showing the 95% confidence range and shows clearly that the data overlaps massively at the beginning and is only likely to be conclusive at the right-hand side of the graph. Finally, the third plot replaces the error bars with scatter bars of the actual data – highlighting the inconclusive nature of tasks 1 through 5 and that even in task 6 we do not have perfect separation between the two systems.

Alongside the display of confidence intervals it would be desirable to report the effect size: a scaled estimate of the difference between groups. Reporting the effect size allows for the practical importance of a result to be determined which cannot be conveyed through statistical significance alone. Encouraging both confidence intervals and effect sizes to be reported enables the reader / reviewer to evaluate the results of an experiment more effectively than a p-value alone, regardless of whether statistical significance was achieved. Also, by reporting a standardised effect size opens up the potential for future meta-analysis of related studies through the use of pooled samples. Another criticism of HCI is the lack of replication: other domains base their science on publishing results that others then replicate to further understand and to confirm (or refute) the original. Ioannidis motives his criticism by highlighting the "high rate of nonreplication (lack of confirmation) of research discoveries is a consequence of the convenience, yet, ill-founded strategy of claiming conclusive research findings solely on the basis fo a single study assessed by formal statistical significance..." (Ioannidis, 2005). In a domain that does not attempt, nor support publication of, replicated results – we don't know how bad our non-replication problem is.

Figure 1. Three plots of the same data – six tasks on two systems (means only; means plus 95% confidence interval error bars; and means plus scatter plots)



CONCLUSION

This short paper has aimed to raise awareness in the mobile-HCI community, and perhaps the wider HCI community, of the fundamental concerns that other disciplines have raised over null-hypothesis testing. While we do not appear to be as bad at "statistical sinning" as other domains, we cannot afford to be complacent – particularly as conferences and journals tend to become monotonically harder to publish in, poor understanding and treatment of null-hypothesis testing may seriously affect the types of papers and results that make it through to publication. We therefore encourage anyone involved in writing up or reviewing experimental work in mobile-HCI to read the papers in our, deliberately short, bibliography.

REFERENCES[1]

Cairns, P. (2007). HCI... not as it should be: Inferential Statistics in HCI Research. *Proceedings of HCI 2007 (People and Computers XXI)*. Lancaster, UK.

Cliner, J. A., Leech, N. L., & Morgan, G. A. (2002). Problems with null hypothesis significance testing (NHST): What do the textbooks say? *Journal of Experimental Education*, *71*(1), 83–92. doi:10.1080/00220970209602058

Cohen, J. (1994). The Earth is Round (p<.05). *The American Psychologist*, *49*(12), 997–1003. doi:10.1037/0003-066X.49.12.997

Demsar, J. (2008). On the Appropriateness of Statistical Tests in Machine Learning. *Proceedings of The 3rd workshop on Evaluation Methods for Machine Learning at ICML 2008.* Helsinki, Finland.

Denis, D. (2003). Alternatives to Null Hypothesis Significance Testing. *Theory & Science, 4* (1).

Drummond, C. (2008). Finding a Balance between Anarchy and Orthodoxy. *Proceedings of The 3rd workshop on Evaluation Methods for Machine Learning at ICML 2008.* Helsinki, Finland.

Gill, J. (1999). The insignificance of null hypothesis significance testing. *Political Research Quarterly*, *52*(3), 647–674.

Ioannidis, J. P. (2005). Why most published research findings are false. *PLoS Medicine*, *2*(8). doi:10.1371/journal.pmed.0020124

Loftus, G. (1993). A picture is worth a thousand p-values: On the irrelevance of hypothesis testing in the computer age. *Behavior Research Methods, Instruments, & Computers*, *25*, 250–256. doi:10.3758/BF03204506

Meehl, P. (1990). Why Summaries of Research on Psychological Theories Are Often Uninterpretable. *Psychological Reports*, *66*, 195–244. doi:10.2466/PR0.66.1.195-244

Wilkinson, L. (1999). Statistical Methods in Psychology Journals: Guidelines and Explanations. *The American Psychologist*, *54*(8), 594–604. doi:10.1037/0003-066X.54.8.594

ENDNOTE

[1] All papers are available on-line by searching for author's surname and title.

Compilation of References

Abascal, J., & Nicolle, C. (2005). Moving towards inclusive design guidelines for socially and ethically aware HCI. *Interacting with Computers*, *17*(5), 484–505. doi:10.1016/j.intcom.2005.03.002

Abowd, G., Atkeson, C., Hong, J., Long, S., Kooper, R., & Pinkerton, M. (1997). Cyberguide: A mobile context-aware tour guide. *Wireless Networks*, *3*, 421–433. doi:10.1023/A:1019194325861

Ahern, S., Eckles, D., Good, N., King, S., Naaman, M., & Nair, R. (2007). *Over-Exposed? Privacy Patterns and Considerations in Online and Mobile Photo Sharing*. In Proceedings of the SIGCHI conference on Human Factors in computing systems (CHI 2007),p.357-366. San Jose, CA:ACM Press.

Ahern, S., King, S., & Davis, M. (2005). *MMM2: mobile media metadata for photo sharing*. Proceedings of the 13th annual ACM international conference on Multimedia, Hilton, Singapore.

Ahern, S., King, S., Qu, H., & Davis, M. (2005). *PhotoRouter: destination-centric mobile media messaging*, p. 209-210. In Proc., MULTIMEDIA 2005. San Jose, CA: ACM Press

Ahtinen, A., Mattila, E., Väätänen, A., Hynninen, L., Salminen, J., Koskinen, E., & Laine, K. (2009). User experiences of mobile wellness applications in health promotion. User study of Wellness Diary, Mobile Coach and SelfRelax. *Proceedings of the 3rd International Conference on Pervasive Computing Technologies for Healthcare*. PCTHealth 2009. London, UK.

Ailisto, H., Pohjanheimo, L., Välkkynen, P., Strömmer, E., Tuomisto, T., & Korhonen, I. (2006). Bridging the physical and virtual worlds by local connectivity-based physical selection. *Journal of Personal and Ubiquitous Computing*, *10*(6), 333–344. doi:10.1007/s00779-005-0057-0

Aitken, S. (2001). *The Geography of Young People: The Morally Contested Spaces of Identity*. London, UK: Routledge.

Ajzen, I., & Fishbein, M. (1980). *Understanding attitudes and predicting social behaviour*. Upper Saddle River, NJ: Prentice Hall.

Alahuhta, P., Ahola, J., & Hakala, H. (2005). *Mobilizing Business Applications – A survey about the opportunities and challenges of mobile business applications and services in Finland.* Technology Review 167/2005. Helsinki, Finland: Tekes.

Alexander, L. M., & Currie, C. (2004). Young people's computer use: implications for health education. *Health Education*, *104*(4), 254–261. doi:10.1108/09654280410546745

Alwan, M., Dalal, S., Mack, D., Kell, S., Turner, B., Leachtenauer, J., & Felder, R. (2006). Impact of monitoring technology in assisted living: outcome pilot. *IEEE Transactions on Information Technology in Biomedicine*, *10*(1), 192–198. doi:10.1109/TITB.2005.855552

Alwan, M., Sifferlin, E., Turner, B., Kell, S., Brower, P., Mack, D., Dalal, S. & Felder, R. (2007). Impact of passive health status monitoring to care providers and payers in assisted living. *Telemedicine and eHealth 13*(3), 279-285.

Amedi, A., Stern, W. M., Camprodon, J. A., Bermpohl, F., Merabet, L., & Rotman, S. (2007). Shape conveyed by visual-to-auditory sensory substitution activates the lateral occipital complex. *Nature Neuroscience*, *10*, 687–689. doi:10.1038/nn1912

Ames, M., Eckles, D., Naaman, M., Spasojevic, M., & House, N. (2010, Feb.). Requirements for mobile photoware. *Personal and Ubiquitous Computing*, *14*(2), 95–109. doi:10.1007/s00779-009-0237-4

Ames, M., & Naaman, M. (2007). *Why we tag: motivations for annotation in mobile and online media*, pp. 971-980. In Proc., CHI 2007. San Jose, CA: ACM Press.

Angin, P., Bhargava, B., & Helal, S. (2010). A mobile-cloud collaburative traffic lights detector for blind navigation. In *Proceedings 11th. international conference on mobile data management*, (pp.296-401).

Antifakos, S., Schwaninger, A., & Schiele, B. (2004). Evaluating the effects of displaying uncertainty in context-aware applications. In Davies, N., Mynatt, E. & Siio, I. (eds.). *Proceedings of Ubicomp 2004: Ubiquitous Computing 6th International Conference* (pp. 54-69). New York: Springer-Verlag.

Aoki, K., & Downes, E. (2003). An analysis of young people's use of and attitudes towards cell phones. *Telematics and Informatics*, *20*(4), 349–364. doi:10.1016/S0736-5853(03)00018-2

Arnall, T. (2006). A Graphic Language for Touch-based Interaction. In *Proceedings of the Workshop on Mobile Interaction with the Real World,* pp. 18-22. Espoo, Finland. Aronson, E. (2004). *The Social Animal*. New York: Worth Publishers, Ninth edition.

Arter, D., Buchanan, G., Jones, M., & Harper, R. (2007). Incidental Information and Mobile Search. In *Mobile HCI 2007 Proceedings* (pp. 129-136).

Attewell, J. (2004). *Mobile Technologies and Learning*. London: Learning and Skills Development Agency.

Axup, J., & Bidwell, N. J. (2005). *Usability of a Mobile, Group Communication Prototype While Rendezvousing.* Paper presented at the CTS 2005, St Louis, Missouri, USA.

Bach-y-Rita, P., Tyler, M. E., & Kaczmarek, K. A. (2003). Seeing with the brain. *International Journal of Human-Computer Interaction*, *15*(2), 285–295. doi:10.1207/S15327590IJHC1502_6

Baillie, L., & Schatz, R. (2005). *Exploring multimodality in the laboratory and the field.* Paper presented at the Proceedings of the 7th International Conference on Multimodal Interfaces, Torento, Italy.

Bainbridge, L. (1995). Verbal protocol analysis. In Wilson, J., & Corlett, E. (Eds.), *Evaluation of Human Work: A practical ergonomics methodology* (pp. 161–179). London: Taylor & Francis Ltd.

Bajaj, A., & Leonard, N. (2004). The CPT Framework: Understanding the Roles of Culture, Policy and Technology in Promoting Ecommerce Readiness. *Problems and Perspectives in Management*, *3*, 242–252.

Balabanovic, M., Chu, L. L., & Wolff, G. J. (2000). *Storytelling with digital photographs*. InProceedings of the CHI 2000 conference on human factors in computing systems, The Hague, Netherlands, p. 564–571.

Ballagas, R., Rohs, M., Sheridan, J. G., & Borchers, J. (2006). The smart phone: A ubiquitous input device. *IEEE Pervasive Computing / IEEE Computer Society [and] IEEE Communications Society*, *5*(1), 70–77. doi:10.1109/MPRV.2006.18

Barkhuus, L., Chalmers, M., Tennent, P., Hall, M., Bell, M., Sherwood, S., & Brown, B. (2005). Picking Pockets on the Lawn: The Development of Tactics and Strategies in a Mobile Game. In Beigl, M., Intille, S., Rekimoto, J., & Tokuda, H. (Eds.), *Ubicomp* (pp. 358–374). Tokyo: Springer. doi:10.1007/11551201_21

Barkhuus, L., Brown, B., Bell, M., Sherwood, S., Hall, M., & Chalmers, M. (2008). From Awareness to Repartee: Sharing Location within Social Groups. In Czerwinski, M., Lund A., M. & Tan, D., S. (Eds.) *CHI*, (pp. 497-506), Florence: ACM.

Barnard, L., Yi, J. S., Jacko, J. A., & Sears, A. (2005). An empirical comparison of use-in-motion evaluation scenarios for mobile computing devices. *International Journal of Human-Computer Studies*, *62*, 487–520. doi:10.1016/j.ijhcs.2004.12.002

Barnes, S. J., & Huff, S. L. (2003). Rising Sun: imode and the wireless internet. *Communications of the ACM*, *46*(11), 79–84.

Baumann, M., Keinath, A., Krems, J. F., & Bengler, K. (2004). Evaluation of in-vehicle HMI using occlusion techniques: experimental results and practical implications. *Applied Ergonomics*, *35*(3), 197–205. doi:10.1016/j.apergo.2003.11.011

Beale, R. (2008). (accepted). Socially-aware design: the 'Slanty' approach. [IJSKD]. *International Journal of Sociotechnology and Knowledge Development*.

Beale, R., & Lonsdale, P. (2004). *Mobile context aware systems: The intelligence to support tasks and effectively utilise resources.* Paper presented at the Mobile Human-Computer Interaction - Mobile HCI 2004, Glasgow.

Beaver, J., Chrysanthis, P. K., Pruhs, K., & Liberatore, V. (2006). To Broadcast Push or Not and What? In *Proceedings of the 7th International Conference on Mobile Data Management* (pp. 40-45). Los Alamitos, CA: IEEE Computer Society.

Beck, E., Christiansen, M., Kjeldskov, J., Kolve, N., & Stage, J. (2003). *Experimental Evaluation of Techniques for Usability Testing of Mobile Systems in a Laboratory Setting.* Paper presented at the OzCHI'2003, Brisbane, Australia.

Bell, M. Hall. M., Chalmers, M., Gray, P., Brown, B. (2006). *Domino: Exploring Mobile Collaborative Software Adaptation Proc. Pervasive 200*6. Dublin, pp. 153-168.

Bell, M., Chalmers, M., Barkhuus, L., Hall, M., Sherwood, S., Tennent, P., et al. (2006) Interweaving Mobile Games with Everyday Life. In Olson, G., M. & Jeffries, R. (Eds.) *CHI*, (pp. 417-426), Montreal: ACM Press.

Bellman, T., & MacKenzie, I. S. (1998). *A probabilistic character layout strategy for mobile text entry.* Paper presented at the Graphics Interface '98, Toronto, Canada.

Benford, S., Seager, W., Flintham, M., Anastasi, R., Rowland, D., & Humble, J. (2004). The error of our ways: The experience of self-reported position in a location-based game. In Davies, N., Mynatt, E., & Siio, I. (Eds.), *Ubicomp* (pp. 70–87). Nottingham, UK: Springer.

Benford, S., Rowland, D., Flintham, M., Drozd, A., Hull, R., Reid, J., et al. (2005) Life on the edge: supporting collaboration in location-based experiences. In van der Veer, G., C. & Gale, C. (Eds.) *CHI* (pp. 721-730), Portland, OR: ACM.

Bennett, G., Lindgaard, G., Tsuji, B., Connelly, K. H., & Siek, K. A. (2006). *Reality testing: HCI challenges in non-traditional environments.* Paper presented at the CHI'06 extended abstracts on Human Factors in Computing Systems, Montréal, Québec, Canada.

Bentley, F., Metcalf, C., & Harboe, G. (2006). *Personal vs. commercial content: the similarities between consumer use of photos and music.* In Proc., CHI 2006. ACM Press, p. 667-676.

Benyon, D., Höök, K., & Nigay, L. (2010). Spaces of interaction, *Proceedings ACM-BCS visions of computer science conference*. Edinburgh, UK.

Berg, S., Taylor, A. S., & Harper, R. (2003). *Mobile Phones for the Next Generation: Device Designs for Teenagers.* Paper presented at the CHI 2003, Ft Lauderdale, Florida.

Bernard, H. R. (2005). *Research Methods in Anthropology: Qualitative and Quantitative Approaches*. Walnut Creek: Rowman Altamira.

Betiol, A. H., & Cybis, W. A. (2005, 12-16 September). *Usability Testing of Mobile Devices: A Comparison of Three Approaches.* Paper presented at the IFIP TC13 International Conference on Human-Computer Interaction - Interact'2005, Rome, Italy.

Beyer, H., & Holtzblatt, K. (1998). *Contextual design: Defining customer-centred systems*. San Francisco: Morgan Kauffman Publishers.

Billsus, D., Brunk, C. A., Evans, C., Gladish, B., & Pazzani, M. (2002). Adaptive interfaces for ubiquitous Web access. *Communications of the ACM*, *45*(5), 34–38. doi:10.1145/506218.506240

Bishop, R. (2005). *Intelligent vehicle technology and trends*. London: Artech House Publishers.

Biswas, J., Mokhtari, M., Dona, J. & Yap, P. (2010). Mild Dementia Care at Home – Integrating Activity Monitoring, User Interface Plasticity and Scenario Verification. *Lecture Notes in Computer Science, 6159/2010,* 160-170.

Bittman, M., Rice, J. M., & Wajcman, J. (2004). Appliances and their impact: the ownership of domestic technology and time spent on household work. *The British Journal of Sociology*, *55*(3), 401–423. doi:10.1111/j.1468-4446.2004.00026.x

Blaauw, G. J. (1982). Driving experience and task demands in simulator and instrumented car: a validation study. *Human Factors*, *24*(4), 473–486.

