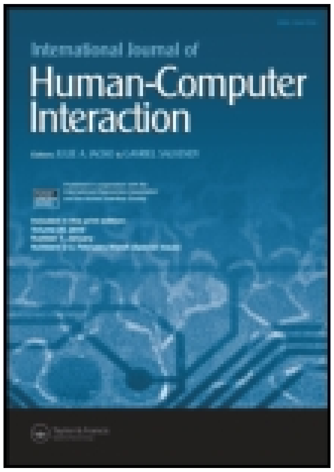

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Use and Design of Handheld Computers for Older Adults: A Review and Appraisal

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Use and Design of Handheld Computers for Older Adults: A Review and Appraisal

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This article presents a comprehensive literature review to investigate whether and why older adults accept handheld computers and how to design elderly-friendly handheld computers. Findings about acceptance, input devices, menu and functions, and output devices are summarized. First, older adults were under social pressure to use mobile phones, but they had low acceptance of advanced functions. Also, they had a different way to judge acceptance factors from younger adults. Second, older adults preferred the physical keyboard to the on-screen keyboard for text entry, whereas they preferred tapping the touch pad to the joystick and buttons for pointing tasks. Third, older adults had shallower mental representation of the mobile phone menus than younger adults. Navigation aids providing contextual information and large cognitive preview per screen could help them. Finally, recommended size and spacing for text and icons are presented.

1. INTRODUCTION

1.1. Objective and Significance

Handheld computers can help bridge the digital divide in this rapidly aging world. Current older adults did not grow up in the computer age, so many of them have not had computers. However, most older adults own mobile phones, which can provide access to information society without requiring prior computer knowledge. For example, using some applications on smartphones or tablets with a touch screen can be more intuitive and easier than on computers. Mobile phones also serve as a platform integrating many functions, such as navigation and e-books. These functions can enhance the mobility, independence, and autonomy of older adults. Therefore, handheld computers can open up new opportunities for older adults.

To design handheld computers for older adults, usability is the first challenge (Kang & Yoon, 2008; Kurniawan, 2006, 2008; Maguire & Osman, 2003; Massimi, Baecker, & Wu, 2007). Normally, older adults are not a targeted group of handheld computer users. Declined sensory-perceptual abilities, motor skills, and cognitive abilities make older adults sensitive to design defects. Usability problems with input devices, menu and functions, and output devices are stressed.

Some of these usability problems can be reduced through new technology, but it may also cause new problems. For example, touch screens can overcome mental problems with indirect input, but they also cause a new problem: When everything on the display can be touched, users cannot differentiate which part can be clicked and which part is pure text. Therefore, it is worthwhile to examine whether new technology works for older adults.

The second challenge, which draws less attention, is acceptance (Arning & Ziefle, 2006, 2007a, 2007b). Older adults are generally less open to new technology. There are many reasons for their resistance, and usability is only one of them. Even though the overall usability is improved, older adults are not necessarily accepting just for the sake of using it (Hanson, 2010). Therefore, it is important to place the devices in broader contexts, not only focusing on the devices. This will help practitioners deliver new applications of handheld computers to older adults.

This article reviews studies on older adults' acceptance and usability of handheld computers. It could serve as a reference for understanding acceptance before announcement of newer models of handheld computers. Also usability recommendations could enrich elderly-specific design and universal design.

1.2. Conceptual Model

This study surveys literature on the interaction between older adults and handheld computers. As Figure 1 shows, this study analyzes acceptance of older adults and usability of handheld computers. To be more specific, this study aims to answer the following two research questions:

RQ1: Whether and why do older adults use or not use handheld computers?
RQ2: What features of handheld computers are or are not elderly friendly?

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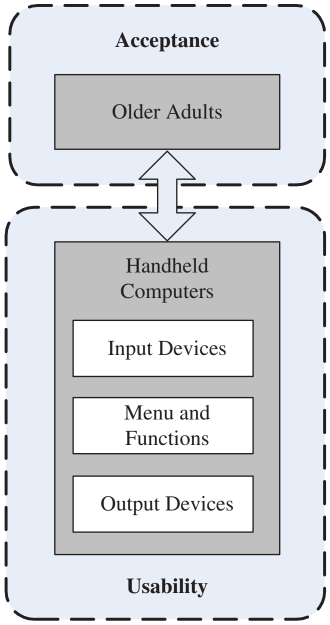

FIG. 1. Conceptual model of use and design of mobile devices for older adults (color figure available onine).

1.3. Literature Search Strategy

This article outlines the following four phases used to systematically survey literature through topic, reference, author, journal, and proceeding.

1. Phase 1: Search by topic. Keywords such as "elder," "older adults," "the aged," "senior," "mobile," "cellular," "phone," "PDA," "technical device," "small screen," "handheld," "portable," "gerontology," "computing," "accessibility," "design for all," "usability," and "universal design" were used to search in digital databases and websites. About 20% of all the literature was collected in this way.
2. Phase 2: Search by reference. For each paper, cited references and related references were collected. The outcome took about 40% of the survey, the largest proportion of collected papers.
3. Phase 3: Search by author. All published studies of the first and second authors and their institutions identified in Phases 1 and 2 were covered. Ten percent more papers were found in this way.
4. Phase 4: Search by journal and proceedings. Journals and proceedings of papers formerly collected were surveyed. Additional journals and proceedings were found by searching titles through keywords in digital database. Then, all the issues of the following journals were perused: *Computers in Human Behavior* (1985∼2010), *Interacting with Computers* (1989∼2008), *Behaviour & Information Technology* (2000∼2010.10), *Ergonomics* (1996∼2010), *International Journal of Human–Computer Studies* (2006∼2010), Univ Access Inf Soc (2008–2010), *Human Factors* (2008–2010), *Applied Ergonomics* (2008–2010), *Human–Computer Interaction* (2008–2010), *International Journal of Human–Computer Interaction* (2008–2010), *Gerontology* (1998∼2008), *Generations* (2000∼2008), *HCI and the Older Population* (2004∼2005), *the Gerontologist* (2000∼2008), *EURASIP Journal on Wireless Communications and Networking* (2004∼2008).

The same procedure was conducted for the following proceedings: *Conference on Human Factors in Computing Systems* (1983∼2008), *ACM SIGACCESS Conference on Assistive Technologies* (1994∼2007), *EC/NSF Workshop on Universal Accessibility of Ubiquitous Computing* (2001), *Mobile Human-Computer Interaction–MobileHCI* (2004), *Universal Access in Ambient Intelligence Environments* (2007), *Human–Computer Interaction–INTERACT* (2005), *Universal Access in HCI: Inclusive Design in the Information Society* (2003), *ACM SIGACCESS Conference on Assistive Technologies* (2004), and *World Congress on Ergonomics*. About 30% of literature was collected in this way.

Literature came from three sources: digital databases of Tsinghua University Library, including Web of Knowledge, SpringerLink, ProQuest, EBSCOhost, Elsevier SD, JSTOR, ACM, IEEE/IET(IEL); hardcopies from National Library of China; and websites (e.g., Google Scholar). The majority of the collected studies relate to mobile phones and personal digital assistants (PDAs), and only a few cover tablet PCs, MP3 players, portable multimedia players, and the digital dictionary. There are 69 studies that examine both handheld computers and older adults and that collect data. Demographic information and methods are presented in the appendix.

For reference, 50.7% of these studies compared older adults with other age groups. The top four methods used in these studies are controlled laboratory studies (56.2%), interviews (17.8%), observations (11.0%), and the survey (6.8%). For controlled laboratory studies, the average of sample size of the older adults was 20.6 ($SD = 14.39$, range = 5–72). For interview, the average sample size was 14.5 ($SD = 8.87$, range = 1–34).

Because the definitions of older adults are not consistent among previous studies, this article defines older adults as those 60 years of age and older. Therefore, demographic information of participants younger than 60 is marked in parentheses.

2. ACCEPTANCE

2.1. Acceptance of General Technology

Usability of handheld computers has long been investigated. Researchers focus on improving usability through considering the influence of age-related declines. The underlying philosophy seems to be that older adults do not accept handheld computers because of poor usability. Thus, as long as usability improves, they would accept handheld computers. However, they may ignore the fact that good usability is not enough to guarantee acceptance. Older adults resist certain technology even though it is easy to use, or even before they use it. The following examples indicate other reasons besides usability related to the retailing industry, home appliances, and computer applications.

In the retailing industry, fewer older adults than younger adults adopted certain innovations. Three large sample studies ($N > 2{,}000$) compared older adults with younger adults and documented resistance to Automatic Teller Machines (ATM), customer telephone calling service, ticket machines, and telephone cards among older adults in the United States, Germany, Finland, and Italy (Gilly & Zeithaml, 1985; Marcellini, Mollenkopf, Spazzafumo, & Ruoppila, 2000; Zeithaml & Gilly, 1987). Reasons for their resistance were more than usability. Take the ATM, for example; older adults liked the traditional interaction with staff in the bank, which made them feel safe. There was no strong advantage of an ATM over the traditional way. In contrast, older adults passively accepted grocery scanners and Electronic Funds Transfer because they realized the advantages in terms of safety and convenience. Therefore, perceived usefulness is one additional reason to explain acceptance.

For home appliances, older adults with older age showed lower acceptance than those with younger age. Two pieces of evidence came from the interview of 1,406 older adults (Zimmer & Chappell, 1999) and the web-based survey of 1,543 older adults (Ahn, 2004; Ahn, Beamish, & Goss, 2008). Age was negatively related to acceptance of three home appliances (i.e., video doorbell intercom, stove guard, and home emergency alert) and 25 types of residential technology. Zimmer and Chappell (1999) found that security concern was the strongest predictor of acceptance. Paradoxically, older adults with older age had higher level of security concern, but they had lower acceptance. This indicated that they did not think the home appliances could alleviate concerns. Social support and postpurchase service did help improve their acceptance, and postpurchase service was more important for people with older age.

For computer applications, older adults' resistance was not determined by usability problems. One typical case was when e-mail was newly introduced to society; older adults tended to judge it more negatively than other communication methods (cell phone, mail, telephone, and visit), regardless of whether they used it or not (Melenhorst & Rogers, 2006). In this case, older adults, including e-mail users and nonusers, did not perceive that the effort to use e-mail was greater than other communication methods. The reason for nonusage of e-mail was that older adults did not fully realize the benefits. Apart from e-mail, older adults also had a low acceptance of computers, the World Wide Web, and 17 types of everyday technology objects (e.g., mobile phone and microwave oven; Asano et al., 2007; Czaja et al., 2006). Czaja et al. (2006) compared three age samples and found computer anxiety, fluid intelligence, and crystallized intelligence were important predictors of acceptance. Therefore, different perception of usefulness and declined cognitive abilities also implied the necessity of studying older adults as a special group.

Many of the reasons for acceptance just mentioned are included in acceptance models, the scope of which is general technology among general population. Two branches of studies indicate two ways to understand acceptance. The first branch focuses on the process. For example, innovation diffusion theory (E. M. Rogers, 1995) and domestication of technology theory (C.-F. Lee & Kuo, 2007) indicate the process from awareness to usage. The second branch focuses on internal psychological factors. Four models are well established. The first two models form the basis in this area: theory of reasoned action (Fishbein & Ajzen, 1975) and theory of planned behavior (Ajzen, 1991). Then, to better explain behaviors in information technology context, the technology acceptance model (TAM; Davis, 1986) was developed. Perceived ease of use and perceived usefulness are two determinants of acceptance. Based on TAM, Venkatesh, Morris, Davis, and Davis (2003) integrated eight models into the unified theory of acceptance and use of technology (UTAUT). It identified two more determinants (i.e., social influence and facilitating conditions). It also began to notice the moderating role of age: the influence of perceived ease of use and social influence on acceptance was stronger for older adults.

No models specifically consider older adults until two models fill the gap. Similarly, one model focuses on the process, and the other one focuses on psychological factors. The first model stimulated decision process in terms of a decision tree. When older adults faced a new technology, their decision was determined by their evaluation of four issues in sequence: (a) advantages, (b) disadvantages, (c) their ability to overcome the disadvantages, and (d) comparison between advantages and disadvantages (Fisk, Rogers, Charness, Czaja, & Sharit, 2009). Only when a product was perceived to deliver advantages, or its advantages can outweigh disadvantages, would older adults accept it. The second model identified four acceptance factors: needs satisfaction, support availability, perceived usability, and public acceptance. They were derived from the factor analysis of the survey among Chinese older adults ($M = 67.9$, $SD = 4.57$, range $= 60$–75). Needs satisfaction and support availability were the most important predictors of acceptance (Wang, 2010). Therefore, enjoyment, connecting to others, or accessing information, which are older adults' important needs, should be satisfied, and effective support such as on-the spot problem-solving services should be provided.

