Designing Mobile Interfaces for Novice and Low-Literacy Users

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While mobile phones have found broad application in bringing health, financial, and other services to the developing world, usability remains a major hurdle for novice and low-literacy populations. In this article, we take two steps to evaluate and improve the usability of mobile interfaces for such users. First, we offer an ethnographic study of the usability barriers facing 90 low-literacy subjects in India, Kenya, the Philippines, and South Africa. Then, via two studies involving over 70 subjects in India, we quantitatively compare the usability of different points in the mobile design space. In addition to text interfaces such as electronic forms, SMS, and USSD, we consider three text-free interfaces: a spoken dialog system, a graphical interface, and a live operator.

Our results confirm that textual interfaces are unusable by first-time low-literacy users, and error prone for literate but novice users. In the context of healthcare, we find that a live operator is up to ten times more accurate than text-based interfaces, and can also be cost effective in countries such as India. In the context of mobile banking, we find that task completion is highest with a graphical interface, but those who understand the spoken dialog system can use it more quickly due to their comfort and familiarity with speech. We synthesize our findings into a set of design recommendations.

Categories and Subject Descriptors: H.5.2 [**Information Interfaces and Presentation**]: User Interfaces

General Terms: Design, Human Factors

Additional Key Words and Phrases: Mobile banking, mobile health, data entry, data accuracy, illiteracy

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1. INTRODUCTION

There were over 4 billion phone users in 2008 [ITU 2009], and close to 60% of subscribers live in developing countries [UNCTAD 2008]. Thus, many entities with a global development focus have turned to the mobile phone as a potential platform for delivering development services, in sectors spanning education, finance, health, agriculture, and governance [Donner 2008]. One of the challenges of delivering such services, however, is that 41% of the population in the least developed countries is

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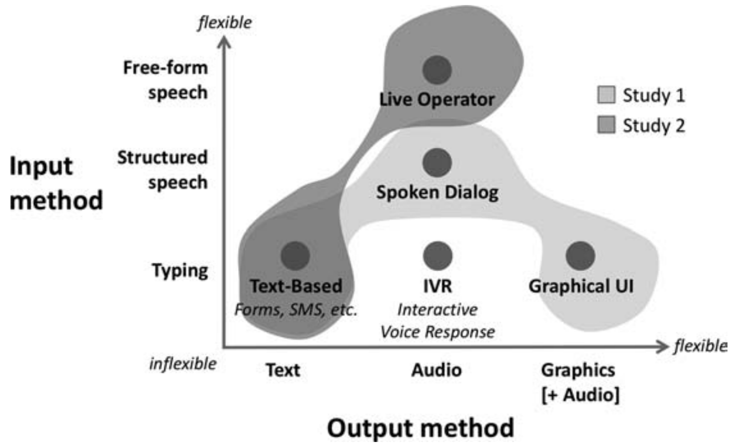


Fig. 1. Design space of mobile user interfaces. Shaded regions indicate the comparative studies presented in this article.

nonliterate [UNESCO 2007], and even the literate among the poor are typically novice users of computer technologies. Previous research shows that nonliterate populations avoid complex functions, and primarily use phones for synchronous voice communication [Chipchase 2005]. This brings us to the question of how we can design mobile phone interfaces such that novice and low-literacy users can use more advanced services, if they were provided.

Mobile devices lend themselves to a rich design space of alternative user interfaces. As depicted in Figure 1, it is natural to classify mobile interfaces along two axes, according to the flexibility of their input and output modalities. Rigorous comparisons between points in this space are only starting to be explored by researchers. Concurrently to the studies conducted in this article, researchers have examined the trade-offs between interactive voice response (spoken menus with keypad navigation) and spoken dialog systems (spoken menus with speech navigation) and have reached varying conclusions regarding the benefits of typed versus spoken inputs [Grover et al. 2009; Patel et al. 2009; Sherwani et al. 2009]. However, to the best of our knowledge, there has never been a quantitative evaluation of mobile interfaces that encompasses the full space of designs, spanning text, audio, and graphics. We present the first such evaluation in this article.

The contributions of this article are twofold. First, in order to understand the usage patterns of nonliterate and semiliterate mobile phone users, we conducted an ethnographic exploration involving 79 subjects and 100 hours of interviews in India, the Philippines, and South Africa. We also leverage 11 interviews conducted in Kenya by Ratan [2008]. This investigation revealed several barriers to using existing text-based interfaces, including difficulties understanding or utilizing hierarchical structures, soft keys, scroll bars, nonnumeric inputs, and specialized terminology. We formulate a set of design recommendations to improve the usability for low-literacy populations, including the provision of graphical cues, voice annotations, and local language support, as well as avoiding complex navigation and inputs.

To evaluate and refine these guidelines, we conducted two separate experiments that quantitatively assess the impact of various design elements on novice and low-literacy users. Depicted graphically in Figure 1 and summarized in Table I, these studies incorporate over 70 subjects in India and represent the second contribution of the article. Both studies compare text-based mobile interfaces to richer alternatives.

Table I. Summary of the Quantitative Studies in This Article

	Study 1: Text vs. Voice and Graphics	Study 2: Text vs. Live Operator
Task	Complete mobile banking transaction	Enter health data with minimal errors
Interfaces Compared	Text (USSD) Spoken dialogue Graphical UI	Text (Electronic Forms) Text (SMS) Live operator
Subjects	58 non-literate and semi-literate subjects (Bangalore, India)	13 literate health workers and hospital staff (Gujarat, India)
Training and Testing	No training provided; Prompts offered during testing	Training provided until proficient; No help offered during testing
Results	Text interface unusable without literacy Spoken dialogue: only 72% of subjects finished task, but quickly and with less assistance Graphical UI: 100% of subjects finished task, but slowly and with more assistance	High error rate on text interfaces: 4.2% for Forms, 4.5% for SMS Live operator decreased errors by order of magnitude (0.45% error rate)
Recommendations	Non-literate subjects need non-text UIs Spoken input, graphical output could combine benefits of studied designs	Where it is economical to do so, employing a live operator is preferable to text UIs for mobile data collection

The first study considers automatic solutions (spoken dialog[1] and graphical, text-free UI [Medhi et al. 2007b]), and the second study compares text input to a live human operator. In both scenarios, we find that the nontext interfaces greatly outperform their textual counterparts. In the context of mobile banking, not a single low-literacy subject could complete a transaction using the text interface, while 72% completed the task using spoken dialog and 100% were successful using a graphical UI. In the context of health data entry, literate health workers and hospital staff demonstrated approximately a 5% error rate using text interfaces, but performed ten times better using a live operator.

Our studies also uncover new trade-offs in designing mobile interfaces for novice and low-literacy users. While the spoken dialog system offered lower rates of task completion than the graphical interface, users that did succeed in completing the task did so more quickly and with less external assistance on the spoken dialog system. We attribute this to the fact that most users are more comfortable and familiar with providing spoken inputs, and thus can complete task more quickly; however, some users lack a basic understanding of the context, the terminology, or the interface and, being unable to acquire that understanding through an automated spoken dialog system, are unable to complete the task at all. For the graphical UI which required typed inputs to proceed, we observed that while task completion rates were higher, more time as well as more external assistance was required. We attribute this to the fact that users required significant prompting, encouragement, and time to press any key as they were nervous that they might "break" or "spoil" the phone. Also, our evaluation of the live operator interface suggests that it offers several benefits in addition to the high accuracy achieved, including the ability to change the interface over time and the ability for users to convey detailed, unstructured information over the phone. In environments such as India, an operator interface is also highly cost effective, and can be less expensive than providing programmable phones to field staff. For these reasons, the results of our study caused a community partner to change their plans for a rural tuberculosis treatment program from using electronic forms to using a live operator.