Blackburn, S., Brownsell, S. & Hawley, M. (2006). *Assistive technology for independence (AT4I).* Final Report of the Assistive Technology for Independence Study, Barnsley Hospital NHS Foundation Trust (BH). Obtained by email from Simon Brownsell simon.brownsell@nhs.net.

Boehm, B. (2003). Value-based software engineering. *Software Engineering Notes*, *28*(2), 1–12.

Braam, P. J. (1998). The Coda Distributed File System. *Linux Journal, 50*.

Brandt, J., Weiss, N., & Klemmer, S. R. (2007). txt 4 l8r: Lowering the burden for diary studies under mobile conditions. In *CHI 2007 proceedings: Special interest group on computer-human interaction conference* (pp. 2303-2308). Amsterdam: ACM.

Brewster, S. A. (2002). Overcoming the lack of screen space on mobile computers. *Personal and Ubiquitous Computing*, *6*(3), 188–205. doi:10.1007/s007790200019

Brewster, S., & Walker, A. (2000). *Non-Visual Interfaces for Wearable Computers.* Paper presented at the IEE workshop on Wearable Computing (IEE, 00/145), London.

Brignull, H., & Rogers, Y. (2003). Enticing people to interact with large public displays in public spaces. In [IOS Press.]. *Proceedings of INTERACT*, *2003*, 17–24.

Brouwer-Janse, M. D., Suri, J. F., Yawitz, M., de Vries, G., Fozard, J. L., & Coleman, R. (1997). User Interfaces for Young and Old. *Interaction*, *2*(2), 34–46. doi:10.1145/245129.245133

Brown, L., & Brewster, S. A. (2003). Drawing by ear: Interpreting sonified line graphs, Proceedings ICAD (pp. 15-22).

Browne, J. (2007). *How Japanese Companies Guide Their Customers To Mobile Internet Experiences.* Forrester Research.

Brunswik, E. (1956). *Perception and the representative design of psychological experiments* (2nd ed.). Berkeley, CA: University of California Press.

Buchanan, G., Farrant, S., Jones, M., Thimbleby, H., Marsden, G., & Pazzani, M. (2001). Improving Mobile Internet Usability. In *Proceedings of WWW* (pp. 673-680). New York: ACM.

Burgess, A. (2002). Comparing national responses to perceived health risks from mobile phone masts. *Health Risk & Society*, *2*, 175–188. doi:10.1080/13698570220137051

Burke, J. W., McNeill, M. D. J., Charles, D. K., Morrow, P. J., Crosbie, J. H., & Donough, S. M. (2009). Optimising engagement for stroke rehabilitation using serious games. *The Visual Computer*, *25*(12), 1085–1099. doi:10.1007/s00371-009-0387-4

Burnett, G. E. (2000). "Turn right at the traffic lights" The requirement for landmarks in vehicle navigation systems. *Journal of Navigation*, *53*(3), 499–510. doi:10.1017/S0373463300001028

Burnett, G. E., Summerskill, S. J., & Porter, J. M. (2004). On-the-move destination entry for vehicle navigation systems: Unsafe by any means? *Behaviour & Information Technology*, *23*(4), 265–272. doi:10.1080/01449290410001669950

Burnett, G. E., & Joyner, S. M. (1997). An Assessment of Moving Map and Symbol-Based Route Guidance Systems. In Noy, Y. I. (Ed.), *Ergonomics and Safety of Intelligent Driver Interfaces* (pp. 115–137). Lawrence Erlbaum.

Burnett, G. E., & Lee, K. (2005). The effect of vehicle navigation systems on the formation of cognitive maps. In Underwood, G. (Ed.), *Traffic and Transport Psychology: Theory and Application* (pp. 407–418). Elsevier. doi:10.1016/B978-008044379-9/50188-6

Burnett, G. E. (2003) A road-based evaluation of a Head-Up Display for presenting navigation information, In Proceedings of HCI International conference, Vol 3 (Human-Centred Computing), pp. 180-184.

Burnett, G. E., Lomas, S., Mason, B., Porter, J. M., & Summerskill, S. J. (2005) Writing and driving: An assessment of handwriting recognition as a means of alphanumeric data entry in a driving context, Advances in Transportation Studies, 2005 Special Issue, pp. 59-72

Burnett, G. E., Smith, D., & May, A. J. (2001) Supporting the navigation task: Characteristics of 'good' landmarks, In Proceedings of the Annual Conference of the Ergonomics Society, Hanson, M.A. (ed), Taylor & Francis, pp 441-446.

Burns, P. (1999) Navigation and the mobility of older drivers. Journal of Gerontology. Series B, Psychological sciences and social sciences, 54 (1), 49-55

Burton, H., Snyder, A. Z., Conturo, T. E., Akbudak, E., Ollinger, J. M., & Raichle, M. E. (2002a). Adaptive changes in early and late blind: A fMRI study of Braille reading. *Journal of Neurophysiology*, *87*, 589–607.

Burton, H., Snyder, A. Z., Diamond, J., & Raichle, M. E. (2002b). Adaptive changes in early and late blind: A fMRI study of verb generation to heard nouns. *Journal of Neurophysiology*, *88*, 3359–3371. doi:10.1152/jn.00129.2002

Card, S. K., Moran, T. P., & Newell, A. (1980). The keystroke-level model for user performance time with interactive systems. *Communications of the ACM*, *23*(7), 396–410. doi:10.1145/358886.358895

Card, S. K., Moran, T. P., & Newell, A. (1983). *The psychology of human-computer interaction*. Hillsdale, N.J.: Lawrence Erlbaum Associates.

Carroll, J., Howard, S., Vetere, F., Peck, J., & Murphy, J. (2002). *Just what do the youth of today want? Technology appropriation by young people.* Paper presented at the 35th Hawaii International Conference on System Sciences.

Carter, S., Mankoff, J., Klemmer, S. R., & Matthews, T. (2008). Exiting the cleanroom: On ecological validity and ubiquitous computing. *Human-Computer Interaction*, *23*(1), 47–99. doi:10.1080/07370020701851086

Carter, S., & Mankoff, J. (2005). Prototypes in the Wild: Lessons Learned from Evaluating Three Ubicomp Systems. *Pervasive*, *4*(4), 51–57. doi:10.1109/MPRV.2005.84

Carter, S., Mankoff, J., & Heer, J. (2007) Momento: Support for Situated Ubicomp Experimentation. In Rosson, M., B. & Gilmore, D., J. (Eds.) *CHI*, (pp. 125-134), San Jose, CA: ACM Press.

Celler, B., Lovell, N., & Brasilakis, J. (2003). Using information technology to improve the management of chronic diseases. *The Medical Journal of Australia*, *179*, 242–246.

Chae, M., & Kim, J. (2003). What's so different about the mobile Internet? *Communications of the ACM*, *46*(12), 240–247. doi:10.1145/953460.953506

Chalmers, M., & Galani, M. (2004). Seamful Interweaving: Heterogenity in the Theory and Design of Interac-tive Systems. In *Proceedings of the ACM Designing Interactive Systems – DIS'04 Conference*.

Chang, S. E., Chen, S., & Liu, Y. (2009). A user study of accessing web applications via voice cellular phone: a model comparison approach. *Behaviour & Information Technology*, *28*(5), 471–484. doi:10.1080/01449290802479711

Charette, R., & Nashashibi, F. (2009). *Real time visual traffic lights recognition based on spot light detection and adaptive traffic lights templates*.World congress and exhibition on intelligent transport systems and servides (ITS'09).

Chen, L., Gillenson, M. L. & Sherell, D. (2004). Consumer acceptance of virtual stores: a theoretical model and critical success factors for virtual stores. *ACM SIGMIS Database archive,* 35, *(2), Spring,* 8–31.

Cheok, A. D., Fong, S. W., Goh, K. H., Yang, X., Liu, W., & Farzbiz, F. (2003). Human Pacman: a sensing-based mobile entertainment system with ubiquitous computing and tangible interaction. In Jamin., S. (Ed.) *NetGames* (pp. 106-117), Redwood City, CA: ACM Press.

Cherns, A. (1976). The Principles of Sociotechnical Design. *Human Relations*, *29*(8), 783–792. doi:10.1177/001872677602900806

Cheverst, K., Davies, N., Mitchell, K., & Friday, A. (2000). Experiences of Developing and Deploying a Context-Aware Tourist Guide: The GUIDE Project. In [ACM Press.]. *Proceedings of MOBICOM*, *2000*, 20–31. doi:10.1145/345910.345916

Cheverst, K., Dix, A., Fitton, D., Friday, A., & Rouncefield, M. (2003). Exploring the utility of remote messaging and situated office door displays. In [Springer.]. *Proceedings of MobileHCI*, *2003*, 336–341.

Cheverst, K., Dix, A., Fitton, D., Kray, C., Rouncefield, M., & Sas, C. (2005). Exploring Bluetooth based mobile phone interaction with the Hermes Photo Display. In [Springer.]. *Proceedings of MobileHCI*, *2005*, 47–54. doi:10.1145/1085777.1085786

Cheverst, K., & Dix, A. D. Fitton C. Graham, & M. Rouncefield (2008). Situatedness of awareness information: Impact on the design and usage of awareness systems. In P. Markopoulos & B. de Ruyter (Eds.), *Awareness Systems: Advances in theory, methodology and design*. Chapter 17, Springer.

Cheverst, K., Davies, N., Mktchell, K., Friday, A., & Efstratiou, C. (2000). Developing a context-aware electronic tourist guide: Some issues and experiences. In *Procedings CHI'00*, 17-24.

Chigona, W., Kankwenda, G., & Manjoo, S. (2008). The Uses and Gratifications of Mobile Internet among the South African Students. In *Portland International Conference for Management of Engineering and Technology 2008 Proceedings* (pp. 2197-2207) PICMET.

Chittaro, L., & Dal Cin, P. (2002). Evaluating Interface Design Choices on WAP Phones: Navigation and Selection. *Personal and Ubiquitous Computing*, *6*, 237–244. doi:10.1007/s007790200023

Choudhurry, M. H., Aguerrevere, D., & Barreto, A. B. (2004). A pocked-PC based navigational aid for blind individuals. In Proceedings IEEE international conference on virtual environments, human-computer interfaces, and measurement systems (VeCIMS),(pp.43-48).

Chu, C., & Pan, J.-G. (2008). The forecasting of the mobile Internet in Taiwan by diffusion model. *Technological Forecasting and Social Change*, *75*, 1054–1067. doi:10.1016/j.techfore.2007.11.012

Church, K., Smyth, B., Bradley, K., & Cotter, P. (2008). A Large Scale Study of European Mobile Search Behaviour. In [ACM.]. *Proceedings of MobileHCI*, *2008*, 13–22. doi:10.1145/1409240.1409243

Church, K., & Smyth, B. (2008). Understanding Mobile Information Needs. In *Proceedings of the 10th international conference on human computer interaction with mobile devices and services* (pp. 493-494). ACM.

Church, K., & Smyth, B. (2009). Understanding the Intent Behind Mobile Information Needs. In *Proceedings of the 13th International Conference on Intelligent User Interfaces* (pp. 247-256). ACM.

Church, K., & Smyth, B. (2008). Who, what, where & when: a new approach to mobile search. In *Proceedings of the 13th International Conference on Intelligent User Interfaces* (pp. 309-312). New York: ACM.

Clark, A. (2008). *Supersizing the mind: Embodiment*. Oxford: Action, and Cognitive Extension. doi:10.1093/acprof:oso/9780195333213.001.0001

Clarke, A. (2005). *Guidelines for the design and deployment of ICT products and services used by children* ([]. Sophia Antipolis, France: ETSI.]. *ETSI EG*, *202*, 423.

Clarkson, E., Clawson, J., Lyons, K., & Starner, T. (2005). An empirical study of typing rates on mini-QWERTY keyboards. In *CHI '05 Extended Abstracts*. ACM Press. doi:10.1145/1056808.1056898

Clawson, J., Voida, A., Patel, N., & Lyons, K. (2008). *Mobiphos: a collocated-synchronous mobile photo sharing application*. In MobileHCI '08: Proceedings of the 10th international conference on Human computer interaction with mobile devices and services, pp. 187–195. New York: ACM.

Cleland, J., Louis, A., Rigby, A., Janssens, U., & Balk, A. (2005). Noninvasive home telemonitoring for patients with heart failure at high risk of recurrent admission and death. *Journal of the American College of Cardiology*, *45*(10), 1654–1664. doi:10.1016/j.jacc.2005.01.050

Cockburn, A., & Siresena, A. (2003). *Evaluating Mobile Text Entry With The Fastap Keypad.* Paper Presented At The People And Computers Xvii (Volume 2): British Computer Society Conference On Human Computer Interaction, Bath, England.

Cockton, G., Lavery, D., & Woolrych, A. (2003). Inspection-based Evaluations. In Jacko, J. A., & Sears, A. (Eds.), *The HCI Handbook, Lawrence Erl. Assoc., 2003* (pp. 1118–1138).

Cockton, G., Woolrych, A., & Lavery, D. (2008). Inspection-based evaluations. In Sears, A., & Jacko, J. (Eds.), *The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications* (2nd ed., pp. 1175–1178). Mahwah, NJ: Lawrence Erlbaum Associates.

Cockton, G. (2004). Value-Centred HCI. *Proceedings of the Third Nordic Conference on Human-Computer Interaction* (pp.149–160).

Colbert, M. (2005). Age differences rendezvousing: reminders for side-stepping. *Personal and Ubiquitous Computing*, *9*, 404–412. doi:10.1007/s00779-005-0032-9

CommunicationsDirect. (2007). *Searching for a Better Mobile Search Solution*. Retrieved October 22, 2007, from http://www.communicationsdirectnews.com/do.php/100/27206

Comscore (2007a). *Press release.* Retrieved October 25, 2007, from http://www.comscore.com/press/release.asp? press=1432

Comscore (2007b). *Press release.* Retrieved October 25, 2007, from http://www.comscore.com/press/release.asp?press=1742

Consolvo, S., & Walker, M. (2003). Using the Experience Sampling Method to Evaluate Ubicomp Applications. *Pervasive Computing*, *2*(2), 24–31. doi:10.1109/MPRV.2003.1203750

Consolvo, S., Harrison, B., Smith, I., Chen, M. Y., Everitt, K., & Froehlich, J. (2007). Conducting In Situ Evaluations for and With Ubiquitous Computing Technologies. *International Journal of Human-Computer Interaction*, *22*(1), 103–118. doi:10.1207/s15327590ijhc2201-02_6

Constantiou, I., Damsgaard, J., & Knutsen, L. (2007). The four incremental steps toward advanced mobile service adoption. *Communications of the ACM*, *50*(6), 51–55. doi:10.1145/1247001.1247005

Cooper, M., Foote, J., Girgensohn, A., & Wilcox, L. (2005). Temporal event clustering for digital photo collections. [TOMCCAP]. *ACM Transactions on Multimedia Computing, Communications, and Applications*, *1*(3), 269–288. doi:10.1145/1083314.1083317

Counts, S., & Fellheimer, E. (2004). *Supporting social presence through lightweight photo sharing on and off the desktop.* In Proc., CHI 2004. ACM Press, p. 599-606.

Crabtree, A., French, A., Greenhalgh, C., Benford, S., Cheverst, K., & Fitton, D. (2006). Developing Digital Records: Early Experiences of Record and Replay. *Computer Supported Cooperative Work*, *15*(4), 281–319. doi:10.1007/s10606-006-9026-z

Crabtree, A., Benford, S., Capra, M., Flintham, M., Drozd, A., & Tandavanitj, N. (2007). The Cooperative Work of Gaming: Orchestrating a Mobile SMS Game. *CSCW*, *16*(1-2), 167–198.

Crabtree, A., & Rodden, T. (2004). Domestic Routines and Design for the Home. *CSCW*, *13*(2), 191–220.

Crabtree, A., Benford, S., Rodden, T., Greenhalgh, C., Flintham, M., & Anastasi, R. (2004). Orchestrating a mixed reality game 'on the ground. In Dykstra-Erickson, E., & Tscheligi, M. (Eds.), *CHI* (pp. 391–398). Vienna: ACM.

Crabtree, A., Benford, S., Greenhalgh, C., Tennent, P., Chalmers, M., & Brown, B. (2006) Supporting Ethnographic Studies of Ubiquitous Computing in the Wild. In Carroll, J., M. (Ed.) *DIS* (pp. 60-69) New York: ACM.

Crossan, A., Murray-Smith, R., Brewster, S., Kelly, J., & Musizza, B. (2005). Gait phase effects in mobile interaction. In *Proceedings of ACM SIG CHI 2005* (pp. 1312-1315). Portland, OR.

Csíkszentmihályi, M. (1990). *Flow: The Psychology of Optimal Experience*. New York: Harper and Row.