These studies show that older adults' acceptance is similar to but not the same as acceptance of the general population. Perceived ease of use and perceived usefulness can also be applied to older adults (Chen & Chan, 2011), but their impact may change. Perceived usefulness may be more important for older adults than younger adults, because not fully realizing usefulness causes resistance. Also, older adults seem to evaluate usefulness in a way different from young people. They have different needs, which also influence acceptance (Wang, 2010).

To make usefulness apparent to older adults, communication channels are important. Contradicting the notion that older adults did not know new technology, most older adults knew many nonadopted technologies, but this was not enough to cause persuasion effects. Intraponsonal communication channels were more effective in persuading older adults, so traditional media (i.e., magazines, televisions, and newspapers) were recommended (Ahn et al., 2008). On the other hand, the indirect way is word of mouth from people around older adults. This was verified by the factor public acceptance (Wang, 2010).

2.2. Acceptance of Handheld Computers

It is necessary to distinguish acceptance of handheld computers from that of general technology. Different from other devices, mobile phones serve as a platform integrating more and more functions. Although computers can also be a platform, handheld computers' limited size, mobility, and privacy make them different from computers. Therefore, these characteristics of handheld computers may imply different acceptance patterns from general technology. The following section reviews two branches of studies. One branch of previous studies first takes adoption as the symbol of acceptance, whereas another branch extends acceptance to the whole life cycle.

People usually urge older adults to use mobile phones, but this seldom happens for other appliances and computers. This was social influence reported by three studies. In a mail survey of 176 mobile phone users, age did not have significant influence on usage. Age only predicted social pressure. Older respondents were under higher social pressure to use mobile phones (Kwon & Chidambaram, 2000). Their first mobile phone was mainly given by others as a gift or bought by other people. Older adults seldom made their own decision to buy mobile phones (Van Biljon & Renaud, 2008). Mallenius, Rossi, and Tuunainen (2007) interviewed older adults in Finland and found that opinions of family members greatly influenced behaviors of older adults. Their children and grandchildren often pushed them to buy mobile phones.

Also, older adults' way to judge usefulness and ease of use is different from that of younger adults. When older adults (range = 50–69) using the diary of the PDA, they perceived it was easy to use if they solved more tasks successfully, whereas younger adults perceived it was easy to use if they solved tasks efficiently. Arning and Ziefle (2007b) extended TAM by including performance. Performance was a main predictor of perceived ease of use, which in turn predicted perceived usefulness. Age was a major moderator influencing the relationship between performance and acceptance. Older adults' perceived ease of use could explain greater variation of perceived usefulness than younger adults. This implies the importance of initial success. Emphasis should be on task effectiveness instead of efficiency to improve acceptance of older adults.

Different from studies about first adoption, other studies consider postadoption behavior. After adoption of mobile phones, the way to use functions influences upgrade behavior. Older adults (range = 50+) had lower usage rate of basic functions (e.g., call) and innovative functions (e.g., camera, camcorder, and MP3) than younger adults. As a result, older adults were less likely to buy next-generation mobile phones (Huh & Kim, 2008).

More specifically, postadoption behavior can be divided into different phases. There are four phases in the domestication of technology theory: (a) appropriation, the process of owning the artifact; (b) objectification, the process of determining roles and functions that will be used; (c) incorporation, the implementation process; and (d) conversion, the process to adapt technology to intended interaction.

Renaud and Van Biljon proposed two models—an adoption matrix and the senior technology acceptance and adoption model (STAM), derived from mapping acceptance factors with the four phases. At first, unified theory of acceptance and use of technology and TAM were integrated into the mobile phone technology adoption model (Van Biljon, 2007; Van Biljon & Kotzé, 2007). It was based on younger adults' usage of core and additional functions. Afterward, the authors interviewed older adults in South Africa and proposed a two-dimensional adoption matrix (Van Biljon & Renaud, 2008) and STAM (Renaud & Van Biljon, 2008). Next, they included older adults to compare age differences in function usage (Renaud & Van Biljon, 2010).

One contribution of the adoption matrix and STAM is to look at possible age differences throughout the whole acceptance process. The adoption matrix found that perceived ease of use and perceived usefulness did not influence older adults' decision in the appropriation phase, because many older adults got mobile phones from other people. Moreover, STAM excludes the appropriation phase completely. The other contribution that Renaud and Van Biljon (2010) identified must-have and optional functions for both age groups. Older adults did not need functions related to personal information (e.g., address book).

However, it is difficult to apply the adoption matrix and STAM for two reasons. First, both models are not validated. They are based on the same interview but are differently structured, sometimes even in contradiction. There is a lack of quantitative support. Second, STAM is too complicated and the adoption matrix is too simple to use. STAM has nine acceptance factors with three kinds of interaction between factors. Besides, both models do not measure the importance of acceptance factors. They are not helpful for designers who cared key influential factors.

Among these studies, only three models are related to older adults' acceptance of handheld computers: the extended TAM (Arning & Ziefle, 2007b), the adoption matrix (Van Biljon & Renaud, 2008), and STAM (Renaud & Van Biljon, 2008). However, 28% of variance in older adults' perceived ease of use and 55% of variance in their perceived usefulness, which cannot be explained by the extended TAM, implies there may be other influential factors besides performance. Also, the adoption matrix and STAM cannot be easily applied. Therefore, this area needs further study.

Handheld computers' unique characteristics do imply different acceptance patterns from general technology. First, mobile phones integrates abundant functions, so researchers divide functions to must-have functions and optional functions (Huh & Kim, 2008; Renaud & Van Biljon, 2010; Van Biljon, 2007). The differentiation of extent of usage could help understand first adption and upgrade behavior. Second, mobility of mobile phones can enhance older adults' safety and security, so the role of social influence is strong. The advantage is that practitioners could indirectly deliver handheld computers from younger people to older adults. But yonger adults' influence is not always positive. For example, if older adults picked up mobile phones that were used by younger adults, these phones may be too difficult for them. This bad impression may influence their upgrade behavior.

Despite these differences, perceived usefulness and perceived ease of use can also explain acceptance of handheld computers. Older adults generally perceive that handheld computers are less useful or easy to use than younger adults feel (Arning & Ziefle, 2006, 2007a, 2007b; Holzinger, Searle, & Nischelwitzer, 2007; W. A. Rogers, Mayhorn, & Fisk, 2004). To improve perception, methods (e.g., improving usability, training, and support) related to acceptance of general technology are helpful.

3. INPUT DEVICES

Among various acceptance factors, perceived ease of use is always important. However, the limited size of handheld computers and declined motor ability of older adults make usability problems with input devices predominant. Older adults are slower in movement and make more submovements (Hertzum & Hornbaek, 2010; Nichols, Rogers, & Fisk, 2006). This influences text entry and pointing tasks. The following section reviews input devices for each task from physical controls to on-screen controls.

3.1. Text Entry

Physical controls. Entering text through physical keys needs not only mental mapping between physical keys and responses of mobile phone displays but also fine motor control of compressed keys.

The major solution to compressed keys is to group letters and digits on one key. To activate one letter on the standard 12-key telephone keypad, people need to quickly tap the key again and again. This is difficult for older adults. Most older adults could not understand the association between the digit and its grouped three letters on the key (Kurniawan, 2008). Even if they understood the association, they had difficulty in the timing and rhythm of key pressing (Weilenmann, 2010). For example, the 1,000 ms time-out period of Nokia 3595 and 1,500 ms of Motorola C155 were too short for slower older adults (Jastrzembski, 2006; Jastrzembski & Charness, 2007). Similarly, to activate one digit on the QWERTY keyboard, people need to press modifier keys, but older adults made repeated errors when holding down modifier keys (Li & Graf, 2007; Massimi et al., 2007).

To overcome these problems with multitap and modifier keys caused by grouped keys, text prediction technology (e.g., T9) comes up. It should be easy to choose predicted words and stop prediction, because older adults found it more distracting if the prediction was not the default one (Kurniawan, 2006, 2008).

There are three other solutions to compressed keys. The first solution is to make better use of space without sacrificing the key size. For example, slide-out phones can have big keys and sufficient interkey spacing. The review of 39 research projects recommended interkey spacing of PDAs and smartmobile phones to be larger than 5.6 to 7.5 mm for older adults (Bekiaris, Panou, & Mousadakou, 2007).

The second solution is to differentiate keys. Coding by tactile cues, color, contour, and position is helpful. The influence of tactile cues on dialing performance was reported in a controlled laboratory study (Mendat, 2006). When older adults dialed 10-digit numbers on a cell phone without looking at the keypad, they adopted the "home" strategy to touch the keypad: they would first locate a key, especially 1 or 5, as a starting point or home key. After that, they dialed numbers in sequence, during which they returned to the home key repeatedly. The results indicated that the role of tactile cues was key type related: For a raised-rubber keypad, the tactile cue located on the number 5 key was significantly better than multiple tactile cues located on the 1, 3, 5, 7, or 9 keys. The opposite result was seen for a flat-smooth keypad. This result may be applicable when looking at the keypad, because the tactile cue on a raised key serves as a landmark. Too many landmarks in a small area could be confusing. As to other coding methods, older women preferred to distinguish keys by position, whereas older men preferred to distinguish them by contour and color (Kurniawan, 2008).

The third solution is to abandon keypads or keyboards. Click wheels, speech-to-text technology, and touch screens could be alternatives. Click wheels are suitable only for a small amount of text entry, such as entering names. Speech to text is seen in elderly-specific phones. For example, F884i RaKu-RaKu Phone Premium had voice-activated e-mails, which supported transcription of voice into a written e-mail message instantly ("Feature," 2008). However, it was prone to errors when users were walking. This could be solved by creating speech enrollment profiles (Price et al., 2009).

On-screen controls. Entering text through on-screen keys could alleviate the problems with compressed keys and avoid mental mapping. However, it also has four problems. First, it requires fine pressure control. Older adults easily press a key too heavily, resulting in redundant entry (Wright et al., 2000), and their hands show instability (C.-F. Lee & Kuo, 2007). Second, its feedback needs improvement. Vibration is not as good as the tactile feedback of key pressing. Visual feedback such as pop-out bubbles can be distracting for older adults, and audio feedback is not differentiated. Third, both hands and pop-out keyboards can block the screen. Fourth, in typing text, one usually needs to switch between letters, digits, and symbols. The change of modes is confusing for older adults (Massimi et al., 2007). The following section examines how these drawbacks influence text entry through keyboards, keypads, and handwriting.

Tapping on-screen keyboards with a stylus is not the best way for text entry. Older adults (range = 55–69) used PDAs with both physical and on-screen QWERTY keyboards to enter or modify a short text. The results showed that participants, regardless of age, entered text more quickly and accurately with physical keyboards than on-screen keyboards. They also preferred physical keyboards to on-screen keyboards, and this preference grew stronger with age (Wright et al., 2000).

Tapping on-screen keypads with a stylus is a good way for digits entry. Nischelwitzer, Pintoffl, Loss, and Holzinger (2007) asked older adults ($M = 65$, range = 36–84) to enter a five-digit blood pressure value into a Motorola A920. They used a stylus to tap a numerical keypad (calculator style), navigation keys (cursor style), or sliders (slider style). The calculator style was most intuitive, whereas older adults did not understand the cursor style and found it hard to control sliders. This is reasonable because the calculator interface only needs one tap for each digit, whereas the cursor style needs more key presses for each digit and it is difficult to roll sliders to each accurate number.

Handwriting with a stylus is natural. Two qualitative studies reported that older adults preferred text entry on a PDA through handwriting rather than physical keyboards, after they were trained to use Graffiti (Sterns, 2005; Sterns & Collins, 2004). Handwriting can also reduce the movements of hands among keys and eye–hand coordination, because people write and see text at the stylus tip, keeping their focus in the same area. In contrast, when people type on physical keyboards, they type and then look at the input area on the display, resulting in change of focus. Therefore, it is suitable for people with arthritic hands and poorer vision abilities.

However, handwriting also has disadvantages. When handwriting needs to change input modes among letters, digits, and symbols, it is difficult for older adults. Handwriting needs fine motor skill, especially when the input area is small. The size of input area influences handwriting performance. C.-F. Lee and Kuo (2007) investigated the difficulties with operating a digital dictionary, a PDA, and a cell phone. Common difficulties of younger adults, middle-aged adults, and older adults were categorized into motion, perception, and cognition. They found that if the handwriting area was not full screen, older adults' hands showed instability. There are recommended sizes of the handwriting input area on PDAs (Ren & Zhou, 2009), but the size is based on younger adults.