In the rest of this article, we describe related work (Section 2) before presenting our ethnographic investigation (Section 3) and each of our user studies (Sections 4 and 5). We conclude in Section 6. Our presentation summarizes and extends research whose

[1]Our spoken dialog system utilizes Wizard-of-Oz speech recognition.

Table II. Previous Work in Evaluating the Accuracy of Mobile Data Collection in the Developing World

	PDAs	Cell Phones
Published Error Rates	–Malaria monitoring in Gambia [Forster, Behrens, Campbell, & Byass, 1991] –Clinical study in Gabon [Missinou et al., 2005] –Tuberculosis records in Peru [Blaya & Fraser, 2006] –Sexual behavior surveys in Peru [Bernabe-Ortiz et al., 2008]	*None?*
Other Programs	–SATELLIFE [Groves, 1996] –DataDyne EpiSurveyor [Selanikio & Donna, 2006] –EpiHandy [Engebretsen, 2005] –Infant health in Tanzania [Shirima et al., 2007] –e-IMCI project in Tanzania [DeRenzi et al., 2008] –Respiratory health in Kenya [Diero et al., 2006] –Tobacco survey in India [Gupta, 1996] –Cash project in India [Anantraman et al., 2002]	–Cell-Life in South Africa [Fynn, 2006] –Jiva TeleDoc in India [United Nations, 2007, p. 42] –Pesinet in Mali [Balancing Act News, 2007] –Malaria monitoring in Kenya [Nokia, 2007] –Voxiva Cell-PREVEN in Peru [Curioso et al., 2005]

preliminary results were presented in two prior conference papers [Medhi et al. 2009; Patnaik et al. 2009]: this new presentation integrates this prior work, and presents additional results and analysis.

2. RELATED WORK

Here we consider related work in evaluating the accuracy of data entry on mobile devices, as well as design techniques to improve usability for low-literacy users.

2.1. Evaluating the Accuracy of Mobile Data Entry

As summarized in Table II, there have been several initiatives to apply PDAs and cell phones for mobile data collection in the developing world. While a fraction of the studies on PDAs include an experimental analysis of the error rate incurred, we are unaware of any prior study which systematically measures the accuracy of data entry (or the likelihood of completing a task) on a low-cost cell phone. This is a central novelty of our work.

As detailed elsewhere [Patnaik et al. 2009], previous studies of PDA entry accuracy have found that novice users can achieve an error rate of less than 2% (i.e., less than 2 errors per 100 entries) given that they receive at least an hour of training [Blaya and Fraser 2006; Forster et al. 1991; Missinou et al. 2005]. In two of these studies, error rates are as low as 0.1–0.6% [Forster et al. 1991] and 0.4% [Blaya and Fraser 2006]. However, in a context where novice users received only 2–3 minutes of training, error rates were observed to be 14%; entry accuracy was substantially higher for those who had completed secondary schooling [Bernabe-Ortiz et al. 2008].

Additional programs have applied PDAs for data collection in the developing world, but have not provided a rigorous analysis of entry accuracy [Anantraman et al. 2002; DeRenzi et al. 2008; Diero et al. 2006; Engebretsen 2005; Gupta 1996; Shirima et al. 2007]. In the case of SATELLIFE [Groves 1996], there are anecdotal reports that PDAs improved data quality [Ladd and Sewankambo 2004] and demonstrated decreased error rates as estimated on a five-point scale [AED Satellife 2004]. An additional report had users rate the usability of the system [Bridges.org 2003]. However, we are unaware of a quantitative assessment of the error rates incurred. DataDyne

EpiSurveyor [Selanikio and Donna 2006] is also argued to be more accurate than paper forms [Selanikio 2009], though we are unaware of a controlled study.

Cell phones have also found broad application for mobile data collection in the developing world, with interfaces spanning electronic forms [Balancing Act News 2007; Fynn 2006; Nokia 2007; Skinner et al. 2007; United Nations 2007] and interactive voice response [Curioso et al. 2005]. While we are unaware of previous evaluations of entry accuracy, there are three studies (published concurrently to our own) that assess the accuracy of novice users in navigating interactive voice response systems [Grover et al. 2009; Patel et al. 2009; Sherwani et al. 2009]. The studies have varying results: one reports that task completion is higher with dialed inputs than with speech inputs [Patel et al. 2009], one reports comparable task completion but a preference for dialed inputs over speech inputs [Grover et al. 2009], and one reports that speech inputs significantly outperform dialed inputs [Sherwani et al. 2009].

To avoid the complexities of navigating electronic forms, the CAM framework offers a hybrid system in which paper forms are used for organization while phones are used for data entry [Parikh 2005]. Each field on the paper form is annotated with a barcode which is recognized by a camera on the phone prior to data entry. Users that lacked prior camera or computer experience were trained to a level of comfort within 5–15 minutes. A separate study measures error rates of 1% or below using the CAM system [Parikh et al. 2006]. This represents an interesting and useful design point, especially in cases where paper forms are already ingrained into the workflow. We focus on solutions that are independent of any paper workflow and which do not necessarily require a camera-phone. While phones that support electronic forms (e.g., via Java) often have cameras, our SMS, USSD, spoken dialog, and live operator solutions are suitable to the most inexpensive phones.

2.2. Design Principles for Low-Literacy Users

Because for the most part illiteracy correlates strongly with poverty, nonliterate users are very different from the target users of typical UI designs [Cooper and Reimann 2003]. Most previous work with nonliterate users focuses on the mechanics of the interface, and on PCs or PDAs. Many researchers have recognized the value of imagery, and have advocated extensive use of graphics [Grisedale et al. 1997; Havelock 1971; Medhi et al. 2007a, 2007b; Parikh et al. 2003a, 2003b]. More specifically, it appears that static hand-drawn representations are better understood than photographs or icons [Medhi et al. 2007a]. Voice instructions and audio annotations are also powerful, and much of the interesting work in this area focuses on the interplay between graphics and audio to generate a usable interface, as reviewed elsewhere [Medhi et al. 2007a, 2007b]. Some authors note that the use of numbers is acceptable, as many nonliterate people can read numerical digits [Medhi et al. 2007b; Parikh et al. 2003a, 2003b].

Other work has focused on ultra-simple navigation as a design goal [Grisedale et al., 1997], or on removing anxieties about technology use. For example, looping video clips which include dramatizations of the overall usage scenario have been found effective in reducing barriers to usage by first-time users [Medhi and Toyama 2007]. Voice recordings of "help" information have also been shown valuable [Medhi et al. 2007b]. These principles have been applied to application domains such as job information systems [Medhi et al. 2007b], health information dissemination [Medhi et al. 2007a], and microfinance [Parikh et al. 2003a, 2003b].

Interfaces for low-literacy users have also been studied in the context of Automatic Teller Machines (ATMs). Two studies propose an icon-based approach for ATMs [Ivatury 2004; Thatcher et al. 2006]. Another study looks at attitudes in literate and semiliterate bankaccount holders towards ATMs and alternative ATM interfaces (speech based and icon based) [Thatcher et al. 2005]. Overall, groups showed a tendency to prefer an icon-based alternative ATM interface over the other choices. Evaluations of a pilot trial by one large bank in India make various recommendations for ATMs for low-literacy users: avoid use of text altogether; loop voice instructions in simple, slow vernacular; provide biometric authentication; use consistent visual cues [Medhi and Ratan 2006].