Csíkszentmihályi, M. (1998). *Finding Flow: The Psychology of Engagement With Everyday Life*. Basic Books.

Cui, J., Wen, F., Xiao, R., Tian, Y., & Tang, X. (2007). *EasyAlbum: an interactive photo annotation system based on face clustering and re-ranking*. Proceedings of the SIGCHI conference on Human factors in computing systems, San Jose, California, USA.

Cui, Y., & Roto, V. (2008). How people use the Web on mobile devices. In *Proceeding of the 17th international conference on World Wide Web* (pp. 905-914). New York: ACM.

Daoust, F., & Hazaël-Massieux, D. (2008). From pages to applications: Mobile Web Best Practices. In *Mobile Internet User Experience Workshop.* Retrieved http://wiki.research.nokia.com/images/b/b6/Daoust-Hazaël-Massieux.pdf

Davies, N., G. S. Blair, K. Cheverst and A. Friday (1996). Supporting Collaborative Applications in a Heterogeneous Mobile Environment, Special Issue of Computer Communications on Mobile Computing, 1996.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quartely*, *13/1989*, 319–339. doi:10.2307/249008

Davis, F. D., & Venkatesh, V. (2004). Toward pre-prototype user acceptance testing of new information systems: implications for software project management. *IEEE Transactions on Engineering Management*, *51*(1). doi:10.1109/TEM.2003.822468

De Angeli, A., Sutcliffe, A., & Hartmann, J. 2006. Interaction, usability and aeshtetics: What influences users' preferences? *Proceedings DIS*, 271-280.

De Graaf, A. (2010). *Gaming motion tracking technologies for rehabilitation*, unpublished manuscript University of Twente, NL.

de Sá, M., Carriço, L., Duarte, L., & Reis, T. (2008) A framework for mobile evaluation. In In Czerwinski, M., Lund A., M. & Tan, D., S. (Eds.) *Ext. Abs. CHI* (pp. 2673-2678), Florence: ACM.

de Saint-Exupery, A. (2009). *Internet of Things – Strategic Research Roadmap*. European Commission – Information Society and Media DG.

Dearman, D., Kellar, M., & Truong, K. (2008). An Examination of Daily Information Needs and Sharing Opportunities. *CSCW '08: Proceedings of the 2008 ACM conference on Computer supported cooperative work* (pp. 679-688). New York: ACM.

Debaty, P., Goddi, P., & Vorbau, A. (2005). Integrating the Physical World with the Web to Enable Context-Enhanced Mobile Services. *Mobile Networks and Applications*, *10*(4), 385–394. doi:10.1007/s11036-005-1552-2

Demiris, G., Oliver, D., Dickey, G., Skubic, M., & Rantz, M. (2007). Findings from a participatory evaluation of a smart home application for older adults. *Technology and Health Care*, *16*, 111–118.

Demumieux, R., & Losquin, P. (2005, 19-22 September). *Gather customer's real usage on mobile phones.* Paper presented at the 7th International Conference on Human Computer Interaction with Mobile Devices and Services (MobileHCI'05), Salzburg, Austria.

Denzin, N. (1978). *Sociological Methods: A Sourcebook* (2nd ed.). New York: McGraw Hill.

Desmet, P. (2002). *Designing Emotions*. Doctoral dissertation, Delft University of Technology, the Netherlands.

Dewar, R. E. (2002). Vehicle Design. In Dewar, R. E., & Olson, P. L. (Eds.), *Human Factors in Traffic Safety* (pp. 303–339). USA: Lawyers & Judges Publishing Company, Inc.

Diefenbach, S., & Hassenzahl, M. (2008). *Give me a reason: Hedonic product choice and justification, Extended Abstracts, CHI 2008, 3051-3056*. Boston: ACM Press.

Diefenbach, S., & Hassenzahl, M. (2009). The beauty dilemma " Beauty is valued but discounted in product choice [Boston: ACM Press.]. *Proceedings CHI*, *2009*, 1419–1426.

Dix, A. J. (1995). Cooperation without (reliable) Communication: Interfaces for Mobile Applications. *Distributed Systems Engineering*, *2*(3), 171–181. doi:10.1088/0967-1846/2/3/005

Dix, A. J. (1999, 15th December). Hazy, Crazy, Lazy Days are Over - Time for Designers to Think. (keynote) *Designing Information for Mobile and Broadband Network Users*, London. Available at http://www.hiraeth.com/alan/papers/mobile-and-b-99/crazy-lazy-ohps.html.

Dourish, P. (2004). What We Talk About When We Talk About Context. *Personal and Ubiquitous Computing*, *8*(1), 19–30. doi:10.1007/s00779-003-0253-8

Drozd, A., Benfoird, S., Tandavanitj, N., Wright, M., & Chamberlain, A. (2006). Hitchers: Designing for cellular positioning. In *Proceedings 8th. international conference on ubiquitous computing* (Ubicomp), 279-296.

Druin, A. (1999). *Cooperative inquiry: Developing new technologies for children with children.* Paper presented at the CHI99.

Drury, C. (1995). Methods for direct observation of performance. In Wilson, J., & Corlett, E. (Eds.), *Evaluation of Human Work: A practical ergonomics methodology* (pp. 35–57). London: Taylor & Francis Ltd.

Duh, H. B., Tan, G. C., & Chen, V. H. (2006). *Usability evaluation for mobile device: a comparison of laboratory and field tests.* Paper presented at the 8th Conference on Human-Computer interaction with Mobile Devices and Services: MobileHCI '06, Helsinki, Finland.

Dunlop, M. D., & Crossan, A. (2000). Predictive text entry methods for mobile phones. *Personal Technologies*, *4*(2). doi:10.1007/BF01324120

Dunlop, M., & Brewster, S. (2002). The challenge of mobile devices for human computer interaction. *Personal and Ubiquitous Computing*, *6*(4), 235–236. doi:10.1007/s007790200022

Dunlop, M. D. (2004). *Watch-Top Text-Entry: Can Phone-Style Predictive Text-Entry Work With Only 5 Buttons?* Paper presented at the 6th International Conference on Human Computer Interaction with Mobile Devices and Services: MobileHCI 04, Glasgow.

Dunlop, M. D., Glen, A., Motaparti, S., & Patel, S. (2006). *AdapTxt: contextually adaptive text entry for mobiles*. Paper presented at the 8th Conference on Human-Computer interaction with Mobile Devices and Services: MobileHCI '06, Helsinki, Finland.

Dutton, D., & Aron, A. (1974). Some evidence for heightened sexual attraction under conditions of high anxiety. *Journal of Personality and Social Psychology*, *30*(4), 510–517. doi:10.1037/h0037031

Engelbart, D. C., & English, W. K. (1968). *A research center for augmenting human intellect.* Paper presented at the AFIPS 1968 Fall Joint Computer Conference, San Francisco, USA.

Engstrom, J., Aberg, N., & Johansson, E. (2005). Comparison between visual and tactile signal detection tasks applied to the safety assessment of in-vehicle information systems. In Proceedings of the third international driving symposium on Human Factors in driver assessment, training and vehicle design. (University of Iowa public policy center, Iowa)

Ericsson, K., & Simon, H. (1984). *Effects of verbalization. Protocol Analysis: Verbal Reports as Data* (pp. 63–107). Boston: The MIT Press.

Escofet, G. (2007). SMS-based WAP push to wither away once mobile search services get their act together. *Mobile Media,* 19*(8)*.

Evreinova, T., Evreino, G., & Raisamo, R. (2004). *Four-Key Text Entry for Physically Challenged People.* Paper presented at the 8th ERCIM workshop: User Interfaces for All (Adjunct workshop proceedings), Vienna, Austria.

Facebook and Twitter Access via Mobile Browser Grows by Triple-Digits in the Past Year (2010, March 3). *comScore*. Retrieved September 28, 2010 from http://www.comscore.com/Press_Events/Press_Releases/2010/3/Facebook_and_Twitter_Access_via_Mobile_Browser_Grows_by_Triple-Digits

Facebook. (2010). Retrieved September 1, 2010, from http://www.facebook.com.

Falke, O., Rukzio, E., Dietz, U., Holleis, P., & Schmidt, A. (2007). *Mobile Services for Near Field Communication (Tech. Rep.)*. Munich, Germany: University of Munich, Department of Computer Science, Media Informatics Group.

Fang, X., Chan, S., Brzezinski, J., & Xu, S. (2006). Moderating Effects of Task Type on Wireless Technology Acceptance. *Journal of Management Information Systems*, *3*(22).

Feiner, S., MacInture, B., Hollerer, T., & Webster, A. (1997). A touring machine: Prototyping 3D mobile augmented reality systems for exploring the urban environment.In *Proceedings first international symposium on wearable computers*, Digest of papers, 74-81.

Ferres, L., Verkhogliad, P., Lindgaard, G., Boucher, L., & Chretien, A. (2007). Improving accessibility to statistical graphs: The iGraph-Lite system. *Proceedings ACM ASSETS*, *07*, 67–74.

Ferres, L., Lindgaard, G., & Sumegi, L. (2010). Evaluating a tool for improving access to complex visual objects, to appear. In *Proceedings ACM ASSETS'10*.

Fields, B., Amaldi, P., Wong, W., & Gill, S. (2007). In Use, In Situ: Extending Field Research Methods. *International Journal of Human-Computer Interaction*, *22*(1&2), 1–6. doi:10.1207/s15327590ijhc2201-02_1

Fishkin, K. P., Jiang, B., Philipose, M., & Roy, S. (2004). I sense a disturbance in the force: Unobtrusive detection of interactions with rfid-tagged objects. In *Proceeding of UBICOMP 2004* (pp. 268-282).

Fitton, D., Cheverst, K., Kray, C., Dix, A., Rouncefield, M., & Saslis-Lagoudakis, G. (2005). Rapid prototyping and user-centered design of interactive display-based systems. *IEEE Pervasive Computing / IEEE Computer Society [and] IEEE Communications Society*, *4*(4), 58–66. doi:10.1109/MPRV.2005.85

Fitton, D. (2006). *Exploring the design, deployment and use of Hermes: A system of situated digital interactive office door displays* (Doctoral dissertation, Lancaster University, 2006).

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*, *47*(6), 381–391. doi:10.1037/h0055392

Flemisch, O., Adams, A., Conway, S. R., Goodrich, K. H., Palmer, M. T., & Schutte, P. C. (2003). *The H-Metaphor as a Guideline for Vehicle Automation and Interaction*. NASA/TM—2003-212672.

Flickr. (2010). Retrieved September 1, 2010, from http://www.flickr.com.

Flowers, J. H., Buhman, D. C., & Turnage, K. D. (2005). Data sonification from the desktop: Should sound be part of standard data analysis software? *ACM Transactions on Applied Perception*, *2*(4), 467–472. doi:10.1145/1101530.1101544

Flowers, J. H., & Hauer, T. A. (1992). The ear's versus the eye's potential to assess characteristics of numeric data: Are we too viouscentric? *Behavior Research Methods, Instruments, & Computers*, *24*(2), 258–264. doi:10.3758/BF03203504

Flowers, J. H., & Hauer, T. A. (1995). Musical versus graphs: Cross-modal equivalence in perception of time series data. *Human Factors*, *37*(3), 553–569. doi:10.1518/001872095779049264

Fogg, B. J., & Tseng, H. (1999). The elements of computer credibility. *Proceedings of CHI 99 Conference* (pp. 80–87).

Forbes, N. L., & Burnett, G. E. (2007). Investigating the contexts in which in-vehicle navigation system users have received and followed inaccurate route guidance instructions, In Proceedings of Third International Conference in Driver Behaviour and Training, Held in Dublin, November, 2007.

Forlizzi, J., & Battarbee, K. (2004). *Understanding experience in interactive systems*. In Proceedings of the 2004 conference on Designing Interactive Systems (DIS 04): processes, practices, methods, and techniques (New York: ACM), p. 261.

Forrester Research. (2006). [ECTAS]. *European Consumer Technology Adoption Study*, *Q4*, 2006.

Fotel, T., & Thomsen, T. U. (2004). The Surveillance of Children's Mobility. *Surveillance & Society*, *1*(4), 535–554.

Froehlich, J., Chen, M. Y., Consolvo, S., Harrison, B., & Landay, J. A. (2007) MyExperience: a system for in situ tracing and capturing of user feedback on mobile phones. In Knightly, E., W., Borriello, G. & Carceres, R. (Eds.) *MobiSys* (pp. 57-70), San Juan, CA: ACM.

Fröhlich, P., Simon, R., & Baillie, L. (2009, April). Mobile Spatial Interaction. *Personal and Ubiquitous Computing*, *13*(4). doi:10.1007/s00779-008-0208-1

Frohlich, D., Kuchinsky, A., Pering, C., Don, A., & Ariss, S. (2002). *Requirements for photoware.* Proceedings of the 2002 ACM conference on Computer supported cooperative work, New Orleans, Louisiana, USA.

Funk, J. L. (2004). *Mobile disruption. The technologies and applications driving the mobile Internet*. Wiley-Interscience.

Furedi, F. (2001). *Paranoid Parenting*. Harmondsworth, UK: Penguin Books Ltd.

Gallo, L., & De Pietro, G. (2009). Input devices and interaction techniques for VR-enhanced medicine. In Damiani, D., & Jeong, J. (Eds.), *Multimedia techniques for device and ambient intelligence* (pp. 115–134). Springer Verlag. doi:10.1007/978-0-387-88777-7_5

Gärtner, U., König, W., & Wittig, T. (2001). Evaluation of manual vs. speech input when using a driver information system in real traffic, in: Proceedings of International driving symposium on human factors in driver assessment, training and vehicle design. (University of Iowa public policy center, Iowa), Available at: http://ppc.uiowa.edu/driving-assessment//2001/index.html

Gefen, D., Karahanna, E., & Straub, D. W. (2003, August). Inexperience and experience with online stores: the importance of TAM and Trust. *IEEE Transactions on Engineering Management*, *50*(3), 307–321. doi:10.1109/TEM.2003.817277

Gemmell, J., Williams, L., Wood, K., Lueder, R., & Bell, G. (2004). Passive capture and ensuing issues for a personal lifetime store. In *Proceeding of ACM CARPE 2004* (pp. 48-55).

Glascock, A., & Kutzik, D. (2006). The impact of behavioral monitoring technology on the provision of health care in the home. *The Journal of Universal Computer Sciences*, *12*(1), 59–80.

Glascock, A. P., & Kutzik, D. (2009). A care informatics approach to telehomecare applications. In Dwivedi, A. (Ed.), *The Handbook of Research on IT Management and Clinical Data Administration in Healthcare* (pp. 368–382). Hershey, PA: IGI Publishing.

Glascock, A., & Kutzik, D. (2004). Moving telematics from the laboratory to a truly enabling technology within the community. In Zhang, D., & Mokhtari, M. (Eds.), *Toward a Human-Friendly Assistive `Environment,Assistive Technology Research Series, 14* (pp. 145–154). Amsterdam: IOS Press.

Glascock, A., & Kutzik, D. (2007a). An evidentiary study of the uses of automated behavioral monitoring. *Conference Proceedings of the 21st International Conference on Advanced Information Networking and Applications, Niagara Falls, Ontario, Canada, 2*(1), 858–862.

Glascock, A., & Kutzik, D. (2007b). From sensors to informatics: Creating communication protocols for caregiving. *Proceedings of the 3rd IET Conference on Intelligent Environments*, 325-332.

Glascock, A., & Kutzik, D. (2008). It's all about the information: The role of informatics in telecare. In William C. Mann (ed) *Aging Disability and Independence: Selected Papers from the 4th International Conference on Aging, Disability and Independence*, pp. 71-85.University of Florida.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. New Brunswick: Aldine Transaction.

Glaser, B. (1965). The constant comparative method of qualitative analysis. *Society for the Study of Social Problems, 12*(4), 436–445. University of California Press. Hagen, P., Robertson, T., Kan, M., & Sadler, K. (2005). Emerging research methods for understanding mobile technology use. In *Proceedings from the 19th conference of the computer-human interaction special interest group (CHISIG) of Australia* (pp. 1-10). ACM.

Goffman, E. (1959). *The presentation of self in everyday life*. New York: Anchor Books.

Goldberg, D., & Richardson, C. (1993). *Touch-typing with a stylus.* Paper presented at the INTERCHI93.

Gong, J., & Tarasewich, P. (2005). *Alphabetically constrained keypad designs for text entry on mobile devices.* Paper presented at the CHI '05: SIGCHI Conference on Human Factors in Computing Systems Portland, USA.

Goodwin, M. H. (1980). He-Said-She-Said: Formal cultural Procedures for the Construction of a Gossip Dispute Activity. *American Ethnologist*, *7*(4), 674–695. doi:10.1525/ae.1980.7.4.02a00050

Gould, J. D., & Lewis, C. H. (1985). Designing for usability: key principles and what designers think. *Communications of the ACM*, *28*(3), 300–311. doi:10.1145/3166.3170

Gourville, J., & Dilip Soman, D. (2002). *Pricing and the Psychology of Consumption. Business Review September 2002 R0209G*www.hbr.org.