All these studies are stylus based; stylus design also influences performance. The stylus design is related to tasks. People may want a smaller stylus when tapping compressed keys and a bigger stylus when drawing. Stylus design should balance requirements across tasks such as text entry, pointing, and drawing. The length of the stylus is usually longer than palm size to ensure comfort griping. For younger adults, the stylus was recommended to be 7 mm wide and longer than 11 cm on a PDA (Ren, Ogasawara, & Kato, 2004) and 0.8 mm wide and longer than 10 cm on tablets (Wu & Luo, 2006).

Following the study of Ren et al. (2004), age effect was examined in a subsequent study. Older adults performed pointing tasks and steering tasks on handheld computers. Their performance was best when the stylus length was from 13 cm to 15 cm, but their subjective evaluation indicated the preference for a pen more than 11 cm. Therefore, stylus-length more than 11 cm was suitable for both younger and older adults (Takahashi, Ogasawara, Ogasawara, & Ren, 2005).

There is a lack of finger input studies on handheld computers. However, two studies investigated finger input on desktop computers, and both of them indicated that on-screen keyboards were better than physical keyboards. When older adults entered Japanese characters, they preferred the on-screen keyboards with Japanese sound characters to the physical QWERTY keyboard, because the on-screen keyboard caused significantly less computer anxiety (Umemuro, 2004, 2007). When older adults entered digits, the on-screen numeric keyboard was quicker than the physical numeric keyboard, but the physical numeric keyboard was more accurate. They preferred the on-screen numeric keyboard (Chung, Kim, Na, & Lee, 2010).

3.2. Pointing

Physical controls. Seven types of physical controls of handheld computers are widely used for pointing tasks: directional pads, jog wheels, keypads, joysticks, trackballs, optical track pads, and click wheels. Previous studies focus on directional pads, jog wheels, and keypads.

The usability of directional pads is influenced by the button arrangement. For two-dimensional directional pads that had up/down buttons, left/right buttons, and an "OK" button on one button, older adults expressed some confusion over left/right buttons of the PDA directional pad (Moor, Connelly, & Rogers, 2004; Siek, Rogers, & Connelly, 2005). The elliptical shape of the directional pad may explain their confusion because left/right parts were smaller than up/down parts. Another kind of directional pads are one-dimensional, which only had up/down buttons. They are seen in many elderly specific phones. For example, Emporia Life Plus, Doro Phone Easy serials, and Jitterbug use one-dimensional directional pads to match their liner menu.

One alternative of directional pads is jog wheels. Two studies reported that older adults liked jog wheels at the side of mobile phones. In a qualitative study, older adults participated in mobile phone design, and they preferred jog wheels to direction pads (Massimi et al., 2007). The jog wheel was also included in a PDA prototype based on the interview of 10 older adults. Older adults could rotate the wheel at the side of PDA to select items on a circular menu. To test it, older adults (range = 50–78) participated in a prototype-based usability evaluation. The results indicated that older adults gave positive feedback to the circle menu and the jog wheel (Zao et al., 2008).

Jog wheels are good but not necessarily better than directional pads. Jog wheels are commonly found on radios and CD players, so older adults are familiar with them. The studies by Massimi et al. (2007) and Zao et al. (2008) indicate that older adults like jog wheels, but they do not rigorously compare jog wheels and directional pads. Jog wheels can be located at the side and the front of handheld computers. A jog wheel at the side of handheld computers is one-dimensional, and it may be easier than the two-dimensional directional pad. However, a jog wheel at the front of handheld computers is usually two-dimensional, but no studies compare it with directional pads.

Another alternative to directional pads is keypads. One qualitative study found that older adults did not use directional pads. Instead, most of them used digits on keypads to activate menu items with corresponding digits (Kim et al., 2007). In fact, using keypads could temporarily separate input and output. It could save the effort of tracking cursor locations, which is needed during pressing directional pads. However, the drawback of using keypads is the need for mental mapping between digits and the numbered menu items.

There is a lack of studies that examine age effects on joysticks, trackballs, optical track pads, and the click wheels of handheld computers. Different from keypads and directional pads, these controls are continuous input and could track movements with varying speeds and directions. Because older adults have some difficulties in moving continuously, the joystick and trackballs were not recommended as computer input devices (Taveira & Choi, 2009). It is worthwhile to investigate whether older adults should use them on handheld computers.

On-screen controls. The common way to select checkboxes, radio buttons, and icons on handheld computers is tapping with a stylus. Researchers investigated an alternative, similar to drawing check marks with a pen on a piece of paper and drawing a straight line or a circle to select multiple items. It is called touching, which meant “the pen may come into contact with the touch screen outside the target and may also be lifted outside the target, but at some point in between it has to touch the target” (Hourcade & Berkel, 2008, p. 171). In other words, touching supports strokes, whereas tapping only supported pointing.

Touching outperforms tapping when selecting a single target, and straight steering outperforms circular steering when selecting multiple targets. Younger adults, middle-aged adults, and older adults had comparable speed and accuracy in touching and steering tasks. However, for the tapping and circular steering tasks, older adults made more errors than the others. Touching contributed to a higher accuracy than tapping for all age groups when the target size was 16 pixel (px), and the benefit of touching over tapping was greater for older adults (Hourcade & Berkel, 2006, 2008). However, the advantage of touching over tapping needs further consideration because the advantage disappeared when targets become larger.

It is reasonable to recommend touching for older adults when targets are small. Touching is evolved from paper–pen interaction and is easy to understand. Touching could support tapping, and it could also support crossing or making checkmarks to select a target. Most participants in the research of Hourcade and Berkel (2008) did not use handheld computers regularly. Thus, the touching would especially benefit novice older adults.

Apart from icons, tapping menu items with a stylus can be intuitive and therefore better than physical controls. Kang and Yoon (2008) also compared the joystick, buttons, and touch pad when older adults (range = 46–59) configured portable media players (PMPs). Older adults had difficulty in distinguishing short and long presses of buttons and the joystick. The interview after configuration tasks showed that 77% of older adults as well as 90% of younger adults preferred the stylus-based touch pad rather than buttons and the joystick. Neither computer experience nor age seemed to influence the preference for the touch pad.

The reason for preference of the touch pad was age related: Older adults thought it was less physically demanding, whereas younger adults thought they needed less time (Kang & Yoon, 2008). Therefore, input devices for older adults should put more emphasis on reducing physical effort instead of improving efficiency.

The preference for input devices depends on tasks (W. A. Rogers, Fisk, McLaughlin, & Pak, 2005). As mentioned, the physical keyboard is better for older adults than the on-screen keyboard in text entry tasks, whereas they prefer the touch pad to the joystick and buttons in pointing tasks. In addition, the preference of a touch pad is also seen in computers. The touch pad of notebook computers was better than trackpoint in point–click tasks and point–drag–drop tasks. Because of the consistence of finger movement and the smooth cursor movement on the display, a touchpad was 20% faster than a trackpoint for older adults (range = 40–65; Armbrüster, Sutter, & Ziefle, 2007).

It should be noted that tapping drop-down menu items with a stylus also causes difficulties for older adults. Moffatt conducted a series of studies (Moffatt, 2008; Moffatt & McGrenere, 2007, 2009; Moffatt, Yuen, & McGrenere, 2008) about older adults' difficulty with stylus-based target acquisition in a Tablet PC. They first identified three difficulties of pen-based selection, and then in subsequent two studies they proposed and tested methods to overcome two of the three difficulties.

Tapping can result in three difficulties: (a) *slipping*, which was defined as “landing on the desired target, but unintentionally slipping off before lifting the pen”; (b) *drifting*, which was “accidentally hovering over an adjacent menu”; and (c) *missing just below*, which related to “erroneously selecting the top edge of the menu item immediately below the target item." Furthermore, these difficulties were age related: *Slipping* was specific to older adults, whereas *drifting* and *missing just below* were found in younger, middle-aged, and older adults. When participants selected an icon or a menu item, accuracy and speed decreased with age (Moffatt, 2008; Moffatt & McGrenere, 2007, p. 3).

To overcome *drifting*, two approaches were tested in a subsequent study: (a) *tap*, which meant one tap was required to switch from a selected menu to a new menu, and (b) *glide*, which used a distance threshold to delay switching. The results showed that *tap* reduced *drifting* and was well received by older adults (range = 55–85). However, most younger adults did not like the *tap* interface. And the *glide* interface did not reduce *drifting* significantly (Moffatt et al., 2008). Further study of *glide* with different distance thresholds is needed

To overcome *missing just below,* two approaches were tested in another study: (a) *reassigned edge*, supported "input on the top edge of a menu item results in the selection of the item above," and (b) *deactivated edge*, just ignored input on the top edge. Older adults needed more time and more taps for target acquisition. The evaluation results indicated the benefit of *deactivated edge* (Moffatt & McGrenere, 2009). However, it is worthwhile to note drawbacks of *deactivated edge*: First, it resulted in more taps by older adults to select a menu item; second, it ignored input of users thus caused confusion and was disliked by many participants. In contrast, the first approach resulted in more errors although it reduced *missing just below*.

It is anticipated that their studies will attempt to overcome the *slipping* problem. However, their main focus is about changing the selection area in a drop-down menu; the possibility of trying different menu structures is not considered and the possible influence of motor skills, spatial ability, is not examined. Although these stylus-based difficulties are related to tablets, they could serve as reference for handheld computers with drop-down menus.

These studies are all stylus based, and there is a lack of studies on finger tapping. Finger tapping results in two new issues. First, a target that was big enough for reading may be too small for finger tapping. This is not a problem for stylus-based tapping because the small stylus tip works fine with small targets. Second, finger tapping makes the distinction between clickable and unclickable interface elements blur. Everything on the display can be tapped, and many menu items and buttons look like text. Because older adults are sensitive to button size and text size, and they are generally less experienced, it is necessary to investigate age differences on finger tapping.

Soft keys. Problems with soft keys exist for both physical and on-screen controls. For example, the "Option" in a Symbian phone would change to "Select" or "OK" in different contexts. Soft keys were usually confusing for older adults (Massimi et al., 2007; Tuomainen & Haapanen, 2003). They (range = 55–86) found it difficult to build mental models of soft keys (Massimi et al., 2007). Actually, problems with soft keys may be more serious for physical controls, because they need to form mental mapping between a physical key and the soft key with changing labels.

There are two solutions to these problems. The first solution is to avoid soft keys through shortcuts. A shortcut key to activate important functions could help older adults (Tuomainen & Haapanen, 2003). On-screen numbered selection or stylus selection would be a better choice than soft keys (Massimi et al., 2007). Kim et al. (2007) found that most older adults used number keys to navigate through the menu. They were confused if the number key was gone or blocked. Shortcuts could avoid soft keys but at the same time add memory load. Users have to memorize functions that a certain key can activate, especially when the number of shortcuts is big and clear indication of shortcuts is absent.

The second solution is to change soft keys. Handheld computers can have a consistent physical key such as the "Menu" in android phones, or make actions originally hidden in the pop-up menu always visible. For example, the operation of the adding button "+" in an iOS phone may be better than that needs to activate "Option" and then choose "Add."

Interaction strategy. Input performance is influenced not only by the design of devices but also by interaction strategies adopted by older adults. With systematic strategy, people formulated hypothesis, implemented, and evaluated the results. In contrast, people with trial-and-error strategy did not formulate hypothesis to direct behavior, and people with rigid exploration strategy did not monitor the results of repetitive actions (Van Der Linden, Sonnentag, Frese, & Van Dyck, 2001).

Some studies reported that older adults used trial-and-error strategies to use handheld computers (Arning & Ziefle, 2007a; Kurniawan, 2006). When participants configured a PMP and a MP3 player, Kang and Yoon (2008) found that older adults often selected wrong functions and repeated their erroneous actions without noticing hints. This was because older adults adopted less systematic exploration strategy, more trial- and-error strategy, and more rigid exploration strategy.

Experience influences adoption of interaction strategies. On one hand, the lack of prior experience results in more frequent adoption of trial-and-error strategy (Kang & Yoon, 2008). On the other hand, for people with little experience, even trial-and-error strategy is difficult for them. Ziefle and Bay (2005) found that older novice mobile phone users (range = 50–64) were intolerant to trial-and-error strategy.

A certain amount of experience seems to be the premise of trial-and-error strategy. This is seen in desktop computers. Older adults without computer experience could not adopt trial-and-error strategy to learn graphical user interface operation in the usability testing of the Electronic Program Guide system (Hara, Nambu, & Harada, 2005). In a subsequent study, they found that older adults could learn new operations through trial-and-error strategy on the condition that elementary operations were well understood (Hara, Naka, & Harada, 2007).