Apart from work that focuses on PCs, PDAs, and ATMs, there is some amount of research that looks at mobile phone UIs for low-literacy users. Researchers have recognized the value of voice feedback [Parikh et al. 2006; Plauché and Prabaker 2006] and speech interfaces [Boyera 2007; Plauché and Prabaker 2006; Sherwani et al. 2007]. Others have questioned suitability of menu-based navigation for novice users [Jones et al. 2000] and have discussed designs that advocate fewer menus and dedicated buttons for this target group [Lehrman 2007]. Again there is work that looks beyond the UI at coping mechanisms of illiterate and semiliterate users when confronted with traditional mobile interfaces [Chipchase 2005, 2006].

3. ETHNOGRAPHY OF NOVICE USERS

To better understand the key challenges of designing mobile interfaces for novice users, we first investigated the current situation among existing users and potential users. Our inquiry focused on mobile banking as the driving application; mobile banking refers to the provision of financial services such as money transfer, payments, and balance inquiries via a mobile phone, often to communities that lack access to traditional bank accounts. Instead of requiring visits to a bank branch or ATM, cash transactions can also be done at retail outlets that serve as intermediaries. While our focus is on mobile banking, most of our observations in this article also extend to other domains (results that are specific to banking have been published elsewhere [Medhi et al. 2009]). In this section we restrict our attention to nonliterate and semiliterate populations.

3.1. Methodology

We conducted a total of 79 interviews and qualitative user studies: 26 in New Delhi and Bangalore, India, 30 in Bohol, Philippines, and 23 in Cape Town and Globersdale, South Africa. (Variations in number are due in part to the complexity of identifying subjects with the characteristics we were seeking.) We also utilize 11 interviews in Kenya by Ratan [2008]. Our subjects had three common background traits: (1) functional illiteracy or semiliteracy but partial numeracy; (2) low levels of formal education (highest education attained being schooling up to the eighth grade of the K-12 education system or its equivalent across the four countries); (3) zero experience with personal computers.

Apart from these commonalities, we looked for varying degrees of experience with using mobile phones: (a) those who did not use or own a mobile phone; (b) those who owned or used mobile phones but did not use any kind of mobile banking systems; and (c) those who used mobile banking systems. 40 of our subjects were in the first category, 34 in the second, and 16 in the third. These traits make them an ideal user population with which to explore our ideas with regards to creating a mobile phone UI suited for nonliterate and semiliterate populations. Subjects were selected with the assistance of both for-profit corporations (running mobile banking services) as well as nonprofit organizations working with poor populations.

There were some commonalities across all locations that were not intentionally chosen, but nevertheless correlated with our target population. Among the key commonalities, across all four locations, our users strongly and positively associated the English language (which they did not speak for the most part) with wealth and prestige. This was due to a combination of mindset inherited from colonial history, as well as the modern-day fact of greater economic opportunities available to English speakers. Also for the most part, all of our subjects were very open with respect to illiteracy, attaching no shame to the inability to read; this is unlike illiterate individuals in developed countries who often hide illiteracy. Our subjects were typically domestic workers and daily wage laborers like plumbers, carpenters, construction workers, mechanics, vegetable vendors, weavers, farm hands, fishermen, drivers, etc. Household income ranged from USD 20–USD 200 per month.

Naturally, differences also exist across geographies. The subjects' primary languages were Kannada, Hindi, and Tamil in India, Tagalog in Philippines, Afrikaans, Xhosa, and Zulu in South Africa, and Kiswahili in Kenya. Relevant to our study, all but the Indian languages can be written in the same Latin alphabet that is standard on mobile phones throughout the world. Some of our subjects had television sets, music players, and gas burners, but these were not owned by all households. A few had seen computers in person (but again, none had ever used them).

The interviews were one-on-one, open-ended conversations that lasted for at least an hour. Questions and discussion themes included basic demographic information, access and use of financial services, and access and use of mobile phones. The study involved over 100 hours spent in the field. We visited individuals at their homes in order to talk to our subjects in a comfortable environment and to observe their living environments. We also conducted interviews at mobile banking agent locations where mobile transactions took place.

We conducted qualitative user studies with our subjects, focusing on a locally available mobile banking service as a usability case study. Subjects were given a set of tasks to perform both on their own handsets and on mobile phones provided by us (in order to determine how much of their usage was by rote memorization). These tasks included the following.

—Dialing a phone number to call a friend.
—Writing a short SMS text message to a friend.
—Depositing a small amount to their account on their own phone.
—Transferring a small amount to a relative from their own phone.
—Diagramming how they perceived the menu structure (for geographies with menu-based UIs). Users were asked in their local language, "Can you draw how this function was accomplished?"
—Performing the first two tasks with a phone supplied to the subject (different in model from theirs: a Nokia 2610).

All users were compensated for their time at the end of the study. We consulted the intermediary organizations to establish the right mode and amount. Participants without mobile phones were given gift cards for local stores and those with mobile phones were given talk-time cards roughly equivalent to half a daily wage.

3.2. Phone Usage

The mobile phone handsets that our subjects used ranged from basic, black-and-white, second-hand purchases costing USD 12 (common in India and Philippines) to brand new purchases with camera and color screen that cost USD 150 (occasionally seen in Kenya and South Africa). We found high usage of texting in the Philippines, especially among young, semiliterate users with education up to eighth grade (even 100 texts per day), to no usage of texting in Kenya, South Africa, and India. There was strong preference for voice calls in Kenya [Ratan 2008] and India [Medhi and Ratan 2008], and for texting in Philippines; the number of voice calls ranged from 5 calls (India, Kenya, and South Africa) to no calls per day (Philippines). Sharing of phones among family members and friends was common. Overall, the kind of phone usage depended on factors such as age, literacy, and pricing strategy. Older users, who mostly were less

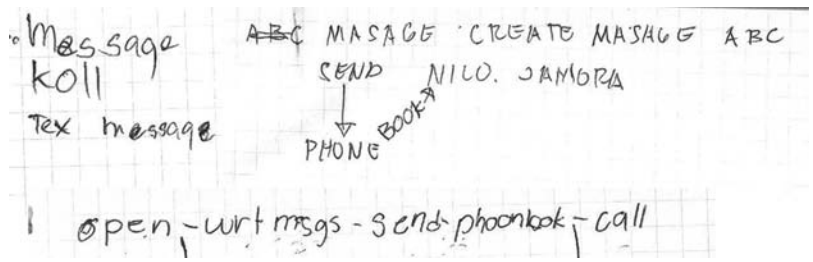


Fig. 2. Diagrams produced by semiliterate subjects to represent menu structures for user tasks.

literate, tended to use their mobile phones only for voice calls. In the Philippines, where a one-minute call was ∼7 times more expensive than texting, we saw strong preference for the latter.

3.3. Usability Barriers

There were a number of challenges encountered by our subjects in interacting with the mobile banking services and navigating through mobile phones in general. We note here that in our analysis we do not decouple the difficulties encountered by users due to low literacy and those due to inexperience with technology, since our target population had both these characteristics. It would be valuable to separate these influences in future work. The challenges encountered by our subjects were as follows.