Graham, C. Rouncefield, M Cheverst, K., Gibbs, M. and Vetere., F. (2007) How Probes Work. In *Proceedings of OzCHI 2007* (pp. 29-37). ACM Press.

Grant, L., Daanen, H., Benford, S., Hampshire, A., Drozd, A., & Greenhalgh, C. (2007). MobiMissions: the game of missions for mobile phones. In Swanson, J. (Ed.), *SIGGRAPH 2007 Educators Program*. San Diego: ACM.

Green, P. (1999). The 15 second rule for driver information systems. Proceedings of the ITS America ninth annual meeting, Washington, D.C.

Green, P. (2004). Driver Distraction, Telematics Design, and Workload Managers: Safety Issues and Solutions. (SAE paper 2004-21-0022), Proceedings of the 2004 International Congress on Transportation Electronics (Convergence 2004, SAE publication P-387), 165-180. Warrendale, PA: Society of Automotive Engineers.

Greenberg, S., & Buxton, B. (2008). Usability evaluation considered harmful (some of the time). In *Proceedings of CHI 2008* (pp. 111-120). ACM Press.

Greenberg, S., Fitzpatrick, G., Gutwin, C., & Kaplan, S. (1999). Adapting the Locales Framework for Heuristic Evaluation of Groupware. In *Proceedings of the Conference of the Computer-Human Interaction Special Interest Group of the Human Factors and Ergonomics Society of Australia - OZCHI'99*.

Greenfield, S. (2000). *The Private Life of the Brain: Emotions, Consciousness, and the Secret of the Self*. New York: John Wiley & Sons.

Greenhalgh, C., French, A., Tennant, P., Humble, J., & Crabtree, A. (2007). From replay tool to digital replay system. In Online Proceedings of *E-Social Science*, Ann Arbor, MI: ESRC/NSF.

Gregg, Lynne (1992). Living in a wireless world with PDAs. *Infoworld.*

Grover, D. L., King, M. T., & Kushler, C. A. (1998). USA Patent No. 5818437. I. Tegic Communications.

Grudin, J. (1988). Why CSCW applications fail: problems in the design and evaluation of organization of organizational interfaces. In [Portland, Oregon, USA: ACM Press.]. *Proceedings of CSCW*, *1988*, 85–93.

Gurrin, C., Jones, G., Lee, H., O'Hare, N., Smeaton, A., & Murphy, N. (2005). *Mobile access to personal digital photograph archives*. Proceedings of the 7th international conference on Human computer interaction with mobile devices & services, Salzburg, Austria.

Hackos, J. T., & Redish, J. C. (1998). *User and task analysis for interface design*. NY: John Wiley and Sons.

Hagen, P., Robertson, T., Kan, M., & Sadler, K. (2005, 21-25 November). *Emerging research methods for understanding mobile technology use.* Paper presented at the OzCHI'2005, Canberra, Australia.

Häikiö, J., Isomursu, M., Matinmikko, T., Wallin, A., Ailisto, H., & Huomo, T. (2007). Touch-based user interface for elderly users. In *Proceedings of MobileHCI* (pp. 289–296). New York: ACM. doi:10.1145/1377999.1378021

Hakala, P. T., Rimpelä, A. H., Saarni, L. A., & Salminen, J. J. (2006). Frequent computer-related activities increase the risk of neck-shoulder and low back pain in adolescents. *European Journal of Public Health*, *16*(5), 536–541. doi:10.1093/eurpub/ckl025

Halttunen, V., Maksimainen, J., & Pirhonen, A. (2010). Less, slower, better. Do information society visions have healthy alternatives? In Suomi, R. & Ilveskoski, I. (eds.) *Proceedings of the Third International Conference on Well-being in the Information Society (WIS 2010).* TUCS General Publication no. 56, University of Turku, 77-88.

Hansen, F. A., & Grønbæk, K. (2008). Social web applications in the city: a lightweight infrastructure for urban computing. In *Proceedings of the 19th ACM Conference on Hypertext and Hypermedia* (pp. 175-180). New York: ACM.

Harada, S., Naaman, M., Song, Y., Wang, O., & Paepcke, A. (2004). *Lost in memories: interacting with photo collections on PDAs*. Proceedings of the 4th ACM/IEEE-CS joint conference on Digital libraries, Tuscon, AZ, USA.

Harrington, V., & Mayhew, P. (2001). *Mobile Phone Theft*. London: Home Office Research, Development and Statistics Directorate.

Hart, R. (2007). *My Mobile: UK Children and their Mobile Phones*. Intuitive Media Research Services.

Hartson, H. R., Andre, T. S., & Williges, R. C. (2003). Criteria For Evaluating Usability Evaluation Methods. *International Journal of Human-Computer Interaction*, *15*(1), 145–181. doi:10.1207/S15327590IJHC1501_13

Hasselgren, J., Montnemery, E., Nugues, P., & Svensson, M. (2003). *HMS: A Predictive Text Entry Method Using Bigrams.* Paper presented at the Workshop on Language Modeling for Text Entry Methods, 10th Conference of the European Chapter of the Association of Computational Linguistics, Budapest, Hungary.

Hassenzahl, M., & Tractinsky, N. (2006). User Experience – a Research Agenda. *Behaviour & Information Technology*, *25*(2), 91–97. doi:10.1080/01449290500330331

Hassenzahl, M. (2006). Hedonic, emotional, and experiential perspectives on product quality. In Ghaoui, C. (Ed.), *Encyclopedia of human computer interaction* (pp. 266–272). Great Barrington, MA: Berkshire Publishing Group.

Hassenzahl, M. (2003). The Thing and I: Understanding the Relationship Between User and Product. In M. A. Blythe, K.Overbeeke, A. F. Monk & P. C. Wright (Eds.), *Funology: From usability to user enjoyment*. Kluwer Academic Publishers.

Haumont, S., & Siren, R. (2007). dotMobi, a Key Enabler for the Mobile Internet. In *Mobile Internet User Experience Workshop.* Retrieved http://research.nokia.com/events/miux.html

Heimonen, T. (2009). Information Needs and Practices of Active Mobile Internet Users. In Mobility '09: *Proceedings of the 6th International Conference on Mobile Technology, Application & Systems*. ACM.

Heimonen, T., & Käki, M. (2007). Mobile Findex – Supporting Mobile Web Search with Automatic Result Categories. In *Mobile HCI 2007 Proceedings* (pp. 113-120).

Helal, A., Cook, D., & Schmalz, M. (2009). Smart Home-Based Health Platform for Behavioral Monitoring and Alteration of Diabetes Patients. *Journal of Diabetes Science and Technology*, *3*(1), 141–148.

Henderson, A. (2005). Design: The innovation pipeline: design collaborations between design and development. *Interactions (New York, N.Y.)*, *12*(1), 24–29. doi:10.1145/1041280.1041295

Hertzum, M. (1999, 28th November - 1st December). *User Testing in Industry: A Case Study of Laboratory, Workshop, and Field Tests.* Paper presented at the 5th ERCIM Workshop on "User Interfaces for All" – Special Theme "User-Tailored Information Environments", Dagstuhl, Germany.

Himanshu, R., Gossweiler, R., & Milojicic, D. (2004). ContentCascade incremental content exchange between public displays and personal devices. In [IEEE Computer Society.]. *Proceedings of MobiQuitous*, *2004*, 374–381.

Hinckley, K., Pierce, J., Horvitz, E., & Sinclair, M. (2005). Foreground and background interaction with sensor-enhanced mobile devices. *ACM Transactions on Computer-Human Interaction*, *12*(1), 31–52. doi:10.1145/1057237.1057240

Hinman, R., Spasojevic, M., & Isomursu, P. (2008) They call it "surfing" for a reason: Identifying mobile Internet needs through PC deprivation. In *CHI 2008 proceedings: Special interest group on computer-human interaction conference: CHI '08 extended abstracts* (pp. 2195-2207). ACM.

Ho, H., & Syu, L. (2010). Uses and Gratifications of Mobile Application Users. In [IEEE.]. *Proceedings of the International Conference on Electronics and Information Engineering*, *1*, 315–319.

Hoschka, P., & Smith, M. (2007). Best Practices: Making Mobile Browsing Better. In *Mobile Internet User Experience Workshop*. http://research.nokia.com/events/miux.html

How, Y., & Kan, M.-Y. (2005). *Optimizing predictive text entry for short message service on mobile phones.* Paper presented at the Human Computer Interfaces International (HCII 05), Las Vegas, USA.

Huang, E., Mynatt, E., & Trimble, J. (2007). When design just isn't enough: the unanticipated challenges of the real world for large collaborative displays. *Personal and Ubiquitous Computing*, *11*(7), 537–547. doi:10.1007/s00779-006-0114-3

Huang, E. M., Koster, A., & Borchers, J. (2008). Overcoming assumptions and uncovering practices: When does the public look at public displays? In [Springer.]. *Proceedings of Pervasive*, *2008*, 228–243. doi:10.1007/978-3-540-79576-6_14

Hudson, S. E., Harrison, C., Harrison, B. L., & LaMarca, A. (2010). Whack gestures: Inexact and inattentive interaction with mobile devices. *Proceedings ACM TEI*, 109-112.

Hutchinson, H., Mackay, W., Westerlund, B., Bederson, B. B., Druin, A., Plaisant, C., et al. (2003). Technology probes: Inspiring design for and with families. In *Proceedings of CHI 2003*, (pp. 17-24). ACM Press.

Hyvärinen, T., Kaikkonen, A., & Hiltunen, M. (2005). *2005*. Salzburg, Austria: Placing Links in Mobile Banking Application. In Proceedings of MobileHCI.

IDC (2009, February). *Worldwide Quarterly Mobile Phone Tracker*.

Insight, I. (2006). *Mobile Phones Could Soon Rival the PC As World's Dominant Internet Platform*. In The Face of the Web. http://www.ipsos-na.com/news/pressrelease.cfm?id=3049

Internet Reports, I. T. U. 2005 (2005). *The Internet of Things*. Available at: http://www.itu.int/osg/spu/publications/internetofthings/.

Ishii, K., & Mikami, S. (2002). Communication and technology: Diffusion, use, and impact of the Internet around the world. In *Proceedings from the 52nd Annual International Communication Association Conference* (pp. 1-14). InternationalCommunications Association.

ISO 13407. (1999). *Human-centred design processes for interactive systems.* International standard. International Standardization Organization. Geneve.

ISO, 2005, Road vehicles – Ergonomic aspects of transport information and control systems – Occlusion method to assess visual distraction due to the use of in-vehicle information and communication systems. Draft International Standard ISO/DIS 16673. ISO/TC 22/SC 13.

Isomursu, M., Isomursu, P., & Horneman-Komulainen, M. (2008). Touch to Access Mobile Internet. In *Proceedings of OzCHI*. New York: ACM. doi:10.1145/1517744.1517751

Isomursu, P., Hinman, R., Isomursu, M., & Spasojevic, M. (2007). Metaphors for the Mobile Internet. *Journal of Knowledge*. *Technology & Policy*, *20*(4), 259–268. doi:10.1007/s12130-007-9033-5

Isomursu, M., Ervasti, M., & Törmänen, V. (2009). Medication Management Support for Vision Impaired Elderly - Scenarios and Technological Possibilities. In *Proceedings of International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL).* Bratislava, Slovak Republic:IEEE.

Isomursu, M., Kuutti, K., & Väinämö, S. (2004). *Experience clip: method for user participation and evaluation of mobile concepts.* Paper presented at the 8th conference on Participatory design: Artful integration: interweaving media, materials and practices, Toronto, Ontario, Canada.

IUP - International Usability Partners. (2008). *IUP Mobile Transactions Report – 2008.*http://www.amber-light.co.uk/iup/IUP-MobileTransactionsReport.ppt

Jackson, P. G. (1998). In search of better route guidance instructions. *Ergonomics*, *41*(7), 1000–1013. doi:10.1080/001401398186559

Jackson, P. (2007). *Defining Mobile Internet Devices*. Forrester Research.

Jacucci, G., Oulasvirta, A., & Salovaara, A. (2006). *Active construction of experience through mobile media: a field study with implications for recording and sharing*. Personal Ubiquitous Computing. *Springer-Verlag London Ltd*, *11*, 215–234.

Jagacinski, R. J., & Flach, J. M. (2003). *Control theory for humans: quantitative approaches to modelling performance*. Mahwah, NJ: L. Erlbaum Associates.

Jambon, F. (2006, 5-8 septembre). *Retours d'expérience lors d'évaluation de dispositifs mobiles en situation réelle.* Paper presented at the 3e Journées Francophones Mobilité et Ubiquité - Ubimob'06, Paris, France.

Jambon, F., Golanski, C., & Pommier, P.-J. (2007, November 4-9). *Meta-Evaluation of a Context-Aware Mobile Device Usability.* Paper presented at the International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies (UBICOMM'07), Papeete, French Polynesia.

Jambon, F., Mandran, N., & Perrot, C. (2007). La RFID au service de l'analyse du parcours muséal des visiteurs. *La lettre de l'OCIM (Office de Coopération et d'Information Muséographiques)*(113), 11-17.

James, C. L., & Reischel, K. M. (2001). *Text input for mobile devices: comparing model prediction to actual performance.* Paper presented at the SIGCHI conference on Human factors in computing systems, Seattle, Washington, United States.

Jamson, H. (2001). Image characteristics and their effect on driving simulator validity. In Proceedings of International driving symposium on Human Factors in driver assessment, training and vehicle design. (University of Iowa public policy center, Iowa).

Järvenpää, S. L., Lang, K. R., Takeda, Y., & Tuunanen, V. K. (2003). Mobile commerce at crossroads. *Communications of the ACM*, *46*(12), 41–44. doi:10.1145/953460.953485

Jensen, K. L., & Larsen, L. B. (2007). *Evaluating the usefulness of mobile services based on captured usage data from longitudinal field trials.* Paper presented at the 4th international conference on mobile technology, applications, and systems and the 1st international symposium on Computer human interaction in mobile technology, Singapore.

Jin, Y., Choi, S., Chung, A., Myung, I., Lee, J., Kim, M., & Woo, J. (2004). GIA: design of a gesture-based interaction photo album. *Personal and Ubiquitous Computing*, *8*(3-4), 227–233. doi:10.1007/s00779-004-0282-y

Johnson, P. (1998). Usability and Mobility: Interaction on the Move. In *Proceedings of the First Workshop on Human-Computer Interaction with Mobile Devices*.

Jones, W. D. (2002). Building safer cars. *IEEE Spectrum*, *39*(1), 82–85. doi:10.1109/6.975028

Jones, M., & Marsden, G. (2006). *Mobile Interaction Design*. England: John Wiley and Sons Ltd.

Jones, N. (2007). *Mobile Web Trends 2007 to 2011. Gartner ID Number: G00148175*. Gartner Research.

Jordan, P. (2000). *Designing pleasurable products. An introduction to the new human factors*. New York: Taylor & Francis.

Joshi, D. (2006). *Mobility as an extension of Man.* Post Graduate Dissertation, National Institute of Design / Motorola India Research Labs, India.

Kaasinen, E. (2003). User needs for location-aware mobile services. *Personal and Ubiquitous Computing*, (6): 70–79. doi:10.1007/s00779-002-0214-7

Kaasinen, E. (2005a, January–February). User acceptance of location-aware mobile guides based on seven field studies. *Behaviour & Information Technology*, *24*(1), 37–49. doi:10.1080/01449290512331319049

Kaasinen, E., Niemelä, M., Tuomisto, T., Välkkynen, P., Jantunen, I., & Sierra, J. (2010). Ubimedia based on readable and writable memory tags. *Multimedia Systems*, *16*(1), 57–74. doi:10.1007/s00530-009-0171-3

Kaasinen, E. (2009). User Acceptance of Mobile Services. *International Journal of Mobile Human Computer Interaction*, *1*(1), 79–97.

Kaasinen, E. (2008). User Acceptance of Mobile Services. In Lumsden, J. (Ed.), *Handbook of Research on User Interface Design and Evaluation for Mobile Technology* (*Vol. 1*, pp. 102–121). Hershey, PA: IGI Global.

Kaasinen, E. (2005b). *User acceptance of mobile services - value, ease of use, trust and ease of adoption.* Doctoral dissertation. VTT Publications 566. Espoo: VTT Information Technology.

Kaasinen, E., Aaltonen, M., Kolari, J., Melakoski, S., & Laakko, T. (2000): Two approaches to bringing Internet services to WAP devices. Proceedings of the 9th international World Wide Web conference on Computer networks (2000) 231-246.