Trial and error easily results in errors, so help should be provided at the right time. Help can be provided before interaction and during interaction. Hara et al. (2007) compared the two kinds of help. General information provided before tackling the tasks was not helpful. In contrast, guidance information provided when older adults confronted difficulties was helpful. This makes sense. Help provided before interaction such as manuals could be not helpful for older adults with trial-and-error strategy. Instead, help should be timely before they fall into an error spiral.

4. MENU

Compared with input problems caused by declined motor skills, problems caused by declined cognitive ability are usually more difficult to deal with. Older adults have slower processing speed (Sjölinder, 2006), poorer working memory (Hawthorn, 2007), episodic memory, prospective memory (Nichols et al., 2006), and spatial ability (Arning & Ziefle, 2007a; Ziefle & Bay, 2005, 2006) than younger adults. These changes influence their use of menu and functions. This section discusses menu, and section 6 discusses functions.

Menu design is related to display size. For desktop computers, when older adults used word-processing programs, the pull-down menu contributed to better performance than on-screen menu and function keys (Czaja, Marting, Thomas, & Prasad, 1997). However, for smaller displays like ATMs, an on-screen menu was more suitable for older adults, whereas the pull-down menu was more suitable for younger adults (Carey, Mizzi, & Lindstrom, 1996; Noyes & Sheard, 2003).

When display size becomes as small as mobile phones, usability problems with menus are predominant for older adults. They generally experience higher disorientation in menu navigation of handheld computers (Arning & Ziefle, 2007a; Sjölinder, 2006; Sjölinder, Höök, Nilsson, & Andersson, 2005; Ziefle & Bay, 2005, 2006), and it is one of the most serious problems with handheld computers (Y. S. Lee, 2007; Kurniawan, 2008; Osman, Maguire, & Tarkiainen, 2003). Menu disorientation bothered older adults (range = 47–79) so much that they rated easy menus as the most important ergonomic factor when buying new mobile phones (Maguire & Osman, 2003). Because menu depth/breadth trade-offs have significant influence on navigation behaviors in handheld computers (Minhee & Jinwoo, 2004), the following section discusses menu depth and menu breadth sequentially.

4.1. Breath of Hierarchical Menu

There are disagreements on narrow or broad menu breadth. The following section discusses two ways to achieve simplicity: reducing functionality and improving the design of individual functions. Reducing functionality seems to be easier.

Some studies reported that handheld computers for older adults should only provide limited functionality (Arning & Ziefle, 2006; Gregor, Newell, & Zajicek, 2002; Kurniawan, 2006; Kurniawan, Mahmud, & Nugroho, 2006; Nasir, Hassan, & Jomhari, 2008; Zao et al., 2008). Older adults used limited functions (Y. S. Lee, 2007; Maguire & Osman, 2003; Tuomainen & Haapanen, 2003), and they were inclined to learn fewer functions than younger adults. Besides, too many functions made it difficult to distinguish desired function from others (Kang & Yoon, 2008).

Extreme examples of limited functionality are Emporia TIME series, Doro Easy 5, and Gainwise S3300 phones, which have no menus. More common practice is to provide only basic functions. Jitterbug Cell Phone only supported calling, and Emporia LIFE series, Just 5, Doro PhoneEasy 345 and 410, and LG NS1000 phones support calls and text messages. Their belief is that less functionality is simple.

However, many studies disagree on limited functionality. In fact, older adults desired various functions (Hellman, 2007; Maguire & Osman, 2003; Massimi et al., 2007). Moreover, reduced functionality may result in sale loss. When people choose from two phones at the same price, one with five functions and the other with 15 functions, most people choose the latter one.

Therefore, many elderly-specific mobile phones provide broad functionality that could attract more older adults. NTT DoCoMo supports mail and GPS navigation, and most mobile phones for Chinese elderly such as Lenovo A589, K-Touch (A7711, A7711s, A7712, A7719, A7713, and N77), Skyworth L160, Alcatel C60 support the torch light, magnifier, and FM radio. Their belief is that elderly-specific functions are selling points.

Menu breadth is related to experience. Usually, novice users desire fewer functions, whereas experienced users desire more functions. It is no longer that simple if one considers growing experience. Novice users may desire more functions as experience grows, and experienced users may also return to fewer functions as they age.

There are three ways that a user could deal with menu breadth. The first is to easily disable unwanted functions. The idea is similar to a cover on the remote control or the cover on the bottom of a TV, hiding functions that are not frequently used. The second is to easily enable wanted functions. Examples are application stores, widgets collections, and the desktop management software. The third is to enable personalization. Examples are grouping and multiple start screens. Grouping can reduce width, but at the same time it increases depth. However, if users can group themselves, it helps, because disorientation is usually caused by the mismatch between users and designers. In contrast, multiple start screens compress menus to be broad and shallow.

Because multiple screens are popular and older adults are prone to information overload, it is necessary to think of how many functions per screen is appropriate. More functions per screen give clear cognitive preview but may hinder visibility and result in information overload. In a controlled laboratory study, 40 older adults used simulated mobile phones with different font size (8 point and 12 point) and preview size (one function per screen and five functions per screen). They used calling and the phone book. The results showed that large font size and large preview size contributed to optimal navigation performance, and if the two factors contradicted, preview size was more important than font size (Ziefle, 2009, 2010). It should be noted that the phone had a seven-line display with 101 × 80 px and a text-based menu. Phones with icon-based menus may be different.

Some researchers even wanted to simplify menus to a list. Older adults would like text-based menus arranged in a list instead of icon-based menus arranged in columns and rows (Kurniawan, 2006; Kurniawan et al., 2006). However, the preference of textual menus or the icon-based menu may depend on whether the icons are transparent and whether the user is familiar with menu-based systems.

4.2. Depth of Hierarchical Menu

Three ways could help older adults navigate deep menu. The first way is to reduce menu depth. For older adults, the menu depth of handheld computers is generally too deep (Tuomainen & Haapanen, 2003). Ziefle and Bay (2004) investigated age effects on perception of menu depth. Participants used a mobile phone with a four-level menu, and sorted functions on cards. The results showed that younger adults structured 3.4 levels on average, whereas older adults (range = 50–64) structured 2.1 levels. Compared with the recommended mobile phone menu depth (less than four levels) for general population (Marsden & Jones, 2002), older adults' problems with menu depth are serious than younger adults. This is caused by their declined spatial ability. Therefore, the shallower mental model of older adults implies the need of the shallower menu.

In practice, many smartphones do provide menu depth not greater than two levels. Android and iOS phones have a screen to access all applications, so the menu depth is one level. However, as the number of applications grows, the presentation of all applications needs more effort to search a desired application. Therefore, iOS phones support people to group applications into folders. This makes menu depth to be two levels, but still less than 2.1 levels from the study of Ziefle and Bay (2004). Compared with feature phones, which usually have deep menus, smartphones have the potential to free older adults from problems with menu depth.

The second way is to provide contextual information. Older adults often forgot their position and route in the menu. Ziefle and Bay (2006) designed two mobile phone menu navigation aids for older adults: *category aid* and *tree aid*. *Category aid* provided landmark knowledge, which showed the name and contents of the current category; *tree aid* provided survey knowledge, which showed the parents, parent-parents, and subcategories. The results showed that *tree aid* was better than *category aid* for both younger and older adults (range = 46–60). This is not surprising because the *tree aid* provides more contextual information of menu depth. Therefore, it is important to provide survey knowledge about the current level in the hierarchical menu.

The third way is to provide shortcuts. There are three kinds of shortcuts. Shortcuts on physical keys are common but require users to understand which button can activate which function. Next, widgets and the notification bar are common in smartphones, but the activation methods should be simple. The widely used tapping and holding can be difficult for older adults, because they had difficulty with long press (Kang & Yoon, 2008). Last, multiple start pages are good, because the broad and shallow menu of handheld computers is better than the narrow and deep one (Chittaro & De Marco, 2005; Marsden & Jones, 2002). However, an easy way to switch screens is needed. Pressing one button to access an overview of screens and 3D effects to switch between screens can be confusing for older adults.

5. FUNCTIONS

5.1. Necessary and Unnecessary Functions

Nearly all the studies agreed that older adults need calling and text messages, but there are disagreements on the necessity of advanced functions. Many surveys asked older adults what functions they needed. Older adults rated the following functions important to them: communication functions (e.g., voice call, texting, call history, address book, automatic volume adjustment, caller blacklist, and caller photo), personal organization tools and memory aids (e.g., calendar, diary, alarm, to-do-list, notebook, and reminders to take phones along; Arning & Ziefle, 2006; Inglis et al., 2003; Kurniawan, 2006, 2008; Maguire & Osman, 2003; Massimi et al., 2007; Zao et al., 2008), entertainment tools (e.g., music player and voice recorder; Kurniawan, 2006; Massimi et al., 2007), navigation (Arning & Ziefle, 2006; Kurniawan, 2006), camera and video (Irie, Matsunaga, & Nagano, 2005). However, some studies reported that video call (Kurniawan, 2006), diary (Wright et al., 2000), alarm (Wright et al., 2000), camera and video (Kurniawan, 2008; Kurniawan et al., 2006), and music players (Kurniawan, 2008) were unnecessary.

Two reasons may explain the disagreements. First, public acceptance influences the necessity. Older adults who desired camera and video in the study of Irie et al. (2005) were from Japan, whereas those who did not want them in the studies of Kurniawan were from the United Kingdom. Second, the necessity may change over time. The early time of the study of Wright et al. (2000) may explain older adults' preference for paper-based reminders rather than diary and alarm in PDAs.

Van Biljon (2007) proposed a model including both must-have and optional functions. For general population, four kinds of functions were must-have: organization, relationships, safety & security, and personal information. Six kinds of functions were optional: personal history, entertainment, m-commerce, nonpersonal information, expansion, image (Van Biljon, Kotzé, & Marsden, 2007). In a subsequent study, they simplified this model to tailor to older adults. Three kinds of functions were must-have: organizations, relationships, and safety and security.

Two kinds of functions were optional: image and personal history (Renaud & Van Biljon, 2010).

5.2. Medication Adherence Application

Health care applications could be integrated into handheld computers and offer great benefits for older adults. Nischelwitzer et al. (2007) developed a medical application integrated on a mobile phone to support older adults with chronic disease. Sterns and Mayhorn conducted a series of studies (Mayhorn, Lanzolla, Wogalter, & Watson, 2005; Mayhorn, Stronge, McLaughlin, & Rogers, 2004; Sterns, 2005; Sterns & Collins, 2004; Sterns & Mayhorn, 2006), which included developing a new application, training older adults (range = 56–89) to use standard PDA applications, and evaluating of usage of this new application in a lab environment and a field study.

Medication applications are helpful, but using them may be difficult for older adults. Sterns and Collins (2004) developed a medication adherence software supported by a PDA. A pillbox holding pills was physically attached to a PDA. When it was time to take medicine, the PDA sent an audio alert. The display would show the picture of tablets and asked for confirmation after taking medicine. However, this application needed users' input text (e.g., pill name) and numbers (e.g., dosage) and for them to choose from the drop-down list (e.g., frequency). This can be challenging because older adults have difficulty in learning handwriting recognition language, reading the screen, understanding how the PDA interprets input, and taking corrective actions.

To overcome these barriers, appropriate training is important. In a subsequent study, Sterns (2005) designed a curriculum especially for older adults (range = 56–78) to use the standard PDA applications. Older adults could learn these applications successfully and no age effect on performance was found. A small-size class (five people) resulted in better performance than a large class (10 people; Sterns, 2005). This is supported by literature on a computer training course for older adults. Small classes (Mayhorn et al., 2004), providing initial success (Kelley, Morrell, Park, & Mayhorn, 1999; Mayhorn et al., 2004), and self-paced training (Czaja et al., 1997; Mayhorn et al., 2004; Noyes & Sheard, 2003) are recommended to optimize successful training performance. Also, enough time for practice could improve performance of older adults and make age-related differences decrease over time (Arning & Ziefle, 2007a; Mayhorn et al., 2005; Moor et al., 2004; Siek et al., 2005; Wright et al., 2000), although practice alone could not diminish age-related performance differences (Mayhorn et al., 2005; Wright et al., 2000).

After learning standard applications, older adults can transfer to the medication adherence application. In a lab environment, Mayhorn et al. (2005) compared age-related differences in performance of medication scheduling. Following the manual with step-by-step illustrations, participants entered medications into a PDA with a stylus. They found that older adults could learn this application but required more time and made more cognitive and motor errors. Apart from the influence of age, slower perceptual speed and lack of prior experience also predicted longer task completion time, and better reading comprehension could predict less cognitive errors. Despite their poorer performance and lower perceived usability, they rated the likelihood of future use slightly higher than younger adults (Lanzolla, 2004; Mayhorn et al., 2005).