Hierarchical navigation. Of the total 90 subjects, 56 subjects were initially unable to understand or navigate hierarchical menus as they currently exist, even for simple tasks such as calling back a number from which a missed call was received. Out of the 40 nonusers of mobile phones, 100% of them were unable to navigate the menus, while 16 out of 50 phone users were able to navigate successfully. Instead of using the call logs or address book, users instead simply dialed the numbers from scratch each time. Diagrams of the perceived menu interaction for a specific task, as drawn by semiliterate users (who could read simple, isolated words in the Latin alphabet), are shown in Figure 2 (for “send a message to a friend in the phone book then call another friend”). Most did not refer to any abstract hierarchical model of the menu. Of the 34 subjects who were able to perform tasks on their own handsets, 23 were unable to accomplish them on the other handset supplied by us. These observations are consistent with earlier work that mentions challenges representing tree structures among literate, but novice, users of information systems [Walton et al. 2002].

Discoverability. Functions buried in deep hierarchies are known to be less discoverable, and we confirmed this with our subjects. An additional issue arose from poor interaction design, such as when functions were categorized under seemingly unrelated functions. In one menu system, registering a new user required navigation as follows: Svcs+ → Prepaid Svcs → [Service Name] → Register. Even literate subjects who were heavy text users could not find the function, since most respondents did not bother looking beyond the unintuitive “Prepaid Svcs” option.

Scroll bars. Vertical scrollbars were not initially understood by 48 out of a total of 90 subjects. Out of this population, 40 were nonusers of mobile phones and 8 were voice-only users. Subjects did not realize that there were functions “beneath” what was displayed. Explicit demonstrations were required to teach these subjects what scrollbars were and how to use them. This group coincided almost entirely with users whose mobile use was restricted to making voice calls.

Soft-key function mapping. All of our subjects were comfortable handling the "hard keys" (direct number entry and send/end keys), regardless of whether they owned mobile phones or not. However, as many as 45 users had difficulty with soft keys: usually unlabeled keys (often appearing directly below the screen) that have different functions in different contexts, or numeric keys when used to choose from an enumerated list on screen. When they were asked to send a text and were required to traverse the many different layers of the UI, they became lost and had no idea which buttons to press just to navigate. If they managed to get past the first step, they were unable to read the textually annotated steps later. The soft keys were difficult to understand because it required mapping soft keys to the changing functions displayed on screen.

Nonnumeric inputs. 27 of the 50 mobile phone users we spoke with used their phones for making and receiving voice calls only, and the proportion was higher in India, Kenya, and South Africa. Twenty-four of these subjects were unable to type even a single word, much less an entire text message. For constructing a USSD syntax[2] comprising of digits and symbols ("*" and "#"), our subjects were comfortable typing the digits, but could not locate the symbols.

Language difficulties. All the mobile banking services issue SMS receipts for transactions. Messages are always entirely in English (except in the case of the mobile banking service M-PESA where the receipts are in English as well as in Kiswahili). Subjects, most of whom were not fluent in English, had difficulty reading the text portions of these receipts, but almost all could identify the numbers and what they meant. However, subjects still had difficulty with receipts indicating multiple transactions.

It was also difficult for subjects to understand specialized or technical terms, even when they were in the local language. Since most of our subjects did not have bank accounts, they were not familiar with the vocabulary of banking. "View last transaction," "Get balance," "Change PIN," and so forth, were all alien concepts, in the absence of detailed explanation. We later observed similar patterns in the health domain; symptoms such as "jaundice" did not translate well into Hindi, and were sometimes more recognizable in English.

All of the banking services provide instruction manuals and information brochures for assisting users. Most of these manuals are overloaded with textual information, mostly in English. For nonliterate users, these are all but useless, since the accompanying visuals often are not self-explanatory. Some of the services offer local language manuals, but these too are complex and laden with banking jargon. We found that most subjects did not attempt to read these manuals, and that human mediation was critical for most successful transactions.

3.4. Design Recommendations

Broad lessons from this exercise led to the following design recommendations.

(1) Provide graphical cues.
(2) Provide voice annotation support wherever possible.
(3) Provide local language support, both in text and audio.
(4) Minimize hierarchical structures.
(5) Avoid requiring nonnumeric text input.
(6) Avoid menus that require scrolling.

[2]USSD (Unstructured Supplementary Service Data) is a standard for transmitting data, typically anticipating real-time responses, using GSM phones. In the context of mobile banking, a user might enter a string such as *109*72348937857623# to request a balance check, which will then appear on his or her handset in a menu format similar to an SMS message.

(7) Minimize soft-key mappings.
(8) Integrate human mediators into the overall system, to familiarize potential users with scenarios and UIs.

The first four items echo design recommendations from previous work [Medhi et al. 2007b]. Items 5–7 were identified as a result of working with mobile phones. The last item is consistent with the literature on computing technology for development [Warschauer 2003]. We note that while our current recommendation is to avoid use of nonintuitive interfaces such as nonnumeric text input, scrolling, and soft keys, it also represents an interesting research agenda to improve the usability of these elements to make them more accessible to first-time users.

4. EXPERIMENT 1: TEXT VS. VOICE AND GRAPHICS

To try to satisfy all the posed design recommendations of the prior section, we investigated richer interfaces that can display graphics and audio. Yet, richer platforms come with their own drawbacks, including greater complexity, greater cost, and less platform universality. Therefore, our goal in this second phase of research is to compare how nonliterate subjects (drawn exclusively from India) react to three different UIs that make trade-offs between cost and richness: (1) a text-based UI, (2) a voice UI (in which users talk to a spoken dialog system over the phone), and (3) a graphical UI (in which users press keys to navigate voice-annotated images on their handset). The graphical UI incorporates what is known about text-free designs for nonliterate users.

4.1. Application Domain

We utilize mobile banking as a driving application to evaluate the interfaces. For the purposes of this study, we limit our attention to the dominant usage scenario that we found among our subjects, namely, remittances or remote money transfers. The three functions critical for any money-transfer service are: (1) money transfer, (2) withdrawal of funds (in the presence of a retail agent), and (3) account balance inquiry. All three UIs were designed with the same information architecture so that we could compare task performance and preference among the UIs.

Figure 3 shows the information architecture of the mobile banking UI design. To access the application, as a first step the user is required to enter his/her PIN. On entering the correct PIN, the user reaches the main menu where he/she gets a choice of three functions: check account balance, withdraw received money, and send money. This is the only point in the menu where the user must use soft keys (map numeric keys with functions in an enumerated list of functions) to make a decision among three options. The rest of the interaction only requires "yes/no" responses, number entry, or acknowledgements.

4.2. User Interfaces

Text UI. This was a menu-based USSD design where the options on the menu were in text in the native language of the subjects, Kannada. To initiate the service, the user had to dial a USSD short code (with "*" at the beginning and "#" at the end). On sending this request, a menu appeared on the user's mobile phone, each of which required entry of additional digits and symbols to choose options in the menu. The user thereafter had to follow the menu prompts in a similar manner to complete the transaction. Figure 4 illustrates some selected screenshots.

—In order to interact with this UI, the buttons on the mobile phone keypad which the user was required to use were #, *, and the numeric keys.
—Currently, Kannada USSD services are not available and hence our design was actually a simulation on a graphics-capable phone.