Kaasinen, E., Ermolov, V., Niemelä, M., Tuomisto, T., & Välkkynen, P. (2006). Identifying User Requirements for a Mobile Terminal Centric Ubiquitous Computing Architecture. In *Proceedings of FUMCA 2006: System Support for Future Mobile Computing Applications*. Retrieved http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4021039

Kaasinen, E., Ikonen, V., Ahonen, A., Anttila, V., Kulju, M., Luoma, J., & Södergård, R. (2002). *Products and Services for Personal Navigation – Classification from the User's Point of View.* Publications of the NAVI programme. Retrieved January 4, 2005, from www.vtt.fi/virtual/navi

Kaasinen, E., Kasesniemi, E.-L., Kolari, J., Suihkonen, R., & Laakko, T. (2001). *Mobile-Transparent Access to Web Services – Acceptance of Users and Service Providers.* Proceedings of International Symposium on Human Factors in Telecommunication. Bergen, Norway. 5.–7.11.2001.

Kaasinen, E., Kulju, M., Kivinen, T., & Oksman, V. (2009). *User acceptance of mobile TV services*. In Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services.

Kahn, V.-J., Markopoulos, P., Eggen, B., IJsselsteijn, W., & de Ruyter, B. (2008). Reconexp: A way to reduce the data loss of the experience sampling method. In *Proceedings of the 10th international conference on human computer interaction with mobile devices and services* (pp. 471-476). ACM

Kaikkonen, A., Kekäläinen, A., Cankar, M., Kallio, T., & Kankainen, A. (2005). Usability Testing of Mobile Applications: A Comparison between Laboratory and Field Testing. *Journal of Usability Studies*, *1*(1), 4–17.

Kaikkonen, A. (2006). *2005- full paper. JIT July 2006*. Usability Problems in Today's Mobile Internet Portals. In Proceedings of Mobility.

Kaikkonen, A. (2008) Full or tailored mobile Web- Where and how do people browse on their mobiles? In *Proceedings of the International Conference on Mobile Technology, Applications, and Systems* (8 pp. unnumbered). New York: ACM.

Kaikkonen, A., & Roto, V. (2003). Navigating in a Mobile XHTML Application. In *Proceedings of CHI2003.*

Kamp, J. F., Marin-Lamellet, C., Forzy, J. F., & Causeur, D. (2001). HMI aspects of the usability of internet services with an in-car terminal on a driving simulator. *IATSS Research*, *25*(2), 29–39.

Kamssu, A. J. (2005). Global connectivity through wireless network technology: a possible solution for poor countries. *International Journal of Mobile Communications*, *3*(3), 249–262. doi:10.1504/IJMC.2005.006583

Kamvar, M., & Baluja, S. (2007). The Role of context in Query Input: Using contextual signals to complete queries on mobile devices. In *Mobile HCI 2007 Proceedings* (pp. 121-128).

Kamvar, M., & Baluja, S. (2006). A Large Scale Study of Wireless Search Behavior: Google Mobile Search. In *Proceedings of CHI* (pp. 701-709). New York: ACM.

Kane, S. K., Bigham, J. P., & Wobbrock, J. O. (2008). Slide rule: Making mobile touch screens accessible to blind people using multi-gouch interaction techniques, *Proceedings ASSETS'08*, Halifax.

Kano, A., Read, J. C., & Dix, A. (2006). *Children's phrase set for text input method evaluations.* Paper presented at the 4th Nordic Conference on Human-Computer interaction: Oslo, Norway.

Kantner, L., & Rosenbaum, S. (1997). Usability studies of www sites: Heuristic evaluation vs. laboratory testing. In *Proceedings of the International Conference on Computer Documentation - SIGDOC '97* (pp. 153-160). ACM Press.

Kaptein, N. A., Theeuwes, J., and van der Horst, R. (1996). "Driving simulator validity: Some considerations." Transp. Res. Rec., 1550, Transportation Research Board, Washington, D.C., 30–36

Karat, C., Halverson, C., Horn, D., & Karat, J. (1999). *Patterns of Entry and Correction in Large Vocabulary Continuous Speech Recognition Systems.* Paper presented at the ACM CHI99: Human Factors in Computing Systems.

Karat, C.-M., Campbell, R., & Fiegel, T. (1992). Comparison of Empirical Testing and Walkthrough Methods in User Interface Evaluation. In *Proceedings of the Conference on Human Factors in Computing Systems - CHI'92* (pp. 397-404). ACM Press.

Karlson, A., Iqbal, S., Meyers, B., Ramos, G., Lee, K., & Tang, J. (2010). Mobile Taskflow in Context: A Screenshot Study of Smartphone Usage. In *Proceedings of the 28th international conference on Human factors in computing systems* (pp. 2009-2018). ACM.

Karlson, A., Meyers, B., Jacobs, A., Johns, P., & Kane, S. (2009). Working Overtime: Patterns of Smartphone and PC Usage in the Day of an Information Worker. In *Dub Human-Computer Interaction and Design.*http://dub.washington.edu/pubs/183. University of Washington.

Katz, J. E., & Aakhus, M. (Eds.). (2001). *Perpetual contact*. New York: Cambridge University Press.

Kellar, M., Reilly, D., Hawkey, K., Rodgers, M., MacKay, B., Dearman, D., et al. (2005). *It's a jungle out there: practical considerations for evaluation in the city.* Paper presented at the CHI'05 extended abstracts on Human factors in computing systems, Portland, OR, USA.

Kellar, M., Watters, C., & Inkpen, K. M. (2007). An Exploration of Web-based Monitoring. In *CHI 2007 proceedings: Special interest group on computer-human interaction conference* (pp. 377-386). New York: ACM.

Kennedy, R. S., Lane, N. E., Stanney, K. M., Lanham, S., & Kingdon, K. (2001). Use of a motion experience questionnaire to predict simulator sickness. In Proceedings of HCI International, 8-10 May, 2001, New Orelans, LA.

Kennedy, T. L. M., Smith, A., Wells, A. T., & Wellman, B. (2008)). *Networked families. A report of Pew Internet & American Life Project*, October 19. Retrieved (4/11/2008) from http://www.pewinternet.org/pdfs/PIP_Networked_Family.pdf

Kern, N., & Schiele, B. (2003). Multi-sensor activity context detection for wearable computing. In *Proceedings of the European Symposium on Ambient Intelligence*, Eindhoven, The Netherlands.

Ketola, P., Roto, V. (2009). *On User Experience Measurement Needs - Case Nokia*. In the *International Journal on Technology and Human Interaction (IJTHI) 5* (3).

Khella, A., & Bederson, B. B. (2004). Pocket PhotoMesa: a Zoomable image browser for PDAs. In Proc., MUM 2004, 83, 19-24. New York: ACM Press.

Kien, T. (2010). *Body movement interaction: An immersive learning game, Masters thesis computer science & Information engineering.* National Central University, Taiwan.

Kim, H., Kim, J., Lee, Y., Chae, M., & Choi, Y. (2002). An empirical study of the use contexts and usability problems in mobile Internet. In *Proceedings from the 35th Hawaii International Conference on System Sciences* (10 pp. unnumbered). Institute of Electrical and Electronics Engineers.

Kim, J., He, J., Lyons, K., & Starner, T. (2007). The gesture watch: A wireless contact-free gesture-based wrist interface. *Proceedings IEEE International symposium on wearable computers*, 15-22.

Kindberg, T., & Jones, T. (2007). “Merolyn the Phone”: A study of Bluetooth naming practices. In [Springer.]. *Proceedings of Ubicomp*, *2007*, 318–335.

Kindberg, T., & Barton, J. (2000). Towards a real-world wide web. In *Proceedings of the 9th Workshop on ACM SIGOPS European Workshop* (pp. 195-200). ACM Press. http://doi.acm.org/10.1145/566726.566766

Kindberg, T., Sellen, A., & Geelhoed, E. (2004). Security and trust in mobile interactions – a study of users’ perceptions and reasoning. In Davies, N., Mynatt, E. & Siio, I. (eds.). *Proceedings of Ubicomp 2004: Ubiquitous Computing 6th International Conference* (pp. 196-213). New York: Springer-Verlag.

Kirk, D., Sellen, A., Rother, C., & Wood, K. (2006). *Understanding photowork*. Proceedings of the SIGCHI conference on Human Factors in computing systems, Montréal, Québec, Canada.

Kistler, J. & Satyanarayanan, M. (1992). Disconnected Operation in the Coda File System. *ACM Transactions on Computer Systems*.

Kjeldskov, J., Skov, M. B., Als, B. S., & Høegh, R. T. (2004). Is it worth the hassle? Exploring the added value of evaluating the usability of context-aware mobile systems in the field. [Springer.]. *Proceedings of MobileHCI*, *2004*, 61–73.

Kjeldskov, J., Graham, C., Pedell, S., Vetere, F., Howard, S., & Balbo, S. (2005). Evaluating the Usability of a Mobile Guide: The Influence of Location, Participants and Resources. *Behaviour & Information Technology*, *24*(1), 51–65. doi:10.1080/01449290512331319030

Kjeldskov, J., & Skov, M. B. (2007). Studying Usability In Sitro: Simulating Real World Phenomena in Controlled Environments. *International Journal of Human-Computer Interaction*, *22*(1), 7–36. doi:10.1207/s15327590ijhc2201-02_2

Kjeldskov, J., & Graham, C. (2003). A Review of Mobile HCI Research Methods. In L. Chittaro (Ed.), *International Symposium on Human Computer Interaction with Mobile Devices and Services - Mobile HCI’03* (pp. 317-335). Springer-Verlag.

Kjeldskov, J., & Stage, J. (2004). New Techniques for Usability Evaluation of Mobile Systems. *International Journal of Human-Computer Studies - IJHCS, 60*(5-6), 599-620.

Klausner, J., & Hotto, R. (1977). Electronic pocket directory. U.S. Patent 4,117,542

Klyubin, A. S., Polani, D., & Nehaniv, C. L. (2005, September). Empowerment: A Universal Agent-Centric Measure of Control. I*n Proceedings of the 2005 IEEE Congress on Evolutionary Computation, 1*, 128-135. IEEE Press.

Koblentz, E. (2003, January 30). Unpublished telephone interview of Michael Levy.

Koblentz, E. (2007, August 29). Unpublished telephone interview of Frank Canova.

Koivumäki, T., Ristola, A., & Kesti, M. (2008). The perceptions towards mobile services: an empirical analysis of the role of use facilitators. *Personal and Ubiquitous Computing*, *12*, 67–75. doi:10.1007/s00779-006-0128-x

Körding, K., & Wolpert, D. (2004). Bayesian integration in sensorimotor learning. *Nature*, *427*, 244–247. doi:10.1038/nature02169

Kreutzer, T. (2008, July). Assessing Cell Phone Usage in a South African Township School. In *Proceedings of e/merge 2008 conference.*

Kuchinsky, A., Pering, C., Creech, M., Freeze, D., Serra, B., & Gwizdka, J. (1999). *FotoFile: a consumer multimedia organization and retrieval system*. Proceedings of the SIGCHI conference on Human factors in computing systems: the CHI is the limit, p.496-503, Pittsburgh, Pennsylvania, USA.

Kumparak, G. (2008). Apple announces Top 10 iPhone App downloads of 2008. Retrieved 3rd December, 2008, from http://www.mobilecrunch.com/2008/12/02/apple-announces-top-10-iphone-app-downloads-of-2008/

Kuo, Y. F., & Yen, S. N. (2009). Towards an understanding of the behavioral intention to use 3G mobile value-added services. *Computers in Human Behavior*, *25*, 103–110. doi:10.1016/j.chb.2008.07.007

Kushler, C. (1998). *AAC Using a Reduced Keyboard.* Paper presented at the Technology and Persons with Disabilities Conference, USA.

Laakko, T., & Hiltunen, T. (2005). Adapting Web Content to Mobile User Agents. *IEEE Internet Computing*, *2*(9), 46–53. doi:10.1109/MIC.2005.29

Lantz, V., & Murray-Smith, R. (2004). Rhythmic interaction with a mobile device. In [Tampere, Finland: ACM.]. *Proceedings of NordiCHI*, *04*, 97–100. doi:10.1145/1028014.1028029

Law, L. C., & Hvannberg, E. T. (2002). Complementarity and convergence of heuristic evaluation and usability test: A case study of universal brokerage platform. In *Proceedings of the Nordic Conference on Human-Computer Interaction - NordiCHI '02* (pp. 71-80). ACM Press.

Lee, J. D., & See, K. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors*, *46*(1), 50–80.

Lee, I., Choi, B., Kim, J., & Hong, S.-J. (2007). Culture-Technology Fit: Effects of Cultural Characteristics on the Post-Adoption Beliefs of Mobile Internet Users. *International Journal of Electronic Commerce*, *4*(11), 11–51. doi:10.2753/JEC1086-4415110401

Lee, S. C., & Starner, T. (2009). Mobile gesture interaction using wearable tactile displays. *Proceedings CHI*, *09*, 3437–3442.

Lehikoinen, J., Salminen, I., & Aaltonen, A. (2007). *Personal Content Experience, Managing Digital Life in the Mobile Age.* Wiley-Interscience.

Levy, M. (1979). Electronic dictionary and language interpreter. U.S. Patent 4,158,236

Lindgaard, G., & Narasimhan, S. (2007). Factors influencing feature-usage in work-related communication. *Behaviour & Information Technology*, *27*(2), 153–168. doi:10.1080/01449290601111218

Lindgaard, G., & Narasimhan, S. (2009). Mobile HCI: thinking beyond the screen-keyboard-mouse interaction paradigm. *International Journal of Mobile HCI*, *1*(1), 24–36.

Ling, R. (2000). *Norwegian teens, mobile telephony and text messages*. Oslo: Telenor Research and Development.

Little, L., & Briggs, P. (2008). *Ubiquitous Healthcare do we want it?* Presented at BCS British HCI Group Conference, Liverpool, UK 1-5th September.

Little, L., Sillence, E., & Briggs, P. (2009). *Ubiquitous systems and the family: Thoughts about the networked home.* In the proceedings of the Fifth Symposium on Usable Privacy and Security (SOUPS), Mountain View, California, USA, 15-17 July 2009.

Liu, H., Xie, X., Ma, W., & Zhang, H. (2003). *Automatic browsing of large pictures on mobile devices*. In Proc., MULTIMEDIA 2003. ACM Press, p. 148-155.

Livingstone, S., & Bober, M. (2004). *UK Children Go Online*. London: LSE.

Lonsdale, P., Barber, C., Sharples, M., Byrne, W., Arvanitis, T., Brundell, P., et al. (2004). *Context awareness for MOBIlearn: creating an engaging learning experience in an art museum.* Paper presented at the Proceedings of MLEARN, Odescalchi Castle, Lake Bracciano, Rome, Italy.

López-de-Ipiña, D., Vázquez, J. I., & Jamardo, I. (2007). *Simplifying Human to Environment Interaction through NFC Technology. In 1as Jornadas Científicas sobre RFID. Ciudad Real, España*. Touch Computing.

López-Nicolás, C., Molina-Castello, F. J., & Bouwman, H. (2008). An assessment of advanced mobile services acceptance: Contributions from TAM and diffusion theory models. *Information & Management*, *45*, 359–364. doi:10.1016/j.im.2008.05.001

Lu, J., Liu, C., Yu, C.-S., & Wang, K. (2008). Determinants of accepting wireless mobile data services in China. *Information & Management*, *45*, 52–64. doi:10.1016/j.im.2007.11.002

Lumsden, J., & Brewster, S. (2003). A paradigm shift: Alternative interaction techniques for use with mobile and wearable devices. *Proceedings conference of the Centre for advanced studies on collaborative research*, Toronto, Canada, 197-210.

Lumsden, J., Kondratova, I., & Durling, S. Investigating Microphone Efficacy for Facilitation of Mobile Speech-Based Data Entry, *Proceedings of The 21rst British Computer Society (BCS) HCI Annual Conference*. Lancaster, UK. 3-7 September 2007.

Macefield, R. (2007). Usability Studies and the Hawthorne Effect. *Journal of Usability Studies*, *2*(3), 145–154.

MacKay, B., & Watters, C. (2003). The Impact of Migration of Data to Small Screens on Navigation. *IT&Society*, *3*(1), 90–101.

MacKay, B., Watters, C., & Duffy, J. (2004). Web Page Transformation When Switching Devices. In *Proceedings Mobile HCI '04* (pp. 228-239). LNCS, vol. 3160.

Mackay, W. E., & Fayard, A.-L. (1997) HCI, Natural Science and Design: A Framework for Triangulation Across Disciplines. In (Editors Names) *Designing Interactive Systems*. (pp. 223-234), Amsterdam: ACM.

MacKenzie, I. S., Zhang, S. X., & Soukoreff, R. W. (1999). Text entry using soft keyboards. *Behaviour & Information Technology*, *18*, 235–244. doi:10.1080/014492999118995

MacKenzie, I. S. (2002a). *KSPC (keystrokes per character) as a characteristic of text entry techniques.* Paper presented at the MobileHCI 02: Fourth International Symposium on Human-Computer Interaction with Mobile Devices, Pisa, Italy.