In a field study, participants who completed training went on with a 3-month use test. The results indicated that most older adults (range = 56–89) missed less medication. The application increased medication compliance (Sterns & Mayhorn, 2006).

The first of the three ways to remind older adults is direct alert from handheld computers. Audio alert, vibration, and visual alert on the display are commonly used. The second way are indirect alerts from other people. Family members, doctors, or carers can receive short messages. They could monitor the medication process. This makes use of social influence. The third are indirect alerts from other objects or devices. Liang, Rau, Zhou, and Huang (2012) proposed design concepts where the medication reminder is embedded in a bag, bracelet, glasses, or walking sticks. MIT age lab developed a pill pet as a reminder to take medication. If the older adult misses a medication dose, the pet with a small display on the front will indicate a worried or saddened face. These efforts deliver alerts in a nonannoying, more delightful way.

5.3. Navigation Applications

Navigation applications integrated into handheld computers provide great potential to enhance the mobility of older adults. However, only a few studies examine age effects. Available studies mainly focus on pedestrian navigation, and there is a lack of studies on in-car use of navigation applications on handheld computers. Previous studies focus on output of landmarks and navigation services, and there is a lack of studies on input.

Older adults had poorer performance in learning environment layout than younger adults. They acquired less information to learn landmarks and rank distance in a supermarket (Kirasic, 2000) and needed more time and more interaction steps than younger adults when they were asked to find certain items in a three-dimensional virtual grocery shop (Sjölinder et al., 2005). Their poorer navigation performance was because of declined spatial ability (Arning & Ziefle, 2009; Garden, Cornoldi, & Logie, 2002; Kirasic, 2000; Sanchez & Branaghan, 2009; Sjölinder et al., 2005) and working memory (Garden et al., 2002). Therefore, older adults need navigation aids.

To investigate appropriate landmark modalities for older adults, Goodman conducted a series of studies (Goodman, Brewster, & Gray, 2004a, 2004b, 2005; Goodman, Dickinson, & Syme, 2004; Goodman & Gray, 2003). They started with gathering older adults' requirements, then designing the first-version interface with photographs, and finally refining the second-version interface with text and speech. The following section follows Goodman's studies and discusses conflicting results about the role of map and the audio-only interface.

Navigation aids could help people at all ages, and were even more helpful for older adults. Goodman and Gray (2003) proposed a design space to consider core functionality issues, form of delivery, and context of use for older adults. In a subsequent study, Goodman et al. (2004) gathered requirements for mobile settings from focus group discussions. Then they developed a navigation aid integrated on a PDA that displayed images of landmarks. In a field study, they found that this navigation aid resulted in significantly less time than a map for older adults to get to a destination. In contrast, the mean time of younger adults did not show any significant difference between this navigation aid and a map (Goodman et al., 2004b). Furthermore, they found that the majority of participants preferred the navigation aid to a map because the photographic interface effectively avoided ambiguous or unclear instructions (Goodman et al., 2004a).

Two reasons could explain the disadvantage of maps for older adults. First, maps need mental rotation to interpret, which is more difficult than the intuitive photographic landmarks. Second, the overview of maps is more of an obstacle because older adults' spatial knowledge mainly remains on the levels of landmark knowledge and route knowledge, and does not reach the level of survey knowledge. This was supported by Sjölinder et al. (2005). They found that the overview map did not benefit older adults in learning the environment and layout. It only provided a sense of security. In contrast, because younger adults had good spatial knowledge, maps could be more effective than navigation aids integrated on handheld computers (Ishikawa, Fujiwara, Imai, & Okabe, 2008; Münzer, Zimmer, Schwalm, Baus, & Aslan, 2006).

Different modalities to present landmarks can be equally effective, but audio-only interface should be adopted with care. In field studies, older adults used three interfaces: text and speech interface, text-only interface, and speech-only interface. Regarding performance, there were no significant differences in mean time, the number getting lost, and workload. However, the speech-only interface resulted in higher disorientation in terms of more press on the back button. Regarding subjective evaluation, older adults preferred the text-only interface and the text and speech interface rather than the speech-only interface (Goodman et al., 2005). This was supported by Heer, Eisenhauer, and Siochos (2003). They compared map only, audio only, and a combination of audio and map mobile navigation aids through an Internet-based, controlled laboratory study. They found that a combination of audio and map was best, whereas audio only was worst. Moreover, compared with their studies (Goodman et al., 2004a, 2004b), the text and speech interface and the text-only interface could be as effective as the photographic interface.

However, audio-only navigation aids can outperform image-based and text-based navigation aids for people with cognition functional loss in the domains of attention, memory, and/or executive functions. Fickas, Sohlberg, and Hung (2008) compared four navigation aids with the bird's-eye image, the image from the user's perspective, audio-only instructions through earphones, and the text-only instruction integrated on a Hewlett Packard iPAQ Pocket PC worn on the wrist. The results showed that audio-only instructions through earphones related to the best performance and 60% of the participants rated it as the most helpful navigation aid.

Two reasons may explain the difference in the role of the audio-only interface. First, more experience with maps may imply better use of visual information. Participants in the study of Fickas et al. (2008) did not use a map, whereas those in the study of Goodman et al. (2005) were regular map users. Second, for ordinary people, the audio modality may be more important in a multitask environment, whereas people with cognition functional loss in the study of Fickas et al. (2008) had fewer choices toward modalities.

Audio navigation aids should have proper voice, length, and speed. A natural male voice speaking in the navigation aid on the PDA was easier for older adults to understand (Goodman et al., 2005). Also, the speech output influenced memory performance of older adults. A long output message caused confusion for older adults, resulting in poorer performance (Gregor et al., 2002). Thus, a short audio message may be more helpful. Slower processing speed of older adults should be noted. The RaKu RaKu Phone took this into consideration and could slow down the speaker's voice by 30% for easier comprehension.

No matter which kind of modality, the amount of details should be suitable because older adults are intolerant to information overload. For example, increasing the amounts of detail did not help map learning. Compared with the map in satellite mode, young adults recalled routes better with the map in the traditional mode (Sanchez & Branaghan, 2009). Because many maps had the traditional mode, the satellite mode, the 3D mode, and the terrain mode, it is worthwhile to investigate which mode is easiest for older adults.

As to navigation services, older adults (range = 55+) desired reliable, easy-to-use services integrated on mobile phones (Osman et al., 2003). Kawamura, Umezu, and Ohsuga (2008) investigated how to present information of static and dynamic barriers such as steep stairs, road without sidewalk, and road construction. Older adults went out in a park with an NTT "mopera" GPS-based mobile phone. They wanted to be notified at the right time and at the right frequency. The notification should select the appropriate kind of barriers according to contexts. Apart from en route barriers, older adults (range = 51–92) also desired pretrip planning and wanted to be supported when they had health emergency or get lost (Mikkonen, Vayrynen, Ikonen, & Heikkila, 2002; Zhou et al., 2009).

Culture difference may influence the design of navigation services. Chinese older adults were likely to use navigation applications only for a short-distance trip rather than a long-distance trip (Zhou et al., 2007). Because Chinese people emphasize family and group goals above individual needs, older adults usually go on long-distance trips with family members. Older adults in individualistic countries may use navigation applications on the long-distance trip.

5.4. Browsing

Browsing on small screens is difficult, especially for older adults. Asano et al. (2007) observed older adults (range = 55+) visit web pages though NTT DoCoMo P90li. They found that older adults had problems with visibility, focus recognition, understanding, operation, and web page structure. Only a few studies focus on older adults' browsing on handheld computers. They mainly discuss visual appearance of hyperlinks and web page structures.

Older adults have difficulty in using traditional underlined hyperlinks. Ziefle, Schroeder, Strenk, and Michel (2007) investigated how younger and older adults handled hyperlinks on a PDA. They searched, inquired, and reserved tickets through a website with or without hyperlinks. The hyperlink interface related to higher task effectiveness in terms of more solved tasks. However, although hyperlinks helped younger adults complete tasks with higher efficiency, it hampered older adults' task efficiency. Older adults who completed tasks with the hyperlink interface had more detour steps, more blind clicks, and more clicks on the home buttons.

One alternative to underlined hyperlinks is hyperlinks in the form of buttons. Sayago (2006) compared hyperlinks like buttons with underlined hyperlinks on PDAs. Older adults got lost several times with underlined hyperlinks. In contrast, the larger link area of hyperlinks buttons enabled them to click links more easily. Therefore, older adults preferred hyperlinks buttons to underlined hyperlinks. This study sheds light on overcoming older adults' difficulties with hyperlinks.

It is worthwhile to investigate whether mobile web pages should have the same structure as desktop web pages. Sayago (2006) compared two structures of mobile web pages. The first structure was the same as that of online websites except that direct links among the first level web pages were disabled. Different from the structure of online websites, the second structure presented all the information on the home page and was structured into sections. Younger and older adults accessed web pages on PDAs. The results showed that younger adults preferred the structure similar to that that of online websites, whereas older adults preferred the structure different from that of online websites.

The form of hyperlinks and web page structures are related to computer experience. Current older adults generally lack computer experience, so they are unfamiliar with underlined hyperlinks and online websites. For them, buttons are more intuitive to click than underlined hyperlinks, and the linear presentation is easier to follow. However, it is questionable whether these results would be applicable to experienced older adults.

Apart from focus on the design of mobile web sites, information security problems associated with mobile browsing should be noted because of older adults' vulnerability to Internet crimes and telemarketing fraud. No available studies focus on information security of older adults' mobile browsing; therefore, this area calls for more studies.

5.5. Manuals

Reading manuals is an important way to learn to use functions, although there are disagreements on whether it is the main approach. Some researchers reported that reading manuals is the main approach (Bruder, Wandke, & Blessing, 2006; Ziefle & Bay, 2005), whereas others reported demonstration from other people (e.g., family, relatives, friends, shop assistants) is the main approach (Bruder, Blessing, & Wandke, 2007; Maguire & Osman, 2003; Massimi et al., 2007). Anyhow, many older adults (range = 58–80) used manuals to shoot problems and recall forgotten operation, but only a few of them read manuals to explore new functions (Bruder et al., 2006).

Older adults want step-by-step manuals. Bruder et al. (2006) interviewed older adults to identify drawbacks of mobile phone manuals and gathered their requirements. They found that most older adults were dissatisfied with manuals. They criticized technical terms, technical details, incomprehensive explanations of what to do, insufficient orientation from user's perspective, and no separation of basic and special functions. Their most desired feature was complete and step-by-step description of basic functions. This was consistent with the well-documented recommendation that manuals for older adults should provide step-by-step illustration (Czaja et al., 1997; Mayhorn et al., 2005; Mayhorn et al., 2004; Morrell, Park, Mayhorn, & Kelley, 2000; Sherry & Arthur, 1998; Tuomainen & Haapanen, 2003).

Besides, manuals should carefully include spatial information. Bay (2003) asked middle-aged and older adults (range = 51–60) to use Nokia 3210 according to three manuals: conventional linear, step-by-step manuals; spatial tree structure manuals with relevant functions; and spatial tree structure manuals with the marked path. For middle-aged adults, spatial tree structure manuals contributed to better performance. In contrast, for older adults, the spatial tree structure manual was difficult, and the conventional linear, step-by-step manual was more suitable. This was supported by Czaja et al. (1997), who found that presenting a conceptual model of software to older adults tended to increase their working memory load. However, if the requirement of spatial ability was not high, spatial information such as representation of menu structure could help older adults (Pak, Czaja, Sharit, Rogers, & Fisk, 2008).

Interactive manuals could be as effective as paper-based manuals. Bruder et al. (2007) trained older adults (range = 50–77) to use a mobile phone through two manuals: a paper-based manual with colored screen shots, and an interactive manual on a touch screen computer. No significant differences between two manuals were found in terms of the number of keystrokes, time taken, use of help, and knowledge. The two manuals did not result in significant age-related differences. This was supported by results of training older adults to use desktop computers. The animated interactive manuals and the illustrated manual contributed to comparable performance (Echt, Morrell, & Park, 1998).

It is meaningful to investigate how to make both a paper-based manual and an interactive manual effective. The successful examples of Echt et al. (1998) and Bruder et al. (2007) used screen shots or static views of their interactive manual. Thus, their paper-based manuals were quite close to the interactive manuals. This may imply the necessity to provide photographic feedback of each step of operation.