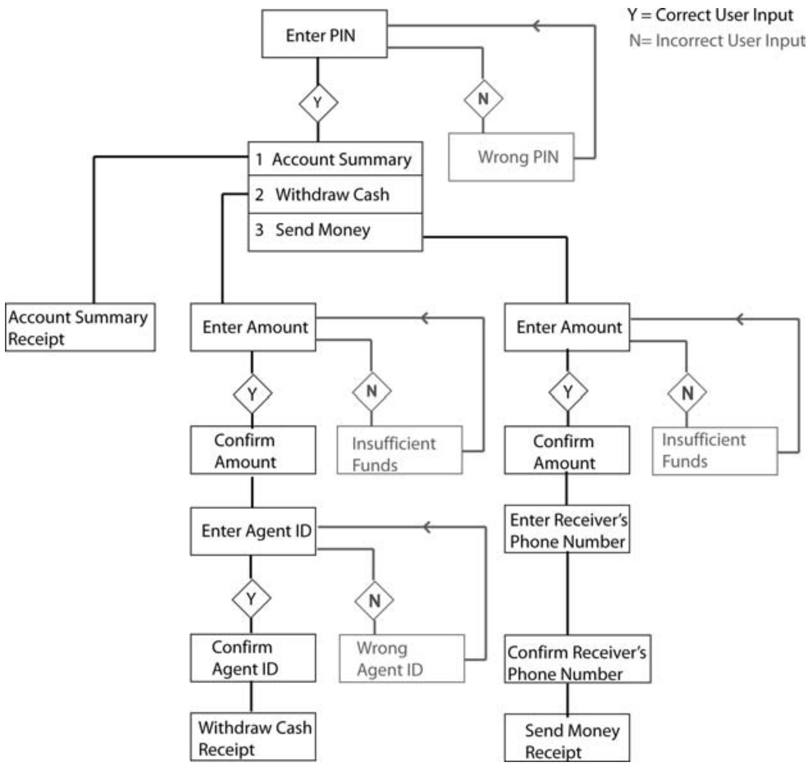


Fig. 3. Information architecture of the mobile banking UI design.

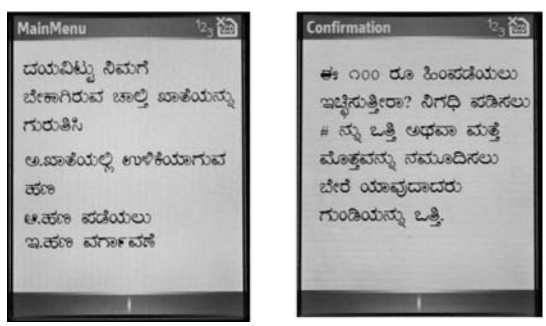
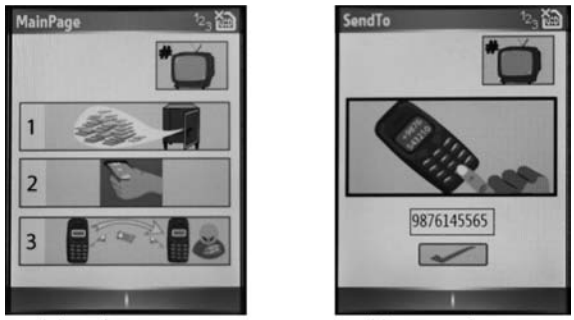


Fig. 4. Screen shots of text-based prototype.

Voice UI. This was a menu-based spoken-dialog system meant to converse with users through voice prompts in Kannada. The user was required to dial a phone number to initiate the service and then speak the option in the menu which they chose. The user thereafter had to follow the menu prompts in a similar manner to complete the transaction.

In order to compare user responses under "ideal" technological conditions, we used a Wizard-of-Oz set-up for the spoken-dialog system (which would otherwise have incurred the conflating issue of accuracy of automated speech recognition). On the server side, an experimenter in one office operated a system on a PC that consisted of buttons with voice feedback for each of the functions of the information architecture.



(a) main menu (b) enter phone number of receiver

Fig. 5. Screen shots of graphical UI.

The voice feedbacks were prerecorded human speech segments. The subjects were in a partner organization's office and were asked to dial the experimenter's phone number. The experimenter would play the recorded files from the PC and through the telephone speaker the system responses would be available on the user's phone earpiece. The experimenter followed the same information architecture as mentioned earlier while playing the responses.

Graphical UI. This was a menu-based design with options appearing as audio-visuals on the mobile phone's display, organized as hierarchical menu options. Every graphic was a static hand-drawn representation. There were voice instructions associated not with every graphic but with the overall screen and played automatically on screen load. These voice instructions were prerecorded human speech segments in Kannada explaining each menu option and what numeric key had to be pressed to accomplish these.

For this design we applied the design principles from previous text-free UI research [Medhi et al. 2007b]. For designing the graphics we went through iterations with nonliterate subjects from slum communities adjacent to those from where our subjects were drawn in Bangalore, India.

We made this design available as a menu-based SIM Toolkit application. In order to interact with this UI, the user was required to use the OK soft key and the numeric hard keys.

We also included a full-context video at the beginning of the application which, in addition to a tutorial of the UI, included dramatizations of what the mobile banking service was, how a user might register for the service, and how the user might use the application.

Figure 5(a) illustrates the main menu which shows the three functions available to a user: account balance, withdraw received money, and sending money options. Figure 5(b) shows the screen where the user is asked to enter the phone number of the person he/she wishes to send money to. It consists of a numeric field where the user is required to make a numeric entry for the phone number to the receiver.

4.3. Experimental Set-Up

The three prototypes that we tested had the same content and information architecture so that we could isolate the differences due to interaction design. We employed a between-subjects evaluation.

Subjects. Our subjects were drawn from one of our project locations, Bangalore, India, from the same community as described in the target community section. The subjects were nonliterate and semiliterate (could write their names, read isolated words, and do some basic addition) adults living in five urban slum communities. We chose a range of such participants varying in age, environment they lived and worked in at present, and varying levels of experience in using mobile phones. Participants ranged in age from 25–65 years. The taxonomic structure which we followed in choosing our participants was: (a) no experience using mobile phones, (b) experience with using mobile phones but only for basic functions such as receiving and making calls, (c) experience with using mobile phones for more complex functions such as sending text messages.

There were a total of 58 participants (60 initially, but two did not show up for the voice-based trial), 28 male and 30 female. Each of the prototypes was tested on one-third of the total participants, that is, 20 participants (10 male and 10 female) in the case of text-based and graphical UIs and 18 participants (8 male and 10 female) in the case of the voice-based UI. The tests were conducted in the NGO office, in an environment participants were familiar with.

Training. As the goal of this experiment was to explore the experience of first-time users, we did not conduct any training of participants prior to their use of the interfaces. The only assistance received was in the form of prompts from the experimenter, on a demand-driven basis during the evaluation. Prompts took the form of spoken encouragement or reminders when the subjects appeared to be stuck or asked for help from the experimenter. The number of prompts was recorded for each subject.

In order to help subjects grasp the general context, however, we did provide an introductory overview that explained the concept of mobile banking. We delivered this overview in the best format that we expect would be available to users of a given UI in the real world. As users of a graphical UI would have graphics-capable phones, we provided a full-context video as an overview; however, as users of the voice and text UIs would typically be using low-cost phones, we provided a live, verbal explanation that mirrored the content in the full-context video. To keep the content consistent, both during the verbal explanation and playing of full-context video, subjects were not allowed to ask any questions to the experimenter.