MacKenzie, I. S. (2002b). *Mobile text entry using three keys.* Paper presented at the Proceedings of the second Nordic conference on Human-computer interaction, Aarhus, Denmark.

MacKenzie, I. S., & Soukoreff, R. W. (2002). *A model of two-thumb text entry.* Paper presented at the Graphics Interface 2002.

MacKenzie, I. S., & Soukoreff, R. W. (2003). *Phrase sets for evaluating text entry techniques.* Paper presented at the ACM Conference on Human Factors in Computing Systems – CHI 2003, New York, USA.

MacKenzie, I. S., Kober, H., Smith, D., Jones, T., & Skepner, E. (2001). *LetterWise: prefix-based disambiguation for mobile text input* Paper presented at the 14th annual ACM symposium on User interface software and technology Orlando, USA.

MacKenzie, I. S., Nonnecke, R. B., McQueen, C., Riddersma, S., & Meltz, M. (1994). *A comparison of three methods of character entry on pen-based computers.* Paper presented at the Factors and Ergonomics Society 38th Annual Meeting, Santa Monica, USA.

MacMillan, D., Morrison, A., Brown, O., Hall, M., & Chalmers, M. (2010) Further into the Wild: Running Worldwide Trials of Mobile Systems. Proc. Pervasive 2010, 210-17, http://dx.doi.org/10.1007/978-3-642-12654-3_13

Madden, M., & Jones, S. (2008). *Networked workers*. A report of Pew Internet & American Life Project, September 24. Retrieved (4/11/2008) from http://www.pewinternet.org/pdfs/PIP_Networked_Workers_FINAL.pdf

Madge, C., & Harrisson, T. (1939). *Britain by Mass-observation: The Book*. Penguin Books.

Maehr, W. (2007). *User Experience of the Mobile Internet*. Unpublished master thesis, Chalmers TH, Gothenburg, Sweden. www.t2i.se.

Maguire, M. (2001). Context of use within usability activities. *International Journal of Human-Computer Studies*, *55*, 453–483. doi:10.1006/ijhc.2001.0486

Mahlke, S. 2006. Studying user experience with digital audio players, submitted to *ICEC2006, 5th International Conference on Entertainment Computing*, 20-22 September, Cambridge.

Maitland, J., Sherwood, S., Barkhuus, L., Anderson, I., Hall, M., Brown, B., et al. (2006) Increasing the Awareness of Daily Activity Levels with Pervasive Computing. In Bardram, J., E., Chachques, J., C. & Varshney, U. (Eds.) *Pervasive Computing Technologies for Healthcare* (pp.1-9) Innsruck: IEEE.

Mallat, N., Rossi, M., Tuunainen, V. K., & Öörni, A. (2009). The impact of use context on mobile services acceptance: the case of mobile ticketing. *Information & Management*, *46*, 190–195. doi:10.1016/j.im.2008.11.008

Mankoff, J., & Abowd, G. D. (1998). *Cirrin: a word-level unistroke keyboard for pen input.* Paper presented at the 11th Annual ACM Symposium on User interface Software and Technology: UIST ‘98., San Francisco, USA.

Mankoff, J., Dey, A. K., Hsieh, G., Kientz, J., Lederer, S., & Ames, M. (2003). Heuristic evaluation of ambient displays. In *Proceedings of CHI 2003*, (pp. 169-176), ACM Press.

Manktelow, N. (2000). One wireless viewpoint: ‘WAP is crap’ In http://news.zdnet.com/2100-9595_22-108667.html?legacy=zdnn

Marino, A., & Carrubba, S. (2009). The effects of mobile-phone electromagnetic fields on brain electrical activity: A critical analysis of the literature. *Electromagnetic Biology and Medicine*, *28*(3), 250–274.

Markkula, G., Kutila, M., & Engström, J. (2005). Online Detection of Driver Distraction - Preliminary Results from the AIDE Project, Proceedings of International Truck & Bus Safety & Security Symposium Alexandria, Virginia, USA, 14 - 16 November 2005.

Mathieson, K., Peacock, E., & Chin, W. W. (2001). Extending the Technology Acceptance Model: the influence of perceived user resources. *The Data Base for Advances in Information Systems*, *32*(3), 86–112.

Matias, E., MacKenzie, I. S., & Buxton, W. (1996). One-handed touch typing on a QWERTY keyboard. *Human-Computer Interaction*, *11*(1), 1–27. doi:10.1207/s15327051hci1101_1

Mattes, S. (2003). The Lane Change Task as a Tool for driver Distraction Evaluation. IHRA-ITS Workshop on Driving Simulator Scenarios, October 2003 - Dearborn, Michigan. Available at: www. nrd.nhtsa.dot.gov/IHRA/ITS/MATTES.pdf

Mattila, E., Pärkkä, J., Hermersdorf, M., Kaasinen, J., Samposalo, K., & Vainio, J. (2008). Mobile diary for wellness management – Results on usage and usability in two user studies. *IEEE Transactions on Information Technology in Biomedicine*, *12*(4), 501–512. doi:10.1109/TITB.2007.908237

Mattila, E. (2010). *Design and evaluation of a mobile phone diary for personal health management.* Doctoral dissertation. VTT Publications 742. Espoo: VTT.

Maunder, A., Marsen, G., & Harper, R. (2007). Creating and Sharing Multi-media Packages Using Large Situated Public Displays and Mobile Phones. In *Proceedings of the MobileHCI 2007 Conference* (pp. 188-191). ACM Press.

Mayfield, B. (2007). *Selected References: Family Meals*. Purdue University, Center for Families. Retrieved (4/11/2008) from http://www.cfs.purdue.edu/CFF/documents/promoting_meals/mealtimereferences.pdf

McGuire, R. (2007). *On Kelly Goto's Gotomobile*. http://www.gotomobile.com/archives/mobile-20-fireside-chat

Meijer, P. B. L. (1992). An experimental system for auditory image representations. *IEEE Transactions on Bio-Medical Engineering*, *39*(2), 112–121. doi:10.1109/10.121642

Meloan, S. (2003). Toward a Global "Internet of Things". Sun Developer Network (SDN). Available at: http://java.sun.com/developer/technicalArticles/Ecommerce/rfid/.

Metcalfe, R. (1995). Metcalfe's law: A network becomes more valuable as it reaches more users. *InfoWorld*, *17*(53), 2.

Michon, J. A. (1985). A critical view of driver behaviour models. In Evans, L., & Schwing, R. S. (Eds.), *Human behaviour and traffic safety*. NY: Plenum Press.

Mihalic, K. (2008). Widgetization of Mobile Internet Experience. In *Mobile Internet User Experience Workshop, 2008.*http://wiki.research.nokia.com/images/7/71/Mihalic.pdf

Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1994). Augmented Reality: A class of displays on the reality-virtuality continuum. In *Proceedings of Telemanipulator and Telepresence Technologies* (pp. 282-292). Boston: SPIE.

Ministry for Foreign Affairs of Finland - Department for Communication and Culture/Unit for Public Diplomacy. (2009) *Virtual Finland – Your Window on Finland*. Retrieved February 5, 2009, from http://finland.fi/.

Mizobuchi, S., Chignell, M., & Newton, D. (2005). Mobile text entry: Relationship between walking speed and text input task difficulty. In *Proceedings of ACM MobileHCI'05* (pp. 122-128), ACM.

Mobile Internet Report. (2009). *Morgan Stanley.* Retrieved September 28, 2010, from http://www.morganstanley.com/institutional/techresearch/pdfs/2SETUP_12142009_RI.pdf

Molich, R., & Nielsen, J. (1990). Improving a human-computer dialogue. *Communications of the ACM*, *33*(3), 338–348. doi:10.1145/77481.77486

Molich, R. (2000). *Usable Web Design (In Danish)*: Ingeniøren|bøger.

Monk, A., Carroll, J., Parker, S., & Blythe, M. (2004). Why are mobile phones so annoying? *Behaviour & Information Technology*, *23*(1), 33–41. doi:10.1080/01449290310001638496

Monk, A., Brant, J., Wright, P., & Robinson, J. (2004). *CUHTec: the Centre for Usable Home Technology.* In CHI '04 extended abstracts on Human factors in computing systems. Vienna, Austria, 1073-1074

Moore, E. (2007). *Content Transformation* [OpenWave]. Retrieved October 22, 2007, from http://mobilemonday.org.uk/ [accessed 2007, 10/22]

Morrison, A., Reeves, S., McMillan, D., & Chalmers, M. (2010). Experiences of Mass Participation in Ubicomp Research. [Copenhagen, Denmark.]. *UbiComp*, *2010*(Sept), 26.

Morrison, A., Tennent, P., & Chalmers, M. (2006). Coordinated visualisation of video and system log data. In *Proceedings of the 4th International Conference on Coordinated and Multiple Views in Exploratory Visualization*, London (UK).

Morrison, A., Tennent, P., Williamson, J., & Chalmers, M. (2007). Using Location, Bearing and Motion Data to Filter Video and System Logs. In *Proceedings of the 5th International Conference on Pervasive Computing* (pp. 109-126), Toronto.

Müller, J., Jentsch, M., Kray, C., & Krüger, A. (2008). Exploring factors that influence the combined use of mobile devices and public displays for pedestrian navigation. In *Proceedings of NordiCHI 2008*. ACM Press. doi:10.1145/1463160.1463194

Müller, J., Paczkowski, O., & Krüger, A. (2007). Situated public news & reminder displays. In *Proceedings of AmI 2007*, (pp. 248-265), Springer. Norman, D. (1999). Affordances, convention, and design. *Interaction*, *6*(3), 38–43.

Muller, M. J., & McClard, A. (1995). Validating an extension to participatory heuristic evaluation: Quality of work and quality of work life. In *Proceedings of the Conference on Human Factors in Computing Systems - CHI'95* (pp. 115-116). ACM Press.

Myers, B. A. (1998). A brief history of human-computer interaction technology. *Interaction*, *5*(2), 44–54. doi:10.1145/274430.274436

Naaman, M., Nair, R., & Kaplun, V. (2008). *Photos on the Go: A Mobile Application Case Study*. In Proceedings of CHI 2008.

Naaman, M., Song, Y., Paepcke, A., & Garcia-Molina, H. (2004). *Automatic organization for digital photographs with geographic coordinates*. Proceedings of the 4th ACM/IEEE-CS joint conference on Digital libraries, Tuscon, AZ, USA.

Nah, F. F.-H., Siau, K., & Sheng, H. (2005). The value of mobile applications: a utility company study. *Communications of the ACM*, *48*(2), 85–90. doi:10.1145/1042091.1042095

Naismith, L., Lonsdale, P., Vavoula, G., & Sharples, M. (2004). *Literature Review in Mobile Technologies and Learning*. Bristol: FutureLab.

National Opinion Poll. (2001). Half of 7–16s have a mobile phone, *NOP Research Group Internet Surveys,* (Vol. 29 January).

National Statistics. (2008). *More pensioners than under-16's for first time ever*. Retrieved (3/11/08) from http://www.statistics.gov.uk/cci/nugget.asp?ID=949.

Nichols, S., & Patel, H. (2002). Health and safety implications of virtual reality: A review of empirical evidence. *Applied Ergonomics*, *33*(3), 251–271. doi:10.1016/S0003-6870(02)00020-0

Nielsen, J. (1994b). *Usability Engineering*. Morgan Kaufmann Publishers.

Nielsen, J. (1994a). Enhancing the explanatory power of usability heuristics. In *Proceedings of the Conference on Human Factors in Computing Systems - CHI'94* (pp. 152-158). ACM Press.

Nielsen, J. (2009). Alertbot February 17, 2009. Mobile Web 2009 = Desktop Web 1998. http://www.useit.com/alertbox/mobile-usability.html

Nielsen, J., & Molich, R. (1990). Heuristic evaluation of user interfaces. In *Proceedings of the Conference on Human Factors in Computing Systems - CHI'90* (pp. 249-256). ACM Press.

Nokia Press Release. (2008). *Multifunctional Mobiles Make the World Go Round: Results of Nokia Nseries Study Reveal Widespread Consumer Demand for Digital Convergence*. Retrieved from April 4, 2008, from http://www.nokia.com/A4136001?newsid=1054096.

Norman, D. A. (2002). *The Design of Everyday Things*: Basic Books. Norman, D. A., & Fisher, D. (1982). Why Alphabetic Keyboards Are Not Easy to Use: Keyboard Layout Doesn't Much Matter. *The Journal of the Human Factors Society*, *25*(5), 509–519.

Norman, D. A. (1998). *The Invisible Computer*. Cambridge, MA: MIT Press.

Norman, D. (2004). *Emotional Design: Why We Love (or Hate) Everyday Things*. New York: Basic Books.

Norman, D. (2007). The next UI breakthrough: command lines. *Interactions* XIV.3 - May / June, 2007

Nowakowski, C., Utsui, Y., & Green, P. (2000). Navigation system evaluation: The Effects of Driver Workload and Input Devices on Destination Entry Time and Driving Performance and Their Implications to the SAE Recommended Practice. Technical Report UMTRI-2000-20, The University of Michigan Transportation Research Institute, USA.

NTT DoCoMo. (2007). *Audio Barcode*. Available at: http://www.nttdocomo.com/technologies/future/audio/index.html.

NTT DoCoMo. (2010). *Osaifu-Keitai*. Available at: http://www.nttdocomo.com/services/osaifu/index.html.

Nylander, S., Lundquist, T., & Brännström, A. (2009). At Home and with Computer Access – Why and Where People Use Cell Phones to Access the Internet. In *Proceedings of the 27th international conference on Human factors in computing systems* (pp. 1639-1642). New York: ACM.

O'Neill, E., Thompson, P., Garzonis, S., & Warr, A. (2007). Reach Out and Touch: Using NFC and 2D Barcodes for Service Discovery and Interaction with Mobile Devices. In LaMarca, A. (Eds.), *PERVASIVE 2007, LNCS 4480* (pp. 19–36). Berlin, Heidelberg: Springer-Verlag.

Oliver, K. J., & Burnett, G. E. (2008). Learning-oriented vehicle navigation systems: A preliminary investigation in a driving simulator, In Proceedings of ACM Mobile HCI conference, To be held in Amsterdam, September, 2008.

Olsson, T., Soronen, H., & Väänänen-Vainio-Mattila, K. (2008). *User needs and design guidelines for mobile services for sharing digital life memories*. In Proceedings of the 10th international conference on Human computer interaction with mobile devices and services, pages 273–282. New York: ACM.

Oulasvirta, A., Tamminen, S., Roto, V., & Kuorelahti, J. (2005). Interaction in 4-second bursts: The fragmented nature of attentional resources in mobile HCI. *Proceedings of CHI 2005* (pp. 919-928). New York: ACM Press.

Paananen, V-M., Kolari, J., & Veistola P. (2000). *WAP ja Mobiili tulevaisuus*. Gummerus Jyväskylä 2000.

Palen, L., & Salzman, M. (2007). Voicemail diary studies for naturalistic data capture under mobile conditions. In *Proceedings from the 2002 ACM conference on computer supported cooperative work* (pp. 87-95). New York: ACM.

Pardo, S., Vetere, F., & Howard, S. (2005). *Broadening Stakeholder Involvement in UCD: Designers Perspectives on Child Centred Design.* Paper presented at the OZCHI 2005, Canberra, Australia.

Parkes, A. M. (1991). Data capture techniques for RTI usability evaluation. In *Advanced telematics in road transport - the DRIVE conference* (*Vol. 2*, pp. 1440–1456). Amsterdam: Elsevier Science Publishers B.V.

Pauty, J., Couderc, J., & Banâtre, M. (2005). *Using context to navigate through a photo collection*. In Proc. MobileHCI.

Pavlovych, A., & Stuerzlinger, W. (2004). *Model for non-expert text entry speed on 12-button phone keypads.* Paper presented at the CHI '04: SIGCHI Conference on Human Factors in Computing Systems, Vienna, Austria.

Payne, T., David, E., Jennings, N. R., & Sharifi, M. (2006). Auction mechanisms for efficient advertisement selection on public displays. In [IOS Press.]. *Proceedings of ECAI*, *2006*, 285–298.

Perlin, K. (1998). *Quikwriting: continuous stylus-based text entry.* Paper presented at the 11th Annual ACM Symposium on User interface Software and Technology: UIST '98, San Francisco, USA.

Peters, G. A., & Peters, B. J. (2002). *Automotive vehicle safety*. London: Taylor and Francis. doi:10.1201/9780203166307

Peters, O. B., & Allouch, S. (2005). Always connected: A longitudinal field study of mobile communication. [Washington, DC: Elsevier.]. *Telematics and Informatics*, *22*(3), 239–256. doi:10.1016/j.tele.2004.11.002

Petrie, H., Furner, S., & Strothotte, T. (1998). Design lifecycles and wearable computers for users with disabilities. In *Proceedings of the First workshop on human-computer interaction with mobile devices*, Glasgow, UK.