6. OUTPUT DEVICES

6.1. Appearance

It is difficult to recommend the shape and color of handheld computers for older adults, because desired appearance is greatly influenced by personal preference. The following section serves only as a reference because of the lack of the support of controlled laboratory studies.

Besides, if elderly-specific mobile phones have an appearance greatly different from mainstream phones, some older adults may resist them. For example, some Finnish older adults refused to use these phones, because they did not want other people to think they were incapable (Mallenius et al., 2007). However, older adults from the United States preferred elderly-specific mobile phones rather than difficult regular phones, which required them to turn to family members for help (Wang, 2010).

Shape. Older women (range = 55–86) liked flip phones because they are easy to pick up and to end calls. They also thought phones with an antenna were easy to pick up from their handbags (Massimi et al., 2007). This was supported by two focus group studies. The results showed that older women liked flip phones with an antenna, whereas older men had no particular bias toward the shape (Kurniawan, 2008).

Some older adults disliked slide-out keyboards. They were confused about which direction to open the keyboards, and they were afraid of breakning the phone by applying too much pressure to open the keyboard. Therefore, they preferred keyboards in clamshell phones or integrated keyboards in flip phones (Massimi et al., 2007).

Older adults' preference for raised keys was well documented (Goodman et al., 2005; Kurniawan, 2006, 2008; Kurniawan et al., 2006; Tuomainen & Haapanen, 2003). Mendat (2006) found that both younger and older adults dialed numbers with the raised-rubber keypad more accurately and quickly than the flat-smooth keypad. This result is consistent with accessibility guidelines. Flat keypads are difficult for visually impaired people, because they cannot depend on the blurred labels to distinguish the keys.

Specifically, the keys should be raised at least 5 mm above the body of the mobile phone (Bekiaris et al., 2007). Also, raised keys were seen in elderly-specific mobile phones such as the Fujitsu's RaKu Raku Phone (Irie et al., 2005).

Size, weight, and position. Mobile phones should be big to grab and hold comfortably (Kurniawan, 2006; Kurniawan et al., 2008), so older adults will not drop them. On the other hand, mobile phones should not be excessively large or heavy (Massimi et al., 2007).

The size and weight of mobile phones should also match their containers. Some older women needed a larger mobile phone to be able to easily get it out of their handbags. In contrast, some older men had relatively strict requirements toward a light and thin mobile phone to fit in a pocket (Kurniawan, 2008; Tuomainen & Haapanen, 2003).

Some older adults associated phone length with sound quality. They thought that mobile phones that had a longer length from ear to mouth and bigger holes on the speakers would have better sound quality (Kim et al., 2007).

Keys at the back or side of mobile phones may be easily pressed by accident by older adults (Maguire & Osman, 2003; Massimi et al., 2007). Also, the battery should be able to be easily taken out and put in, and the phone should fit well in its charging stand (Mallenius et al., 2007).

Color. Color preference is gender related. For older women, color was reported to be a priority over other features when they chose mobile phones. Some older women liked a noticeable color, whereas others liked silver (Kurniawan, 2006, 2008; Kurniawan et al., 2006). The reason given for liking a plain color was that mobile phones of a noticeable color were prone to being stolen (Goodman & Gray, 2003; Kurniawan, 2006, 2008; Kurniawan et al., 2006; Nasir et al., 2008). In contrast, older men had no particular bias toward the color of mobile phones (Kurniawan, 2008).

Color should not be the only way of conveying information. An inverted color scheme with black buttons and white characters could enhance visibility. The color scheme should be carefully selected when designing mobile phones. The RaKu RaKu Phone even used a software to check color accessibility (Irie et al., 2005).

6.2. Display

Older adults' visual ability declines. They are less able to resolve visual details, to detect contrast, and to discriminate shorter wavelength light (Nichols et al., 2006). Therefore, display of handheld computers should be bright enough and provide large and clear text and icons.

Screen. A small screen leads to difficulty in recognizing and selecting a desired function. It is well documented that older adults liked mobile phones or PDAs with a large screen, sufficient contrast and illumination, good readability (Arning & Ziefle, 2006; Kurniawan, 2008; Maguire & Osman, 2003; Tuomainen & Haapanen, 2003), and sufficient time before the backlight turns off (Kurniawan, 2006).

Both younger and older adults would like "seeing text on one page" to avoid scrolling (Darroch, Goodman, Brewster, & Gray, 2005). Older adults had difficulty in relating the partial view caused by scrolling with the overall view, so they were disorientated (Hawthorn, 2000).

A screen magnifier is a possible solution to the mobile device's limited screen. Zhao, Rau, Zhang, and Salvendy (2009) investigated appropriate magnification mode (overlapping mode and parallel mode), background color, and output mode (mono mode or dual mode) for the screen magnifier on a tablet PC. They found that a screen magnifier with the overlapping mode, the yellow-highlighted background, and dual output mode for lower density text was more suitable for older adults.

Font. Vertical length of numbers influences visibility. When older adults read 11 numbers on each of six mobile phones, they took a longer time than younger adults to finish reading the numbers and they misread more numbers. This was because of their declined visual functions (i.e., 50 cm near vision and cataract cloudiness). The good news was that the vertical length of numbers could compensate for visual decline, because long numbers contributed to a better performance than short numbers. For older adults, the vertical length of the characters on mobile phones should be longer than 3 mm (Omori, Watanabe, Takai, Takada, & Miyao, 2002).

Reading text requires a moderate font size. Darroch et al. (2005) presented text with a font size between 2 and 16 points on HP iPAQ hx4700. They examined age effects on reading time, subjective rating, and comments. First, older adults had a comparable reading time with younger adults with a font size between 6 and 16 points. Second, the subjective rating indicated that both younger and older adults preferred a font size between 10 and 11 points. Third, older adults made positive comments on a font sizes of 8, 10, and 12 points, whereas younger adults made positive comments on the font sizes of 8 and 10 points. Therefore, on this handheld computer with a screen resolution of 640 × 480, a font size between 8 and 12 points was recommended for both younger and older adults.

The study of Darroch et al. (2005) contradicts the belief that older adults need larger text. One possible reason is that they did not investigate the influence of font size on reading errors. It is questionable whether older adults could read text with a font size between 8 and 12 points as accurately as younger adults.

Interline and intercharacter spacing also impacts text reading. Wang et al. (2009) presented Chinese text with different intercharacter spacing (0 px, 2 px, and 4 px) and interline spacing (2 px, 4 px, 6 px, and 8 px) on NEC N6305. Older adults were asked to read articles and search for specified characters. For higher text readability, lower visual fatigue, and higher preferences, 8-point Chinese characters should be presented at an interline spacing of 6 to 8 px, intercharacter spacing of 2 to 4 px.

Icon. Not all older adults are aware of the exact meaning of standard application icons in a PDA and cell phones (Goodman et al., 2005), especially when similar icons are arranged together or the icons are incomplete (C.-F. Lee & Kuo, 2007). The following section includes studies of icon pattern, icon size, and icon arrangement.

There are disagreements over the role of the concrete icon pattern. Older adults preferred icons with the realistic pictures to those with illustrated drawings. They thought pictures were clearer (Moor et al., 2004; Siek et al., 2005). However, other studies reported that icon concreteness (i.e., whether icons were concrete or abstract) did not help older adults understand icon meaning. Instead, icons with close semantic distance, which meant stronger association between an icon and its meaning, were more helpful for older adults (Leung, 2009; Leung, McGrenere, & Graf, 2009).

Larger icon size could improve older adults' performance. When 24-px icons became 32-px icons on the PocketPC, older adults (range = 65–84) had comparable accuracy with other age groups. Larger icon improved the accuracy and speed of tapping and steering tasks, and the speed of touching tasks. Therefore, the recommended icon size for middle-aged adults (range = 50–64) was 24 px (5.76 mm), whereas for older adults it was 32 px (7.68 mm; Hourcade & Berkel, 2006, 2008).

However, two studies recommended an icon size nearly two times that recommended by Hourcade and Berkel (2006, 2008). When reading icons from 5 mm, to 25 mm on a PDA, older adults preferred 20 mm icons ($M = 18.5$ mm; $SD = 6.687$ mm), whereas younger adults preferred 10 mm or 5 mm ($M = 10$ mm; $SD = 3.33$ mm) on a PDA (Moor et al., 2004; Siek et al., 2005). Because the two studies just asked older adults whether they could read icons, lacking measures of reading time and accuracy, the icon size recommended by Hourcade and Berkel (2006, 2008) has more reference significance.

Icons can be arranged on screen at different numbers and spacing. Leonard et al. (2005) investigated the role of the number of icons per screen (4, 8, and 12 icons) and intericon spacing (0.25, 0.5, and 1 icon). Older adults (range = 50+) searched, selected, and manipulated playing card icons with a stylus on a Pocket PC. The results showed that more icons per screen resulted in longer trial time and visual search time, and larger intericon spacing resulted in longer drag distance (Leonard, Jacko, & Pizzimenti, 2005). It is worth mentioning that the majority of older adults were visually impaired with age-related macular degeneration. Further consideration is needed to generalize this result.

7. SUMMARY AND DISCUSSION

7.1. Acceptance

Most previous studies investigate older adults' acceptance from two perspectives. The first is the acceptance process. Typical examples are the adoption matrix (Van Biljon & Renaud, 2008) and STAM (Renaud & Van Biljon, 2008). The second is internal psychological factors, which are summarized in Figure 2. Older adults' acceptance of handheld computers is influenced by usefulness, social influence, usability, and support. The typical example is the extended TAM (Arning & Ziefle, 2007b). However, most of these acceptance factors are derived from qualitative studies without quantitative validation.

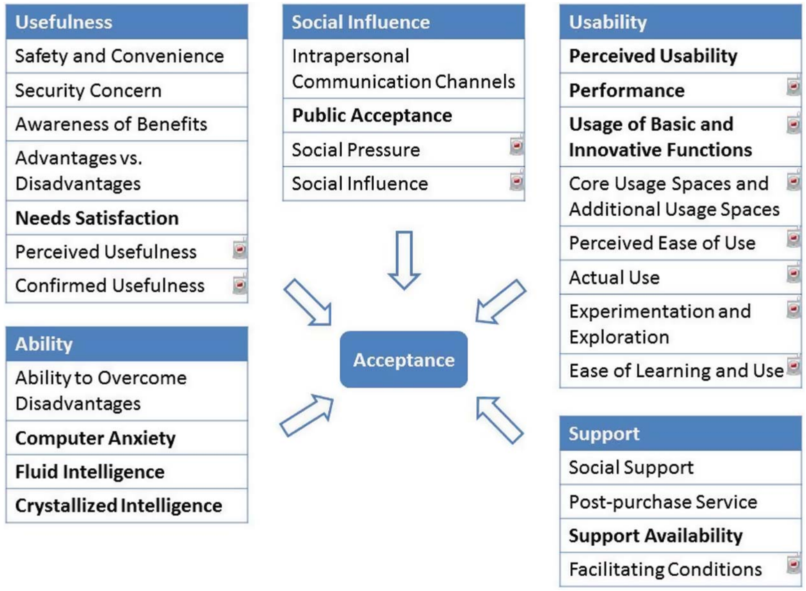

FIG. 2. Older adults' acceptance factors (color figure available onine).

Note.  = the acceptance factors of handheld computers. Bold words = the acceptance factors are validated in quantitative research.

There is a lack of rigorously validated models investigating older adults' acceptance of handheld computers.

Most studies focus on usability, but it is not necessary and sufficient for acceptance. On one hand, usability is not enough to guarantee acceptance. Older adults' performance of using handheld computers explained only a small variation of acceptance (Arning & Ziefle, 2007b). On the other hand, poor usability does not necessarily result in resistance. Older adults may sacrifice usability for advantages. Although they perceived usability lower than younger adults, they had higher acceptance (Lanzolla, 2004; Mayhorn et al., 2005). Few studies investigate how much usability and other acceptance factors contribute to acceptance. Future studies may identify key influential factors of acceptance.

It is also important to note two differences in understanding older adults' acceptance of handheld computers. First, it differs from the acceptance of general technology. Handheld computers differ from other appliances in that they serve as a platform to integrate more and more functions. Prior studies usually care about the purchase or owning of handheld computers, but no study investigates the acceptance of functions. How will older adults go beyond basic functions to advanced functions? Future studies can extend acceptance at the product level further to the function level. Also, handheld computers differ from desktop computers in their mobility, limited size, and privacy. These characteristics may imply that there are new acceptance factors. However, previous studies only try to apply acceptance factors of general technology to handheld computers. Future studies may work on unique acceptance factors of handheld computers.