Testing. Across all the three prototypes, once we were satisfied that our subjects understood the capability of the application, we then told them the following story: A sibling of theirs who lived in a different town desperately needed money urgently. Assuming that the sibling also had a mobile banking account, their objective was to send Rs. 400 to that sibling.

The preceding task was to be considered incomplete when either of these two things happened: (1) Despite repeated prompts, subjects gave up on the task, (2) subjects committed a fatal error (e.g., checked “account summary” when they were asked to “transfer money” of Rs. 400 and could not navigate their way back to the “transfer money” menu despite repeated prompts).

Device and documentation tools. The device where the applications were tested was a graphics-capable phone. This phone was selected because of higher-quality graphics and for ease of prototyping. While the graphics capabilities are required for the graphical UI, they are unutilized by the voice and text UIs. We used the same phone to test all three UIs, and did not observe any effects (on the voice and text UIs) that would have been different with a low-cost phone. The technique for data collection was detailed notes taken by us in situ while the participants were performing the task. This included recording total time taken and total number of prompts required for task completion.

4.4. Results

Consistent with prior research [Medhi et al. 2007b], the tests confirmed that nonliterate subjects were unable to make sense of the text-based UI. More interestingly, they

Table III. Overall Results of the User Study

	Task Completion	Time Taken*	Prompts Required*
Text UI	0%	—	—
Voice UI	72%	5.2 min	4.0
Graphical UI	100%	13 min	14

**Averaged across subjects who completed the task*[3]

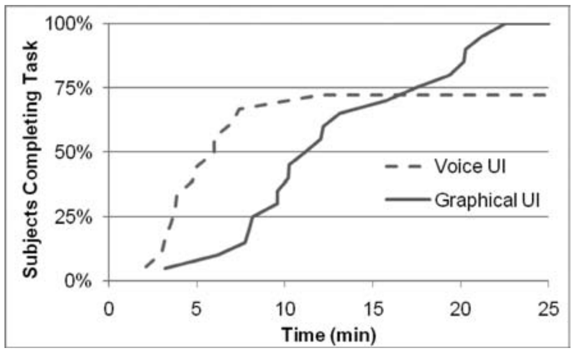


Fig. 6. Percent of subjects who completed the task within a given amount of time.

showed that while completion rates were much better for the graphical UI, subjects who could complete the task on the voice UI did so more quickly and with less assistance. Detailed results appear in Table III.

None of the subjects (0 out of a total of 20 subjects) was able to navigate the text-based UI even with significant prompting and encouragement. Most of the subjects were simply unable to read the text at all, and even those who could read isolated words were not able to read fluently enough to put what was written into the context of the scenario. This was as expected, and we concentrate the remainder of the analysis on the nontext-based UIs.

Among the nontext designs, overall task completion for voice-based UI was 72% (13/18), whereas in the graphical UI, it was 100% (20/20). However, among subjects who did complete the task, time taken on the graphical UI was more than twice the time taken on the voice UI. A single-factor ANOVA test conducted shows statistical significance ($F = 21.49 > F_{crit} = 4.160$, $p < 0.001$). The trade-off between task completion rate and the amount of time required is illustrated graphically in Figure 6. A similar trend exists for the number of prompts required; subjects completing the graphical UI required more than thrice the prompts required by subjects completing the voice UI ($F = 30.48 > F_{crit} = 4.160$, $p < 0.001$). We discuss possible explanations for these trends in the next section.

We also analyze the impact of gender on the results. For the voice UI, 60% (6 out of 10) of female subjects could complete the task, whereas for male subjects it was approximately 88% (7 out of 8, 2 male subjects did not show up). Overall for task completion, female subjects took twice the time to complete the test compared to men (see Figure 7), and this difference was statistically significant ($F = 14.6 > F_{crit} = 4.8$, $p = 0.003$). But in terms of the help required, both male and female subjects took

[3]That is, for the voice UI, the time taken and prompts required are reported for the 72% of subjects that completed the task. Comparing instead the median figures (including users that did not complete the task) we find that the voice UI required 6.0 minutes and 4 prompts, while the graphical UI required 11 minutes and 11 prompts.

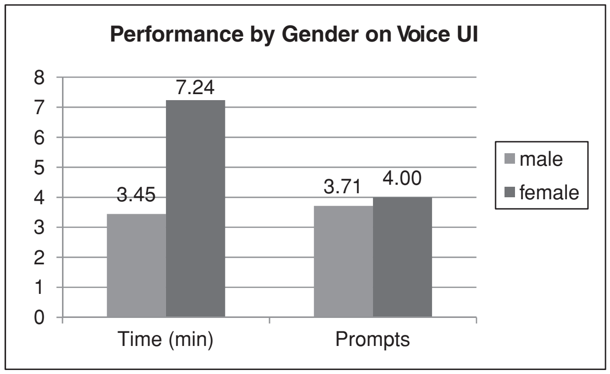


Fig. 7. Performance by gender on the voice UI.

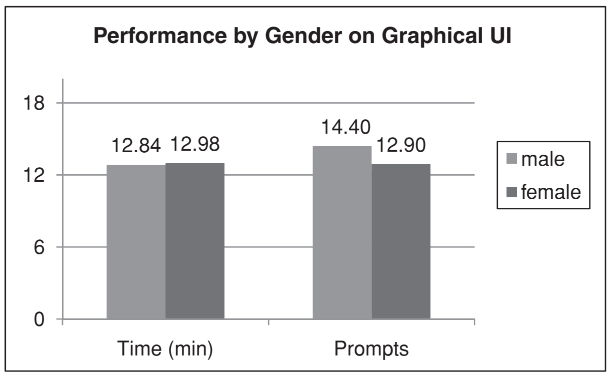


Fig. 8. Performance by gender on the graphical UI.

similar number of prompts for completing the test ($F = 0.051 < F_{crit} = 4.8$, $p = 0.826$), as shown in Figure 7.

For the graphical UI, there were no major differences in terms of time taken and help required between male and female subjects. Male and female subjects took the same time for completion ($F = 0.003 < F_{crit} = 4.413$, $p = 0.958$). Male and female subjects also took almost the same number of prompts for task completion on the graphical UI ($F = 0.289 < F_{crit} = 4.413$, $p = 0.598$). Details are in Figure 8.

4.5. Discussion

It may seem counter-intuitive that the voice UI could result in lower task completion rates while simultaneously requiring less time and fewer prompts for those who did complete the task. Based on our observations and post-trial interviews, we offer several explanations for this phenomenon. We divide our analysis according to two orthogonal questions: why were users faster and more independent on the voice UI, and why were they also more likely to give up?

Users were faster and more independent on the voice UI. Three factors were responsible for the speed and independence of users who completed tasks on the voice UI. First, users were less hesitant to provide spoken inputs than to provide typed inputs. Except for dialing the phone number initially, the rest of the interaction on the voice UI mirrored a normal conversation on a normal phone, and users were comfortable participating in the conversation just as they would do otherwise. In contrast, interaction with the graphical UI required typed inputs, an unfamiliar mode of interaction that causes anxiety for novice users. Subjects were nervous that their keypress might “break” or “spoil” the phone, and thus required significant prompting, encouragement, and time to press any key.