Pettitt, M. A., Burnett, G. E., Bayer, S., & Stevens, A. (2006). Assessment of the occlusion technique as a means for evaluating the distraction potential of driver support systems. *IEE Proceedings in Intelligent Transport Systems*, *4*(1), 259–266. doi:10.1049/ip-its:20060027

Pettitt, M. A., Burnett, G. E., & Karbassioun, D. (2006). Applying the Keystroke Level Model in a driving context. In Proceedings of the Ergonomics Society Annual conference, Bust, P.D. (ed), Taylor & Francis, Contemporary Ergonomics 2006, pp. 219-223.

Pettitt, M. A., Burnett, G. E., & Stevens, A. (2007) An extended Keystroke Level Model (KLM) for predicting the visual demand of in-vehicle information systems, To appear in Proceedings of the ACM Computer-Human Interaction (CHI) conference, To be held San Jose, May 2007.

Piaget, J. (1970). *Science of Education and the psychology of the child*. New York: Orion Press.

Pigeau, A., & Gelgon, M. (2005). *Building and tracking hierarchical geographical & temporal partitions for image collection management on mobile devices*. In Proc., MULTIMEDIA 2005. ACM Press (2005), p. 141-150.

Pikovsky, A., Rosenblum, M., & Kurths, J. (2001). *Synchronization: A universal concept in nonlinear sciences*. Cambridge University Press. doi:10.1017/CBO9780511755743

Pirhonen, A., Brewster, S. A., & Holguin, C. (2002). Gestural and Audio Metaphors as a Means of Control for Mobile Devices. In *Proceedings of ACM CHI 2002* (pp. 291-298), Minneapolis, MN: ACM Press Addison Wesley.

Platzer, E. (2009). A Critical Review of User Acceptance Research in the Area of Mobile Services. *Libri*, *59*, 213–227. doi:10.1515/libr.2009.019

Platzer, E., & Petrovic, O. (2010). Development of technology acceptance research for mobile services. *Proceedings of MIPRO*, *2010*, 1154–1159.

Po, S. (2003). *Mobile usability testing and evaluation*. Master's thesis, University of Melbourne, Australia.

Po, S., Howard, S., Vetere, F., & Skov, M. B. (2004, September, 13-16). *Heuristic Evaluation and Mobile Usability: Bridging the Realism Gap.* Paper presented at the Mobile Human-Computer Interaction (MobileHCI'2004), Glasgow, UK.

Powers, W. T. (1973). *Behavior: The Control of Perception*. Aldine de Gruyter.

Preece, J., Rogers, Y., & Sharp, H. (2007). *Interaction design: Beyond human-computer interaction*. Hoboken, NJ: John Wiley & Sons Ltd.

Prensky, M. (2004). *What Can You Learn from a Cell Phone? – Almost Anything*. Available: www.marcprensky.com/writing/Prensky-What_Can_You_Learn_From_a_Cell_Phone-FINAL.pdf, [2008, 12th November].

Proschowsky, M., Schultz, N., & Jacobsen, N. E. (2006). *An intuitive text input method for touch wheels.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems: CHI '06, Montréal, Canada.

Ramachandran, V. S., & Blakeslee, S. (1998). *Phantoms in the brain*. London: Fourth Estate.

Rasmussen, K. B., Castelluccia, C., Heydt-Benjamin, T., & Capkun, S. (2009). Proximity-based access control for implantable medical devices.In *Proceedings, ACM CCS'09*, 410-419

Rayner, J. (1999). 'Why this NSPCC advert is harmful to children'. *The Observer,* 12.

Read, J. C. (2005). The ABC of CCI. *Interfaces*, *62*, 8–9.

Read, J. C. (2007). A study of the usability of handwriting recognition for text entry by children. *Interacting with Computers*, *19*(1), 57–69. doi:10.1016/j.intcom.2006.08.009

Read, J. C., Gregory, P., MacFarlane, S. J., McManus, B., Gray, P., & Patel, R. (2002). *An Investigation of Participatory Design with Children - Informant, Balanced and Facilitated Design.* Paper presented at the Interaction Design and Children, Eindhoven.

Read, J. C., MacFarlane, S. J., & Gregory, A. G. (2004). *Requirements for the Design of a Handwriting Recognition Based Writing interface for Children.* Paper presented at the Interaction Design and Children 2004, Maryland, US.

Reed, M. P., & Green, P. A. (1999). Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialling task. *Ergonomics*, *42*(8), 1015–1037. doi:10.1080/001401399185117

Reichl, P., Schatz, R., Fröhlich, P., Dantcheva, A., & Baillie, L. (2007). The LiLiPUT prototype: A wearable lab environment for user tests of mobile telecommunications applications, Experience report. *Proceedings CHI'07,* San Jose, CA, pp. 1833-1838.

Reijnveld, K., de Looze, M., Krause, F., & Desmet, P. (2003). Measuring the Emotions Elicited by Office Chairs. In *Proceedings of the International Conference on Designing Pleasurable Products and Interfaces* (pp. 6-10). New York: ACM.

Rekimoto, J., & Ayatsuka, Y. (2000). CyberCode: designing augmented reality environments with visual tags. In *Proceedings of DARE 2000 on Designing Augmented Reality Environments* (pp. 1-10). New York: ACM.

Reuters. (2009). *French exec blames email for staff stress*. Retrieved (24/9/2010) from http://www.reuters.com/article/idUSTRE58N6ES20090925.

Rheingold, H. (2005). *Farmers, Phones and Markets: Mobile Technology In Rural Development*. Retrieved October 24, 2007 from http://www.thefeaturearchives.com/topic/ Technology/Farmers__Phones_and_Markets__Mobile_Technology_In_Rural_Development.html

Rice, B. (1982). The Hawthorne defect: Persistence of a flawed theory. *Psychology Today*, *16*(2), 70–74.

Riekki, J., Salminen, T., & Alakärppä, I. (2006). Requesting Pervasive Services by Touching RFID Tags. *IEEE Pervasive Computing / IEEE Computer Society [and] IEEE Communications Society*, *5*(1), 40–46. doi:10.1109/MPRV.2006.12

Rigas, D., & Alty, J. (2005). The rising pitch metaphor: An empirical study. *International Journal of Human-Computer Studies*, *62*(1), 1–20. doi:10.1016/j.ijhcs.2004.06.004

Robinson, M., & Clore, G. (2002). Belief and feeling: Evidence for an accessibility model of emotional self-report. *Psychological Bulletin*, *128*(6), 934–960. doi:10.1037/0033-2909.128.6.934

Robinson, B. A., & Longe, M. R. (2000). USA Patent No. 6,801,190 / 7,088,345.

Rodden, K., & Wood, K. (2003). *How do people manage their digital photographs?* Proceedings of the SIGCHI conference on Human factors in computing systems, Ft. Lauderdale, Florida, USA.

Rogers, E. M. (1995). *The diffusion of innovations* (4th ed.). New York: Free Press.

Rogers, Y., Connelly, K., Tedesco, L., Hazlewood, W., Kurtz, A., & Hall, R. (2007). Why it's worth the hassle: The value of in-situ studies when designing ubicomp. In [Springer.]. *Proceedings of Ubicomp*, *2007*, 336–353.

Ross, T., May, A. J., & Grimsley, P. J. (2004). Using traffic light information as navigation cues: implications for navigation system design. *Transportation Research Part F: Traffic Psychology and Behaviour*, *7*(2), 119–134. doi:10.1016/j.trf.2004.02.004

Ross, T., Vaughan, G., Engert, A., Peters, H., Burnett, G. E., & May, A. J. (1995). *Human factors guidelines for information presentation by route guidance and navigation systems (DRIVE II V2008 HARDIE, Deliverable 19)*. Loughborough, UK: HUSAT Research Institute.

Roto, V. (2006). *Web Browsing on Mobile Phones - Characteristics of User Experience.* Doctoral dissertation, TKK Dissertations 49, Helsinki University of Technology, Finland. http://research.nokia.com/people/virpi_roto/dissertation.html

Roto, V. Oulasvirta, A., Haikarainen, T. Kuore-lathi, J., Lehmuskallio, H. & Nyyssonen, T. (2004). Examining mobile phone use in the wild with quasi-experimentation. *HIIT Technical report*, downloaded from http://www.i-cherubini.it/mauro/blog/2008/10/16/examining-mobile-phone-use-in-the-wild-with-quasi-experimentation/ 12 December, 2008.

Roto, V., & Kaasinen, E. (2007). *Workshop on Mobile Internet User Experience.* Retrieved February 24, 2009, from http://wiki.research.nokia.com/index.php/MobileInternetUX-2007.

Roto, V., & Kaasinen, E. (2008). *2nd International Workshop on Mobile Internet User eXperience (MIUX'08).* Retrieved February 24, 2009, from http://wiki.research.nokia.com/index.php/MobileInternetUX-2008.

Roto, V., & Kaikkonen, A. (2003). Perception of Narrow Web Pages on a Mobile Phone. *In proceedings of HFT 2003*

Roto, V., & Rautava, M. (2008). *User Experience Elements and Brand Promise*. International Engagability & Design Conference (Idec4), in conjunction with NordiCHI'08 conference, Lund, Sweden.

Roto, V., Geisler, R., Kaikkonen, A., Popescu, A., & Vartiainen, E. (2006). Data Traffic Costs and Mobile Browsing User Experience. In *MobEA IV workshop on Empowering the Mobile Web*.

Rubicon. (2008). The Apple iPhone: Successes and Challenges for the Mobile Industry. Retrieved 5th January, 2009, from http://rubiconconsulting.com/downloads/whitepapers/Rubicon-iPhone_User_Survey.pdf

Rukzio, E., Boll, G., Leichtenstern, K., & Schmidt, A. (2007). Mobile interaction with the real world: An evaluation and comparison of physical mobile interaction techniques. In [Springer.]. *Proceedings of AmI*, *2007*, 1–18.

Rukzio, E., Schmidt, A., & Hussmann, H. (2004). Physical Posters as Gateways to Context-aware Services for Mobile Devices, In *Sixth IEEE Workshop on Mobile Computing Systems and Applications (WMCSA 2004)* (pp. 10-19). Washington DC: IEEE Computer Society.

Sadato, N., Okada, T., Honda, M., & Yonekura, Y. (2002). Critical period for cross-modal plasticity in blind humans: A functional MRI study. *NeuroImage*, *16*, 389–400. doi:10.1006/nimg.2002.1111

Sade, S., & Finland, O. N. (2002). Mobile ease-of-use and desirability through user-centered design. In *Proceedings of the SSGRR-2002 Summer Conference on Infrastructure for e-Business, e-Education, e-Science, and e-Medicine*.

Sandnes, F. E. (2005). *Evaluating mobile text entry strategies with finite state automata.* Paper presented at the MobileHCI 05: 7th international Conference on Human Computer interaction with Mobile Devices and Services, Salzburg, Austria.

Sarker, S., & Wells, J. D. (2003). Understanding mobile handheld device use and adoption. *Communications of the ACM*, *46*(12), 35–40. doi:10.1145/953460.953484

Sarvas, R., Oulasvirta, A., & Jacucci, G. (2005). Building social discourse around mobile photos: a systemic perspective. In *Proc., MobileHCI 2005, 111* (pp. 31–38). New York: ACM Press.

Schilit, B., Trevor, J., Hilbert, D., Res, I., & Seattle, W. (2002). Web interaction using very small Internet devices. *Computer*, *10*(35), 37–45. doi:10.1109/MC.2002.1039516

Schmiedl, G., Seidl, M., & Temper, K. (2009). Mobile Phone Web Browsing – A Study on Usage and Usability Of The Mobile Web. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services (article 70).* New York: ACM.

Scholtz, J., & Consolvo, S. (2004). Toward a Framework for Evaluating Ubiquitous Computing Applications. *Pervasive Computing*, *3*(2), 82–88. doi:10.1109/MPRV.2004.1316826

Schulte-Mecklenbeck, M., & Huber, O. (2003). Information search in the laboratory and on the Web: With or without an experimenter. *Behavior Research Methods, Instruments, & Computers*, *35*(2), 227–235. doi:10.3758/BF03202545

Scott, J., Brown, L. M., & Molloy, M. (2009). Mobile device interaction with force sensing. *Proceedings pervasive computing*. *LNCS*, *5538*, 133–150.

Sears, A., & Zha, Y. (2003). Data Entry for Mobile Devices Using Soft Keyboards: Understanding the Effects of Keyboard Size and User Tasks. *International Journal of Human-Computer Interaction PU - Lawrence Erlbaum Associates*. *Inc.*, *16*(2), 163–184.

Selwyn, N. (2003). Schooling the mobile generation: the future for schools in the mobile-networked society. *British Journal of Education*, *24*(2), 131–144. doi:10.1080/01425690301905

Shannon, C. (1951). Prediction and Entropy of Printed English. *The Bell System Technical Journal*, *30*, 50–64.

Share Online. (2010). Retrieved September 1, 2010, from http://europe.nokia.com/support/learn-how/sharing-and-blogging.

Shneiderman, B. (1998). *Designing the user-interface* (3rd ed.). Addison Wesley.

Shneiderman, B., Bederson, B., & Drucker, S. (2006). Find that photo!: interface strategies to annotate, browse, and share. *Communications of the ACM*, *49*(4).

ShoZu. (2010). Retrieved September 1, 2010, from http://www.shozu.com/.

Silfverberg, M., MacKenzie, I. S., & Korhonen, P. (2000). *Predicting text entry speed on mobile phones.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems (CHI'00), The Hague, The Netherlands.

Simeral, E.J., & Branaghan, R.J. (1997). A Comparative Analysis of Heuristic and Usability Evaluation Methods. *STC Proceedings (1997).*

Simon, R., & Fröhlich, P. A. (2007). Mobile Application Framework for the Geospatial Web. In *Proceedings WWW2007* (pp. 381-389).

Simpson, R., LoPresti, E., Hayashi, S., Guo, S., Ding, D., & Ammer, W. (2005). A prototype power assist wheelchair that provides for obstacle detection and avoidance for those with visual impairments. *Journal of Neuroengineering and Rehabilitation*, *2*, 2–30. doi:10.1186/1743-0003-2-30

Skog, T. (2006) *Ambient Information Visualization* (Licenciate Thesis, IT-university of Göteborg, 2006).

Smith, H., Rogers, Y., & Brady, M. (2003). *Managing one's social network: does age make a difference?* Paper presented at the Interact 2003, Zurich.

Society of Automotive Engineers (SAE). (2000). *Navigation and Route Guidance Function Accessibility While Driving (SAE Recommended Practice J2364), version of January 20th, 2000*. Warrendale, PA: Society of Automotive Engineers.

Sohn, T., Li, K., Griswold, G., & Hollan, J. (2008). A diary study of mobile information needs. In *CHI 2008 proceedings: Special interest group on computer-human interaction conference* (pp. 433-442). New York: ACM.

Sokala, H. (2002). *Maailma taskussa- kuinka matkapuhelimella tienattiin ja tuhottiin miljardeja.* Otava, Keuruu 2002.

Soukoreff, R. W., & MacKenzie, I. S. (2002). *Using Fitts' law to model key repeat time in text entry models.* Paper presented at the Graphics Interface 2002.

Sounders, S., & Theurer, T. (2008). *High Performance Web Sites 14 rules for faster-loading pages Yahoo guidelines*, http://www.techpresentations.org/High_Performance_Web_Pages

Srinivisan, R. (1999). Overview of some human factors design issues for in-vehicle navigation and route guidance systems. Transportation Research Record 1694 (paper no. 99-0884), (Washington, DC: National Academy Press).

Stanford, V. (2002). Pervasive health care applications face tough security challenges. *Pervasive Computing*, *1*(2), 8–12. doi:10.1109/MPRV.2002.1012332

Stevens, A., Bygrave, S., Brook-Carter, N., & Luke, T. (2004). *Occlusion as a technique for measuring in-vehicle information system (IVIS) visual distraction: a research literature review. Transport Research Laboratory (TRL) report no. TRL609. TRL*. Berkshire, United Kingdom: Crowthorne.

Strachan, S., & Murray-Smith, R. (2009). Bearing-based selection in mobile spatial interaction. *Personal and Ubiquitous Computing*, *13*(4), 265–280. doi:10.1007/s00779-008-0205-4

Strategy Analytics. (2008, November). *Mobile Internet: Global Market Forecast.*

Suri, J. F. (2005, November). *Thoughtless Acts.* San Francisco, USA: Chronicle Books.

Svanæs, D., Alsos, O. A., & Dahl, Y. (2008). (in press). Usability testing of mobile ICT for clinical settings: Methodological and practical challenges. *International Journal of Medical Informatics*.

Swindells, C., Inkpen, K. M., Dill, J. C., & Tory, M. (2002). That one there! Pointing to establish device identity. In *Proceedings of the 15th Annual ACM Symposium on User interface Software and Technology* (pp. 151-160). New York: ACM.