Second, older adults' acceptance of handheld computers differs from general population's acceptance. Age differences were found in acceptance factors and antecedents. Previous studies showed that older adults generally had lower perceived ease of use and perceived usefulness than younger adults. Task effectiveness was more important for older adults' perceived ease of use, whereas task efficiency was more important for younger adults' perceived ease of use (Arning & Ziefle, 2007b). However, few studies investigate how age could change the influence of acceptance factors on acceptance.

7.2. Input

As to text input, both physical keyboards and on-screen keyboards have their problems. For physical QWERTY keyboards, the main problems are related to modifier keys and compressed keys. For physical 12-key telephone keypads, the main problem is related to the multitap. In contrast, on-screen keyboards can have multiple layouts, but changing layouts is confusing for older adults. Solutions to these problems are summarized in Table 1.

Preference of input devices depends on tasks. For the text entry task, both younger and older adults preferred physical QWERTY keyboards to on-screen QWERTY keyboards (Wright et al., 2000). In contrast, for the pointing task, most older adults preferred tapping on-screen controls with a stylus rather than pressing physical controls (Kang & Yoon, 2008).

Different selection methods could reduce the problem of instable hands. Older adults usually make more submovements, so tapping is not easy for them. One solution is to support touch and slide. This proved to be better than tapping when the target is small (Hourcade & Berkel, 2006, 2008).

TABLE 1
Summary About Usability

Problems Using Handheld Computers	Design Notes

Physical controls
• compressed keys
• modifier keys (Li & Graf, 2007; Massimi et al., 2007).
• distinguishing short and long press (Kang & Yoon, 2008).
12-key telephone keypads:
• multi-tap to activate grouped letters
  ○ could not understand the association (Kurniawan, 2008).
  ○ could not press quickly (Jastrzembski, 2006; Jastrzembski & Charness, 2007; Weilenmann, 2010).
Directional pads:
• some confusion about the two-dimension directional pad (Moor, et al., 2004; Siejijuk et al., 2005).
	• key size and spacing
	  ○ key area larger than 0.6–0.8 cm
	  ○ interkey spacing 5.6–7.5 mm (Bekiaris et al., 2007).
	• activating keys
	  ○ flat key top
	  ○ the pressure to activate a key between 0.5N and 0.9N (Bekiaris et al., 2007).
	• differentiating keys by tactile cues
	  ○ if a raised-rubber keypad, locating the tactile cue on the number 5 key
	  ○ if a flat-smooth keypad, locating tactile cues on 1, 3, 5, 7, 9 keys (Mendat, 2006).
	• differentiating keys by color, contour, and position
	  ○ if older women, distinguishing keys by position
	  ○ if older men, distinguishing keys by contour and color (Kurniawan, 2008).
	• text prediction
	  ○ may be distracting when choosing among candidate words (Kurniawan, 2006, 2008).
	• shortcuts
	  ○ may use digits on keypads to activate menu items with corresponding digits (Kim et al. 2007; Massimi et al., 2007)
	• jog wheel vs. directional pad
	  ○ older adults preferred jog wheels to directional pads (Massimi et al., 2007)
	  ○ jog wheels could locate at the side (Massimi et al., 2007; Zao et al., 2008).

On-screen controls with a stylus
• inappropriate pressure
• inadequate feedback
• the change of modes (Massimi et al., 2007).
• softkeys (Massimi et al., 2007; Tuomainen & Haapanen, 2003).
Handwriting:
• instable hands if the handwriting area was not full screen (Lee & Kuo, 2007).
	• stylus length
	  ○ more than 11cm for both younger and older adults (Takahashi et al., 2005).
	• ways to select targets
	  ○ tapping
	  ○ touching, better when the target size was 16-pixel (Hourcade & Berkel, 2006, 2008).
	• discrete control vs. continuous control for digit entry.
	  ○ on-screen navigation keys, difficult to understand
	  ○ sliders with a stylus, difficult to control
	  ○ on-screen numerical keypad, best (Nischelwitzer et al., 2007)
	• physical control vs. on-screen control for text entry
	  ○ on-screen QWERTY keyboard with a stylus
	  ○ physical QWERTY keyboard, better (Wright et al., 2000).

(*Continued*)

TABLE 1
(Continued)

Problems Using Handheld Computers	Design Notes
	• physical control or on-screen control for pointing tasks ○ joystick ○ buttons ○ touchpad with a stylus, preferred by most older adults (Kang & Yoon, 2008). • handwriting vs. typing ○ physical keyboard ○ handwriting, preferred by older adults (Sterns, 2005; Sterns & Collins, 2004)
when tapping the drop-down menu with a stylus, errors include: • slipping • drifting • missing just below	• the tap interface ○ reduced drifting and was well received • the glide interface • the reassigned edge interface • the deactivated edge interface ○ reduced missing just below, ○ but also resulted in more taps (Moffatt, 2008; Moffatt & Mcgrenere, 2007, 2009; Moffatt et al., 2008)
Menus • disorientation (Arning & Ziefle, 2007a; Kurniawan, 2008; Lee, 2007; Maguire & Osman, 2003; Osman at al, 2003; Sjölinder, 2006; Sjölinder et al., 2005; Ziefle & Bay, 2005, 2006) • deep menu ○ older adults have shallower mental model than younger adults. ○ could on average recall 2.1 levels (Ziefle & Bay, 2004).	• the total number of functions ○ reducing functionality ○ broad functionality (Hellman, 2007; Maguire & Osman, 2003; Massimi et al., 2007) ○ both must-have and optional functions in a model (Renaud &Van Biljon, 2010). • the number of functions per screen ○ large font size helps ○ large preview size (i.e. more functions per screen) helps ○ if the two factors contradict, preview size more important than font size (Ziefle, 2009, 2010) • dimensions of the menu ○ icon-based menus arranged in columns and rows ○ text-based menus arranged in a list, preferred by some older adults (Kurniawan, 2006; Kurniawan et al., 2006) • providing contextual information ○ one navigation aid showing the name and contents of the current category ○ the other one showing the parents, parent-parents, and subcategories, better (Ziefle & Bay, 2006)
Manuals • technical term • technical details • incomprehensive explanations of what to do • insufficient orientation from users' perspective • no separation of basic and special functions (Bruder et al., 2006).	• manual structure ○ linear step-by-step manuals, preferred by older adults ○ spatial tree structure manuals with relevant functions, can be confusing ○ spatial tree structure manuals with the marked path, can be confusing (Bay, 2003). • interactivity ○ an interactive manual ○ a paper-based manual with colored screen shots, can be equally effective (Bruder et al., 2007).

(*Continued*)

TABLE 1
(Continued)

Problems Using Handheld Computers	Design Notes
Functions	
When entering medications with a stylus, reasons for difficulties include: • perceptual speed • experience • reading comprehension (Lanzolla, 2004; Mayhorn et al., 2005)	• training ◦ small class size, five people better than 10 people per class (Sterns, 2005). ◦ initial success ◦ self-paced training ◦ enough practice time (Mayhorn et al., 2004) • different ways of medication alert (Liang et al., in press)
When navigating in real environment, reasons for difficulties include: • spatial ability (Arning & Ziefle, 2009; Sjölinder et al., 2005) • working memory (Garden et al., 2002)	• modalities to present landmarks in the mobile navigation aid ◦ the photographic interface, more helpful than a map (Goodman et al., 2004a, 2004b) ◦ the text and speech interface ◦ the text only interface ◦ the speech only interface, resulted in higher disorientation (Goodman et al., 2005). • angle of view in navigation aids ◦ the bird's-eye image ◦ the image from the user's perspective ◦ the text only instruction ◦ audio only instructions through earphones, most helpful and contributed to best performance (Ficksa, et al., 2008) • navigation service ◦ presenting en route static and dynamic barriers (Kawamura et al., 2008). ◦ pre-trip planning and emergency (Mikkonen et al., 2002; Zhou et al., 2007). ◦ short and long distance trips (Zhou et al., 2007).
When browsing mobile web pages, problems with: • visibility • focus recognition • understanding • operation • web page structure (Asano, et al., 2007)	• hyperlinks ◦ underlined hyperlinks, hampered older adults' performance (Ziefle et al., 2007). ◦ hyperlinks like buttons, preferred by older adults (Sayago, 2006) • the structure of mobile web pages ◦ the structure similar to that that of online websites, preferred by younger adults ◦ the structure different from that of online websites, preferred by older adults (Sayago, 2006).
Font	
• poor visibility	• vertical length, longer than 3 mm (Omori et al., 2002) • font size, between 8 and 12 point for both younger and older adults (Darroch et al., 2005) • font arrangement, if 8-point Chinese characters, interline spacing of 6–8 pixels, intercharacter spacing of 2–4 pixels (Wang et al., 2009)

(*Continued*)

TABLE 1
(Continued)

Problems Using Handheld Computers	Design Notes
Icon	
• meaning of icons	• icon concreteness ○ icons with the realistic pictures better than those with illustrated drawings (Moor et al., 2004; Siek et al., 2005). ○ whether icons are concrete or abstract did not help (Leung, 2009; Leung et al., 2009). • icon semantic distance ○ stronger association between an icon and its meaning, more helpful for older adults (Leung, 2009; Leung et al., 2009). • icon size ○ 32 pixels (7.68 mm) (Hourcade & Berkel, 2006, 2008). • icon arrangement ○ the number of functions per screen influenced performance (Leonard et al., 2005).

Future studies could continue to find the best input device for text input from four ways. First, there is a lack of studies on finger input. Results of stylus-based input may not apply to finger input because finger input supports gestures and blurs the distinction between touchable and untouchable interface elements. It is worthwhile to investigate how well older adults learn and recall gestures, and how to provide better clues besides buttons and hyperlinks for touchable and untouchable interface elements.

The second way is to better balance keyboard layout and combined operation. Older adults have difficulty with compressed keys, so the 12-key telephone keypads would be better than the QWERTY keyboards when the space is the same. However, older adults also have difficulty with combined operation such as short and long press on one key, so QWERTY keyboards would be better than the 12-key telephone keypads. Future studies may compare physical and on-screen the 12-key telephone keypads, half QWERTY keyboards, and full QWERTY keyboards. This could identify the more important issue when there is a conflict between key size and combined operation.

Third, future studies can improve handwriting and compare it with other input devices. Older adults feel confusing when switching among letters, symbols, and digits. Even so, it is intuitive and may be more helpful for languages other than English. No quantitative studies compare handwriting with physical and on-screen keyboards. Also, it is also interesting to compare stylus-based handwriting and finger handwriting. This could help practitioners know whether it is necessary to equip a capacitive touch screen with a special stylus.

The fourth way is to test new interaction technology (e.g., voice interaction, QR, RFID, and NFC). The first step is to ensure access to the technology. If older adults cannot easily enable the technology, they cannot enjoy the convenience. Then, it is necessary to consider how to easily switch between new interaction technology and traditional controls.

7.3. Menu and Functions

Deep menu is difficult for older adults, because they had shallower mental representation of the mobile phone menus than younger adults (Ziefle & Bay, 2004). One solution is to provide contextual information of each level of menu. The navigation aid that shows the parents and parent-parents is better than that which only shows current category (Ziefle & Bay, 2006).

Broad menu needs to fit the right number of functions per screen. More functions per screen contributes to better performance of older adults, but it also results in smaller font size. When the contradiction happens, more functions per screen is more important than larger font size (Ziefle, 2009, 2010).

Older adults used to have serious problem with deep menu, but now they may have more problems with broad menu. Feature phones used to provide deep hierarchical menus, and older adults could only remember two levels (Ziefle & Bay, 2004). This is no longer a big problem because the menu depth of most Android and iOS phones is less than two levels. However, current smartphones may cause new problems at the same time. Older adults may have difficulty in switching among multiple start screens, organizing applications, and closing applications during multitasking. Future studies could investigate older adults' mental model of multiple start screens and shortcuts.

There is no conclusion on how many and which functions are suitable for older adults. Future studies could segment older adults. Their technical experience, lifestyle, and personality may influence their needs of functions. This could help practitioners better reach different groups of older adults.

Access to functions is important. Before discussing the design of applications, it is worthwhile to think about how to deliver applications to older adults. Past experience may make older adults have wrong mental models. For example, searching mobile web pages on feature phones requires users to find the function and input URL. In contrast, on current smartphones, widgets such as Google search just appear on the start screen and do not need a URL. Because many older adults use old mobile phones, they may perceive some functions as unnecessarily complex. Even if they adopt smartphones, they are not expected to download applications from application stores. If they cannot access applications, advantages of functions is empty talk.