Second, subjects found it easier to determine which word they should speak on the voice UI versus determining which button they should press on the graphical UI. At the top-level menu, the voice UI required subjects to speak their selection, for example, “Account Summary”, “Withdraw Money,” etc. In contrast, the graphical UI required subjects to map numeric keys to functions, for example, press 1 for the account summary, press 2 to withdraw money, etc. For the rest of the interaction, there was only one way to accomplish a task and the user was not required to make any decisions. For the voice UI this interaction was almost like an informal telephone conversation with “yes/no” questions, whereas in the graphical UI the subject needed to understand the buttons and push the right ones to accomplish the task.

Third, some subjects had prior experience with voice UIs, whereas no subjects had prior experience with graphical UIs. Out of the 13 subjects who completed the task on the voice UI, 7 had prior experience using voice UIs for functions such as mobile phone recharge, setting caller tunes, etc. All of the subjects (7/7) who were previously exposed to voice UIs succeeded in completing the task.

Users were more likely to give up on the voice UI. Despite the influences detailed earlier, the rate of task completion on the voice UI was nonetheless lower than the graphical UI. We attribute this to three factors. First, using the voice UI, some subjects did not understand the concept of mobile banking. Post-trial interviews revealed that full-context video in the graphical UI helped in better understanding the concept of mobile banking and the scenarios in which it could be used, as compared to a verbal explanation that mirrored the content of the same, in the case of voice UI.

Second, under the voice UI, some people could not understand technical banking terms in the local language. Since most of our subjects did not have bank accounts, they were not familiar with the vocabulary of banking (“account summary,” “withdraw cash receipt,” etc.). We suspect using alternative colloquial terms could have resulted in better comprehension. Under the graphical UI, such subjects relied on the graphical cues to guide them through the process. However, when they could not understand the spoken options, they were unable to complete the process; even with encouragement and prompts from the experimenters they did not put the prompted explanations about the terminology into the context of the scenario.

Third, some subjects did not understand the basic mode of interaction using the voice UI. They did not understand the concept of speaking with a voice that responded only in a certain, fixed manner; for example, subjects would keep saying “What Sir?”, “Yes Sir”, “Can’t understand what you are saying, Sir”, thinking it was a real person. These subjects had never been exposed to voice UIs earlier.

These factors are compounded by the fact that it is perhaps more difficult to provide helpful prompts to users of the voice UI versus users of the graphical UI. With the graphical UI: (a) the experimenter and subjects share a common view of the computer device, and (b) users employ different modalities for the tasks; *viewing* the graphics output and *listening* to the experimenter prompts. In contrast, with the voice UI: (a) the experimenter observes only one side of the conversation (we did not conduct a real-time audio tap of the other side), and (b) users employ the same modalities for the tasks, listening to both system and experimenter prompts. Such competing usage of the speech channel could contribute to cognitive overload of the user, making it difficult to provide effective assistance with the dialog system.

Summary. We believe that task completion was lower on the voice UI because some subjects lacked a basic understanding of mobile banking, banking terminology, or the concept of automated spoken dialog systems. For subjects that passed these basic requirements, they completed the task quickly and with less assistance because of their general comfort with speaking versus typing, their comprehension of what to speak (versus what to type), and (in some cases) their prior experience with voice UIs. While our focus in this study was on the first-time experience of low-literacy users, it remains an important question for future work to understand the impact of increased training or experience on users' ability to complete tasks.

5. EXPERIMENT 2: TEXT VS. LIVE OPERATOR

In our second usability experiment, we expand our attention to consider a very interactive interface: that of a live operator, in which users accomplish tasks by talking to an actual human over the phone. We compare this interface to textual interfaces, based on either electronic forms or SMS. Unlike the previous experiment, we focus our attention on literate subjects who nonetheless have limited exposure to technology. We also focus on an application in mobile data collection, where users always succeed in reporting data, but do so with varying degrees of accuracy. Thus, we report our results in terms of the error rate in data entered, rather than the rate of task completion.

The basic result of our experiment is that the operator interface is about 10 times more accurate than either electronic forms or SMS. While forms and SMS exhibited error rates of 4.2% and 4.5%, respectively, corresponding to approximately one error in every 20 entries, the live operator interface exhibited only one error in our entire trial (corresponding to an error rate of 0.5%). This came as a surprise to us and (in combination with the cost effectiveness of call centers in India) caused our application partners to switch their plans from using an electronic forms interface to using an operator interface in a realistic setting.

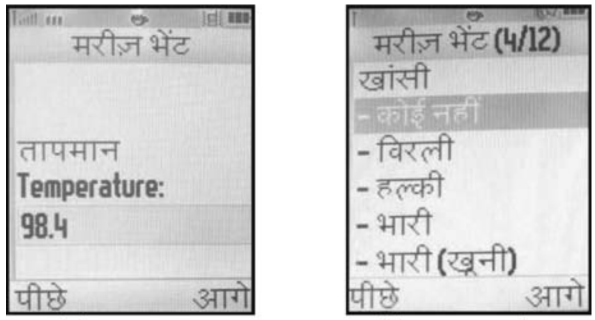
5.1. Application Domain

We focus on an application in rural healthcare, in which health workers are tasked with interviewing patients and uploading their symptoms via a phone. This application was designed in partnership with a tuberculosis treatment program for their use in rural India. In many tuberculosis treatment programs, patients consume antibiotics three times per week under the direct supervision of a health worker. It is critical that patients finish the full six-month treatment regimen in order to defeat the disease; otherwise they risk developing antibiotic resistance. By promptly uploading patient symptoms from rural areas to a doctor in a central location, our partners hope to offer improved medical guidance, ensuring the effectiveness of drugs, addressing real and perceived side-effects, and enabling more patients to complete the course of treatment.

The information architecture consists of a fixed series of questions. First, the patient is identified by name. Then, eleven health indicators are entered. The first three indicators are numeric: temperature, weight, and pulse. The next indicator is multiple-choice, designating the patient's cough as either absent, rare, mild, heavy, or severe (with blood). The final indicators are yes/no questions, indicating the presence or absence of seven symptoms and side-effects: night sweats, chest pain, loss of appetite, nausea, coughing with blood, yellow eyes, and fatigue. These indicators were chosen in consultation with tuberculosis health experts.

5.2. User Interfaces

Electronic forms UI. In this interface, the user navigates a set of textual forms and menus to enter the health data. As illustrated in Figure 9, numeric fields are entered



(a) enter temperature (b) enter cough

Fig. 9. Screen shots of the electronic forms interface.

directly while multiple-choice options are selected from a list. The forms were implemented using Java.

The electronic forms underwent several design iterations, including gathering feedback from a 3-day session with 22 health workers prior to this study. Based on feedback from the workers, we chose to employ hybrid English/Hindi menus for some of the forms, since some medical terms are easier to understand in English, but others are easier to understand in Hindi. We also changed from using multi-select lists (with a checkbox per symptom) to a simpler interface utilizing individual yes/no questions.

Compared to other interfaces considered in this section, electronic forms are visually rich and enable health data to be stored locally on the phone in case the connectivity is poor. On the negative side, electronic forms require a programmable phone (such as a Java phone) which elevates the cost per health worker. The interface can be programmed to use either SMS or GPRS to upload data to a server, depending on local cost and reliability constraints.

SMS UI. This interface requires health workers to construct a stylized SMS message in which all patient symptoms are encoded numerically. Workers carry a cue card (see Figure 10) that instructs them how to encode the patient's health indicators into a single SMS. The last box in Figure 10 represents a complete patient report that is sent to the server. While it would have been possible to encode certain symptoms using text rather than numeric digits, we opted for a numeric encoding due to familiarity and speed with numeric input. The cue card was translated into the local language.