Swisscom. (2007). *Mobile market research, December 2007.*

Syvanen, A., Beale, R., Sharples, M., Ahonen, M., & Lonsdale, P. (2005, November 28-30th). *Supporting Pervasive Learning Environments: Adaptability and Context Awareness in Mobile Learning (poster).* Paper presented at the IEEE International Workshop on Wireless and Mobile Technologies in Education (WMTE 2005), Tokushima, Japan.

Taylor, N., Cheverst, K., Fitton, D., Race, N., Rouncefield, M., & Graham, C. (2007). Probing communities: Study of a village photo display. In [ACM Press.]. *Proceedings of OzCHI*, *2007*, 17–24. doi:10.1145/1324892.1324896

Taylor, C., Samuels, N., & Ramey, J. (2009). Always On: A Framework for Understanding Personal Mobile Web Motivations, Behaviors, and Contexts of Use. [IJMHCI]. *International Journal of Mobile Human Computer Interaction*, *1*(4), 24–41. doi:10.4018/jmhci.2009062603

Taylor, A. S., & Harper, R. (2002). *Age-old Practices in the "New World": A study of gift giving between teenage mobile phone users.* Paper presented at the CHI 2002, Minneapolis.

Taylor, C., Onicello, A., Somohano, S., Samuels, N., Whitaker, L., & Ramey, J. (2008). A framework for understanding mobile internet motivations and behaviors. In *CHI 2008 proceedings: Special interest group on computer-human interaction conference* (pp. 2679-2684). New York: ACM.

Teng, Tina. 6/7/10. *iSuppli Issues Fast Facts on Latest iPhone*. http://www.isuppli.com/Mobile-and-Wireless-Communications/News/Pages/iSuppli-Issues-Fast-Facts-on-Latest-iPhone.aspx. iSuppli Corp.

The New York Times. (2010). *France Télécom Needs 'Radical Change' After Suicides,* Report Says. Retrieved (27/9/2010) from http://www.nytimes.com/2010/03/09/technology/09telecom.html?_r=1&scp=3&sq=&st=nyt.

Theimer, M., Demers, A., & Welch, B. (1993). *Operating System Issues for PDAs*. In Proceedings of the Fourth Workshop on Workstation Operating Systems. IEEE.

Tijerina, L., Palmer, E., & Goodman, M. J. (1998). Driver workload assessment of route guidance system destination entry while driving. Technical Report UMTRI-96-30, The University of Michigan Transportation Research Institute, USA.

Times, N. F. C. (2010). *Sony Faces an Uncertain Market for its FeliCa Technology*. Available at: http://www.nfctimes.com/news/chart-article-contactless-e-money-japan-felica-chips.

Toffin, D., Reymond, G., Kemeny, A., & Droulez, J. (2003). Influence of steering wheel torque feedback in a dynamic driving simulator. In Proceedings of the Driving Simulation Conference North America 8-10 Oct 2003, Dearborn, USA.

Tornros, J. (1998). Driving behaviour in a real and a simulated road tunnel – A validation study. *Accident; Analysis and Prevention*, *30*(4), 497–503. doi:10.1016/S0001-4575(97)00099-7

Tractinsky, N., & Zmiri, D. (2006). Exploring attributes of skins as potential antecedents of emotion in HCI. In Fishwick, P. (Ed.), *Aesthetic computing* (pp. 405–421). Cambridge, MA: MIT Press.

Transport Canada (2006). R Occlusion Research. Presentation given to the AAM driver focus task force, Detroit June 2006.

Treen, C. (2009). *Usability evaluation in the mobile world: Will existing methods suffice?* MA Thesis, Department of Psychology, Carleton University, Ottawa, Canada.

Treiman, R., & Bourassa, D. C. (2000). The development of spelling skill. *Topics in Language Disorders*, *20*, 1–18. doi:10.1097/00011363-200020030-00004

Trivedi, B. (2010). *Sensory hijack: rewiring brains to see with sound*, New Scientist, 2773, August 14, downloaded from http://www.newscientist.com/article/mg20727731.500-sensory-hijack-rewiring-brains-to-see-with-sound.html?full=true, 6 October 2010

Tsai, J. Y., Kelley, P., Drielsma, P., Cranor, L., Hong, J., & Sadeh, N. (2009). Who's Viewed You? The Impact of Feedback in a Mobile Location Sharing System. *Proceedings of*, *CHI2009*, 2003–2012.

Tsimhoni, O., Smith, D., & Green, P. (2002). Destination entry while driving: Speech recognition versus a touch-screen keyboard. Technical Report UMTRI-2001-24, The University of Michigan Transportation Research Institute, USA.

Tufano, D. R. (1997). Automotive HUDs: The overlooked safety issues. *Human Factors*, *39*(2), 303–311. doi:10.1518/001872097778543840

Tufegdzic, Pamela. (8/10/10). *Cell Phone Gaming Soars as Consoles and Handhelds Sputter*. http://www.isuppli.com/Home-and-Consumer-Electronics/News/Pages/Cell-Phone-Gaming-Soars-as-Consoles-and-Handhelds-Sputter.aspx. iSupply Corp.

Turunen, M., & Hakulinen, J. Hella, J., Rajaniemi, J-P., Melto, A., Mäkinen, E., Rantala, J., Heimonen, T., Laivo, T., Soronen, H., Hansen, M., Valkama, P., Miettinen, T. & Raisamo, R.,(n.d.). Multimodal interaction with speech, gestures, and haptic feedback in a media center application, *Proceedings INTERACT'09*, 836-837.

Vaage, O. (2000). *Mediabruks undersøkelse*. Oslo: Statistics Norway.

Väänänen-Vainio-Mattila, K., Oksman, V., & Vainio, T. (2007). Exploring the User Experience Factors in Designing Successful Mobile Internet Services for Business Use. In *Mobile Internet User Experience Workshop, 2007.* http://research.nokia.com/events/miux.html

Väänänen-Vainio-Mattila, K., & Ruuska, S. (2000). Designing Mobile Phones and Communicators for Consumers' Needs at Nokia. In E. Bergman (Ed.), *Information Appliances and Beyond: Interaction Design for Consumer Products* (pp. 169-204). Morgan Kaufmann.

Välkkynen, P., Niemelä, M., & Tuomisto, T. (2006a). Evaluating Touching and Pointing with a Mobile Terminal for Physical Browsing. In *Proceedings of NordiCHI* (pp. 28–37). New York: ACM. doi:10.1145/1182475.1182479

Välkkynen, P., Tuomisto, T., & Korhonen, I. (2006b). Suggestions for Visualising Physical Hyperlinks. In Proceedings of Pervasive Mobile Interaction Devices Workshop (pp. 245-254). Berlin, Heidelberg: Springer.

Van Erp, J. B. F. (2005). Presenting directions with a vibrotactile torso display. *Ergonomics*, *48*(3), 302–313. doi:10.1080/0014013042000327670

Van House. N., Davis, M., Ames, M., Finn, M., & Viswanathan, V. (2005). *The uses of personal networked digital imaging: an empirical study of cameraphone photos and sharing*. In CHI '05 extended abstracts on Human factors in computing systems, pages 1853– 1856. New York: ACM.

van Veen, N. (2006). *Breaking The Mobile Internet's Low Adoption Spell*. Forrester Research.

van Veen, N. (2007). *Mobile Internet Pricing Strategies Mature.* Forrester Research.

Vartiainen, E., Kaasalainen, J., & Strandell, T. (2008). *Designing user experience for a mobile imaging application*. Proceedings of IADIS International Conference Interfaces and Human Computer Interaction, Amsterdam.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *Management Information Systems Quarterly*, *27*(3), 425–478.

Vetere, F., Howard, S., Pedell, S., & Balbo, S. (2003). Walking through mobile use: Novel heuristics and their application. In *Proceedings of the Conference of the Computer-Human Interaction Special Interest Group of the Human Factors and Ergonomics Society of Australia OZCHI2003*.

Video Research. (2002). *Mobile Phone Usage Situation*. Tokyo: Video Research.

Vogiazou, Y., Reid, J., Raijmakers, B., & Eisenstadt, M. (2006). A research process for designing ubiquitous social experiences. In Mørch, A., Morgan, K., Bratteteig, T., Ghosh, G., & Svanaes, D. (Eds.), *NordiCHI* (pp. 86–95). Oslo: ACM Press. doi:10.1145/1182475.1182485

W3C. (2008a). *Mobile Web Best Practices 1.0. Basic Guidelines.* W3C Recommendation 29 July 2008. Retrieved February 28, 2009, from http://www.w3.org/TR/mobile-bp/

W3C. (2008b). *W3C mobileOK Basic Tests 1.0.* W3C Recommendation 08 December 2008. Retrieved February 28, 2009, from http://www.w3.org/TR/mobileOK-basic10-tests/

W3C. (2009). *Mobile Web Application Best Practices.* Editors' Draft 01 January 2009. Retrieved February 28, 2009, from http://www.w3.org/2005/MWI/BPWG/Group/Drafts/BestPractices-2.0/ED-mobile-bp2-20090101

Wallen Warner, H. M., & Aberg, L. (2005). Why do drivers speed? In Underwood, G. (Ed.), *Traffic and transport psychology: theory and application* (pp. 505–511). Oxford, UK: Elsevier. doi:10.1016/B978-008044379-9/50195-3

Wang, H., & Wang, S. (2010). User Acceptance of Mobile Internet Based on the Unified Theory of Acceptance and Use of Technology: Investigating the Determinants and Gender Differences. *Social Behavior and Personality*, *38*(3), 415–426. doi:10.2224/sbp.2010.38.3.415

Wang, M., Xie, X., Ma, W., & Zhang, H. (2003). *MobiPicture: browsing pictures on mobile devices*. In Proc., MULTIMEDIA 2003. New York: ACM Press, p. 106-107.

Want, R., Hopper, A., Falcao, V., & Gibbons, J. (1992). The active badge location system. *Transactions on Information Systems*, *10*(1), 91–102. doi:10.1145/128756.128759

Want, R., Fishkin, K. P., Gujar, A., & Harrison, B. L. (1999). Bridging physical and virtual worlds with electronic tags. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems: the CHI is the Limit* (pp. 370-377). New York: ACM.

Ward, N. J., & Parkes, A. M. (1994). Head-up displays and their automotive application: An overview of human factors issues affecting safety. *Accident; Analysis and Prevention*, *26*(6), 703–717. doi:10.1016/0001-4575(94)90049-3

Ward, D. J., Blackwell, A. F., & MacKay, D. J. (2000). *Dasher - a data entry interface using continuous gestures and language models.* Paper presented at the 13th Annual ACM Symposium on User interface Software and Technology: UIST '00, San Diego, USA.

Waterson, S., Landay, J. A., & Matthews, T. (2002). *In the lab and out in the wild: remote web usability testing for mobile devices.* Paper presented at the CHI'02 conference on Human Factors in Computing Systems extended abstracts, Minneapolis, Minnesota, USA.

Week, W. (2008, September). *Gunning for the Hockey Stick*. Retrieved February 24, 2009, from http://www.wireless week.com/ Article- Gunning- Hockey- Stick.aspx

Weiser, M. (1991). The Computer for the 21st Century. *Scientific American*, *265*(3), 94–104. doi:10.1038/scientificamerican0991-94

Weisskirch, R. (2009). Parenting by Cell Phone: Parental Monitoring of Adolescents and Family Relations. *Journal of Youth and Adolescence*, *38*(8), 1123–1139. doi:10.1007/s10964-008-9374-8

Wharton, C., Rieman, J., Lewis, C., & Polson, P. (1994). The cognitive walkthrough method: A practitioner's guide. In Nielsen, J., & Mack, R. L. (Eds.), *Usability Inspection methods* (pp. 105–140). New York: John Wiley & Sons.

White, R. W., & Drucker, S. M. (2007). Investigating Behavioral Variability in Web Search. In *Proceedings WWW2007* (pp. 21-30).

Wickens, C. D. Lee, J.D., Liu, Y., and Becker, S.E.G. (2004). An Introduction to Human Factors Engineering (2nd Edition). New Jersey, USA: Pearson.

Wigdor, D., & Balakrishnan, R. (2003). *TiltText: using tilt for text input to mobile phones.* Paper presented at the 16th annual ACM Symposium on User Interface Software and Technology (UIST '03), New York, USA.

Wigdor, D., & Balakrishnan, R. A. (2004). *Comparison of consecutive and concurrent input text entry techniques for mobile phones.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems (CHI '04), New York, USA.

Wikman, A., Nieminen, T., & Summala, H. (1998). Driving experience and time-sharing during in-car tasks on roads of different width. *Ergonomics*, *41*(3), 358–372. doi:10.1080/001401398187080

Wilhelm, A., Takhteyev, Y., & Sarvas, R. Van House, N., Davis, M. (2004). *Photo annotation on a camera phone*. CHI '04 extended abstracts on Human factors in computing systems, Vienna, Austria.

Williams, M., Jones, O., Fleuriot, C., & Wood, L. (2005). *Children and emerging wireless technologies: investigating the potential for spatial practice.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems, Portland, Oregon, USA.

Williamson, J. (2006). *Continuous Uncertain Interaction.* PhD thesis, Dept. Computing Science, University of Glasgow.

Williamson, J., & Murray-Smith, R. (2005). *Dynamics and probabilistic text entry.* Paper presented at the Hamilton Summer School on Switching and Learning in Feedback systems.

Williamson, J., Murray-Smith, R., & Hughes, S. (2007). Shoogle: Multimodal Excitatory Interaction on Mobile Devices. In *Proceedings of ACM CHI 2007*, San Jose.

Wilson, C. E. (2006). Triangulation: the explicit use of multiple methods, measures, and approaches for determining core issues in product development. [-ff]. *Interaction*, *13*(6), 46. doi:10.1145/1167948.1167980

Wireless World Forum. (2005). *Survey of Mobile Phone Use*.

Yi, J. S., Choi, Y. S., Jacko, J. A., & Sears, A. (2005). Context awareness via a single device-attached accelerometer during mobile computing. In *Proceedings of ACM Mobile HCI 2005* (pp. 303-306).

Yoshii, H., Matsuda, M., Habuchi, C., Dobashi, S., Iwata, K., & Kin, N. (2002). *Keitai Denwa Riyou no Shinka to sono Eikyou*. Tokyo: Mobile Communications Kenkyuukai.

Young, K., Regan, M., & Hammer, M. (2003). Driver distraction: a review of the literature, Monash University Accident Research Centre, Report No. 206, November 2003.

Zhai, S., & Kristensson, P. (2003). *Shorthand writing on stylus keyboard.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems: CHI '03, Ft. Lauderdale, Florida, USA.

Zhang, J., Huang, J. & Chen, J. (2010). Empirical Research on User Acceptance of Mobile Searches. *Tsinghua Science and Technology,* 15,.*(2)*, 235-245.

Zhao, H., Plaisant, C., & Shneiderman, B. (2005). "I hear the pattern" – interactive sonification of geographical data patterns. *Proceedings CHI*, *05*, 1905–1908.

Zhao, H., Plaisant, C., Shneiderman, B., & Lazar, J. (2008). Data sonification for users with visual impairment: A case study with georeferenced data. *ACM Transactions on Computer-Human Interaction*, *15*(1), 4–28.

Zuverink, D. (2008). Beyond Browsers: Taking Mobile Applications Online. In *Mobile Internet User Experience Workshop, 2008.*http://wiki.research.nokia.com/images/9/92/Zuverink.pdf

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Sujan Shrestha is a research student from Brunel University, UK. His research focuses on improving user experience of mobile web browsing. Recent usability evaluations indicate that the biggest problems for mobile users are difficulties in finding what they were looking for. The aim of this ongoing research is to develop an adaptive method that will keep a consistent navigational structure of websites which will help people visualize their current location and options, and minimize guesswork.

Elizabeth Sillence is a senior lecturer in Psychology at Northumbria University in the UK and is also a member of the Psychology and Communication Technologies (PaCT) Lab. With a background in computer mediated communication and online communities her current research interests focus on trust and personalization in social technologies. She is involved in e-health and e-security research and has an interest in qualitative research methods. Elizabeth has published widely on the issues of trust and e-health and regularly presents her work at national and international conferences. As a mother of two young children she is both amazed and alarmed at their proficiency with technology.

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Elina Vartiainen works as Senior Researcher in User Experience with Nokia Research Center, Finland, where her work mainly consists of user research and interaction design. Her recent projects include the Minimap Web page visualization method (http://www.nokia.com/browser), currently used in the Web browser of Nokia S60 mobile phones, and Nokia Image Exchange (http://imageexchange.nokia.com/), an innovative solution for mobile photo sharing. She received a Doctor of Science degree in computer science from Helsinki University of Technology in 2009. The doctoral thesis introduced design implications for mobile user interfaces of Internet services.

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