Studies of three functions are summarized in Table 1. For medication application, entering medications could be difficult. For browsing application, older adults had problems with hyperlinks. For navigation application, different modalities can be comparative effective, but the speech-only interface should be carefully used (Goodman et al., 2005). Future studies may investigate how much details in maps is suitable for older adults, which could help them choose from traditional mode, the satellite mode, the 3D mode, and the terrain mode.

7.4. Output

A font size between 8 and 12 points is recommended for both younger and older adults (Darroch et al., 2005). However, interpreting this result needs to consider resolution and input devices. For finger input, the font size big enough to read may be too small for fingertips. Also, a too-large font may result in scrolling and poorer overview of functions per screen.

Larger icon size could improve older adults' performance. The recommended icon size for older adults was 32 px (7.68 mm; Hourcade & Berkel, 2006, 2008). Also, intuitive icon patterns could help older adults. However, there is disagreement on which of concrete icons or abstract icons are better for older adults. Future studies can work on how to help older adults understand icon meaning.

The one-to-many relationship between input and output seems to be confusing for older adults. They need to build mental models of a physical key with multiple digits and letters, a softkey with multiple labels, a directional pad and multiple menu items. Even if they understand the one-to-many relationship, they have a hard time to switch through multitap, or short and long press (Kang & Yoon, 2008). Unfortunately, tapping and holding are common in current smartphones to activate pop-up menus. In practice, some older adults use digits on keypads to activate menu items with corresponding digits (Kim et al., 2007). They like the one-to-one relationship.

One remaining question is whether handheld computers for older adults should be different from mainstream products. This may depend on experience and age effects. Among quantitative studies, four items were not related to age differences: keyboards (Wright et al., 2000), raised-rubber keypads (Mendat, 2006), the stylus (Hourcade & Berkel, 2006, 2008; Kang& Yoon 2008; Takahashi et al., 2005), and font size (Darroch et al., 2005). In contrast, five items were related to age differences: perceived ease of use (Aring & Ziefle, 2007b), mental model of menus (Ziefle & Bay, 2004), hyperlinks (Sayago, 2006; Ziefle et al., 2007), spatial information in manuals (Bay, 2003), and icon size (Hourcade & Berkel, 2006, 2008). Therefore, it seems that input devices for older adults could be the same as mainstream products, whereas menus and output devices could be different. However, more studies are needed to study elderly specific design and universal design.

To conclude, design handheld computers for older adults should consider not only usability but also acceptance in broader contexts. Although many mobile phones for older adults feature big fonts, big buttons, large displays, and loud volume, this is just the tip of the iceberg. Below the water lie design modifications related to older adults' declined cognitive abilities.

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APPENDIX

TABLE A1
Method and Demographic Information

		Older Adults				Middle-Aged Adults				Younger Adults			
Studies	Method	*N*	*M*	*SD*	Range	*N*	*M*	*SD*	Range	*N*	*M*	*SD*	Range
Arning & Ziefle (2006)	Survey	50	52.8	6.1	N/A	0	N/A	N/A	N/A	50	24.8	2.2	N/A
Arning & Ziefle (2007a)	Controlled laboratory study	48	58.2	6.0	N/A	0	N/A	N/A	N/A	48	23.2	2.4	N/A
Arning & Ziefle (2007b)	Controlled laboratory study	16	56.4	6.7	50–69	0	N/A	N/A	N/A	16	23.8	2.8	18–27
Arning & Ziefle (2009)	Controlled laboratory study	16	56.4	6.7	N/A	0	N/A	N/A	N/A	16	23.8	2.8	N/A
Asano et al. (2007)	Controlled laboratory study	10	65.4	N/A	55+	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Bay (2003)	Controlled laboratory study	18	N/A	N/A	51–60	18	N/A	N/A	32–50	0	N/A	N/A	N/A
Bruder et al. (2006)	Interview, Observation	20	68	N/A	58–80	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Bruder et al. (2007)	Controlled laboratory study	49	65.3	N/A	50–77	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Darroch et al. (2005)	Controlled laboratory study	12	N/A	N/A	61–78	0	N/A	N/A	N/A	12	N/A	N/A	18–29
Goodman et al. (2004a, 2004b, 2005)	Controlled laboratory study	16	N/A	N/A	63–77	0	N/A	N/A	N/A	16	N/A	N/A	19–34
Goodman et al. (2005)	Controlled laboratory study	24	N/A	N/A	60–78	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Hourcade & Berkel (2006, 2008)	Controlled laboratory study	20	71.6	N/A	65–84	20	57.4	N/A	50–64	20	19.5	N/A	18–22
Huh & Kim (2008)	Survey	23	N/A	N/A	50+	0	N/A	N/A	N/A	102	N/A	N/A	27–49
Inglis et al. (2003)	Interview, Focus Group	10	72.9	N/A	54–86	7	38.4	22–54	N/A	0	N/A	N/A	N/A
Jastrzembski (2006)	Controlled laboratory study	20	69.1	3.5	60–75	0	N/A	N/A	N/A	20	18.7	1.3	N/A
Kang & Yoon (2008)	Controlled laboratory study 1	30	52	4.6	46–59	0	N/A	N/A	N/A	30	25	2.1	21–29
Kang & Yoon (2008)	Controlled laboratory study 2	30	54	4.5	46–59	0	N/A	N/A	N/A	30	25	1.8	20–27
Kawamura et al. (2008)	Controlled laboratory study, Usability Testing	20	N/A	N/A	70–90	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Kim et al. (2007)	Interview, Observation	11	64.8	3.82	61–72	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Kurniawan (2006, 2008); Kurniawan et al. (2006)	Focus Group	7	Median =67.5	N/A	N/A	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Kurniawan (2006, 2008); Kurniawan et al. (2006)	Online Survey	100	N/A	N/A	72 people aged 60–65	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Kurniawan (2008)	Delphi Interview	1	78	N/A	78	0	N/A	N/A	N/A	1	28	N/A	28
Kurniawan (2008)	Focus Group	7	Median =65	N/A	N/A	0	N/A	N/A	N/A	0	N/A	N/A	N/A

Lanzolla (2004); Mayhorn et al. (2005)	Controlled laboratory study	25	67.36	5.24	60–76	0	N/A	N/A	N/A	26	18.65	1.4	17–23
Lee & Kuo (2007)	Controlled laboratory study	5	67.9	3.8	65+	5	52.1	3.9	45–58	5	27.9	5.2	21–35
Lee (2007)	Survey	154	70.8	7.0	56–90	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Lee (2007)	Interview	12	70.8	7.8	58–84	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Leonard (et al. (2005)	Controlled laboratory study	13	N/A	N/A	50+	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Leung (2009); Leung et al. (2009)	Qualitative Exploratory Study	0	N/A	N/A	N/A	10	N/A	N/A	20–91	0	N/A	N/A	N/A
Leung (2009); Leung et al. (2009)	Controlled laboratory study	18	N/A	N/A	65+	0	N/A	N/A	N/A	18	N/A	N/A	20–39
Li & Graf (2007)	Observation	21	N/A	N/A	61–85	21	N/A	N/A	40–60	21	N/A	N/A	18–39
Liang et al. (in press)	Self Report, Interview, Observation, Persona	12	N/A	N/A	65+	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Maguire & Osman (2003)	Interview	17	59.5	N/A	47–79	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Mallenius et al. (2007)	Interview	16	N/A	N/A	N/A	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Massimi et al. (2007)	Participatory Activity, Paper Prototyping	5	73.2	11.52	55–86	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Mayhorn et al. (2005)	Controlled laboratory study	25	67.3	5.24	60–76	0	N/A	N/A	N/A	26	18.6	1.4	18–23
Mendat (2006)	Controlled laboratory study 1	16	71.4	4.63	62–83	0	N/A	N/A	N/A	16	18.5	0.7	18–20
Mendat (2006)	Controlled laboratory study 2	16	64	3.97	60–74	0	N/A	N/A	N/A	16	19	1.7	18–25
Mendat (2006)	Controlled laboratory study 3	14	70.1	4.32	62–78	0	N/A	N/A	N/A	14	19.4	1.7	18–23
Mendat (2006)	Controlled laboratory study 4	10	66.2	3.99	60–71	0	N/A	N/A	N/A	10	19.8	1.8	18–23
Mikkonen et al. (2002)	Ideation Session	33	77	N/A	59–92	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Mikkonen et al. (2002)	Concept Study	44	74	N/A	51–87	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Moffatt & McGrenere (2007)	Controlled laboratory study	12	76.3	N/A	70–85	12	62.1	N/A	55–69	12	31.7	N/A	18–54
Moffatt & McGrenere (2009)	Controlled laboratory study	12	73	N/A	66–81	0	N/A	N/A	N/A	12	24	N/A	19–30
Moffatt et al. (2008)	Controlled laboratory study	12	72	N/A	65–85	0	N/A	N/A	N/A	12	21	N/A	19–25
Moor et al. (2004); Seik et al. (2005)	Controlled laboratory study	10	N/A	N/A	75–85	0	N/A	N/A	N/A	10	N/A	N/A	25–30
Nasir et al. (2008)	Survey	176	N/A	N/A	56+	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Nischelwitzer et al. (2007)	Usability Testing, Card Sorting, Paper Prototyping	15	65	N/A	36–84	0	N/A	N/A	N/A	4	26	N/A	20–33
Omori et al. (2002)	Controlled laboratory study	60	N/A	N/A	60–86	0	N/A	N/A	N/A	70	N/A	N/A	18–59
Osman et al. (2003)	Focus Group	12	N/A	N/A	55+	0	N/A	N/A	N/A	12	N/A	N/A	20–25
Osman et al. (2003)	Interview	17	N/A	N/A	47–79	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Renaud & Van Biljon (2008, 2010); Van Biljon & Renaud (2008)	Interview, Observation	34	N/A	N/A	60–92	0	N/A	N/A	N/A	0	N/A	N/A	N/A

(Continued)

TABLE A1
(Continued)

		Older Adults				Middle-Aged Adults				Younger Adults			
Studies	Method	*N*	*M*	*SD*	Range	*N*	*M*	*SD*	Range	*N*	*M*	*SD*	Range
Sayago (2006)	Usability Testing	4	N/A	N/A	N/A	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Sjölinder (2006)	Controlled laboratory study	24	63.8	N/A	60–72	0	N/A	N/A	N/A	24	23.4	N/A	22–26
Sterns & Mayhorn (2006)	Controlled laboratory study	25	67.3	5.25	N/A	0	N/A	N/A	N/A	24	18.6	1.4	N/A
Sterns (2005); Sterns & Mayhorn (2006)	Traning, Retention Test	44	72	7.08	56–89	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Takahashi et al. (2005)	Controlled laboratory study	12	N/A	N/A	60–71	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Tuomainen & Haapanen (2003)	Interview, Observation	22	N/A	N/A	59–79	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Van Biljon (2007); Van Biljon & Kotzé (2007)	Interview	2	N/A	N/A	40–49	2	N/A	N/A	30–39	2	N/A	N/A	20–29
Wang et al. (2009)	Controlled laboratory study	12	66	11	N/A	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Weilenmann (2010)	Observation	5	N/A	N/A	N/A	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Wright et al. (2000)	Controlled laboratory study 1	8	62	4.6	57–68	8	62	5.3	59–69	0	N/A	N/A	N/A
Wright et al. (2000)	Controlled laboratory study 2	8	52.8	4.4	56–68	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Wright et al. (2000)	Controlled laboratory study 3	8	60	2.9	55–65	8	38.6	3.9	35–45	8	20.4	1.1	18–25
Zao et al. (2008)	Observation, Interview, Persona	10	N/A	N/A	N/A	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Zao et al. (2008)	Paper-based Prototype Usability Testing	15	61.2	N/A	50–78	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Zhao et al. (2009)	Controlled laboratory study	72	73.9	3.78	67–84	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Zhou et al. (2007)	Focus Group	9	72.6	2.51	68–75	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Ziefle & Bay (2004)	Controlled laboratory study, Card Sorting	16	N/A	N/A	50–64	0	N/A	N/A	N/A	16	N/A	N/A	20–32
Ziefle & Bay (2005)	Controlled laboratory study	16	55.5	N/A	50–64	0	N/A	N/A	N/A	16	23.1	N/A	20–32
Ziefle & Bay (2006)	Controlled laboratory study	16	52.9	3.7	46–60	0	N/A	N/A	N/A	16	25.1	1.4	23–28
Ziefle (2010)	Controlled laboratory study	40	58.9	7.4	55–73	0	N/A	N/A	N/A	0	N/A	N/A	N/A
Ziefle et al. (2007)	Controlled laboratory study	10	59	3.7	N/A	0	N/A	N/A	N/A	10	22.6	2.4	N/A