Unlike the electronic forms interface, the SMS interface is compatible with all low-cost phones (it does not require a programmable phone). Some workers also have more experience in sending SMS messages than they do in navigating complex forms. On the negative side, the SMS encoding is somewhat complicated and requires an up-to-date cue card. It is also relatively easy for adversarial workers to fake a visit by resending an old SMS.

Live operator UI. In this interface, the health worker calls a live operator and dictates the symptoms over the phone. The operator is seated in front of a computer and enters the symptoms directly into a database. As illustrated by the sample interaction in Figure 11, the health worker interacts with both the operator and the patient at the same time, relaying the operator's questions to the patient and repeating the patient's reply to the operator. The operator confirms answers with the worker; this adds to the length of the call but could potentially increase the accuracy.

Employing a live operator offers several advantages over the other interfaces. Health workers do not need to be literate to talk to the operator. It is easy to change and adapt

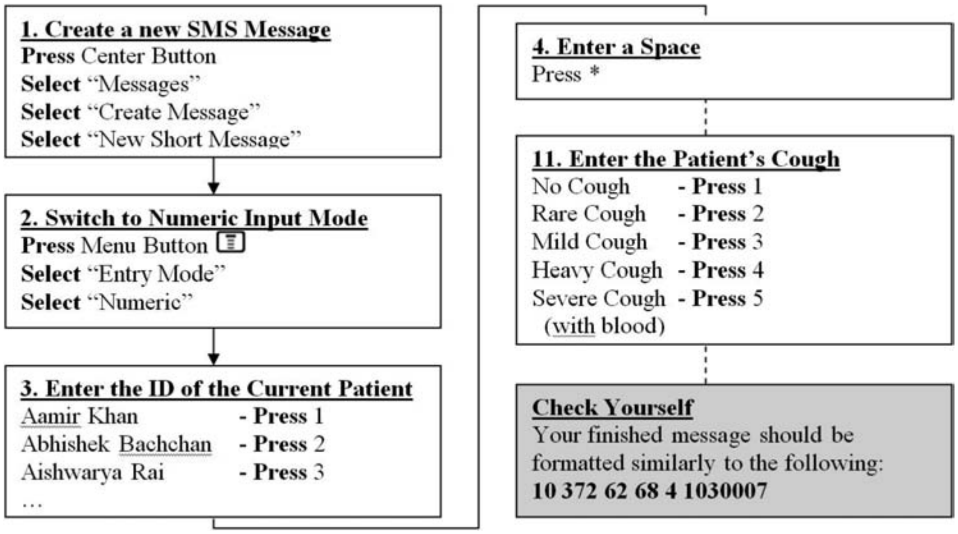


Fig. 10. Cue card provided for SMS interface (excerpt). The actual cue card was in the local language.

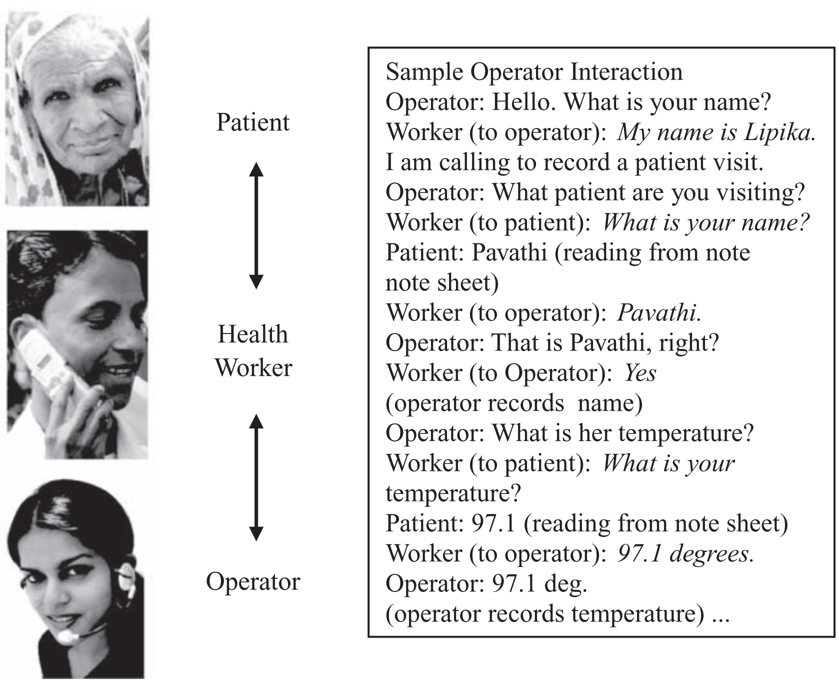


Fig. 11. Example interaction under live operator interface.

the survey questions over time, without distributing a new program or cue card. It is also easy for workers to convey detailed, free-form notes that do not fit into the standard survey. The potential drawbacks of the operator interface are the unconventional three-way social interaction, and also the cost (of employing the operator and consuming airtime). However, in countries such as India, we have found that the costs of the operator are less than the costs of programmable phones for a single TB treatment program [Patnaik et al. 2009]. This makes the operator interface a very realistic and attractive option.

5.3. Experimental Set-Up

The user study took place in the Surat and Bharuch districts of the Indian state of Gujarat during July and August of 2008. We employed a within-subjects evaluation.

Subjects. There were 13 subjects, consisting of 6 community health workers and 7 hospital paramedical staff. Eleven of the subjects were native Gujarati speakers and all spoke Hindi. Unlike the previous study, all of these subjects were literate.

The education level of the health workers ranged from 10–12 years, and their average age was 26. While 5 out of 6 health workers had used a cell phone, only one of them owned a cell phone. In contrast, the education level of the hospital staff ranged from class 10 to a B.A. degree (4 out of 7 had obtained postsecondary training). The average age of the hospital staff was 29, and all but one of them owned a cell phone. A detailed breakdown of the subjects is available in a prior paper [Patnaik et al. 2009].

Initially, we had hoped to perform the study entirely with community health workers, as they are often the primary agents of remote data collection (including in our partner's tuberculosis treatment program). However, this turned out to be infeasible because some community health workers were unable to travel to the public health center for training and testing, and it was not feasible for us to travel to each worker's home. This prompted us to broaden the study to include hospital staff from other centers.

Training. Subjects were trained in groups by at least two trainers at a given time. Initially, examples were presented on a whiteboard and subjects were instructed to practice entering in the data on either electronic forms or as an SMS using the cue card. After this stage, a paper with a set of example patients was handed out, and subjects were instructed to practice entering in this data. In the final stage, subjects were instructed to practice role playing patient-worker interactions with each other.

Subjects received variable amounts of training, depending on their experience and availability. Health workers were trained in large groups for a duration of 6–8 hours, while hospital staff were trained in small groups for 45 minutes to 2 hours. The longer training sessions were not necessarily more effective, given that the group size was larger. While it would have been desirable to achieve more uniform training, this was difficult given the logistics of transportation and worker schedules. Prior to the completion of training, all subjects had completed at least two perfect interactions on both electronic forms and SMS, and at least one perfect interaction on the live operator mode.

Testing. Subjects were tested in pairs, alternating who was being tested on data entry and who was playing the fake patient for that data point. The order of the interfaces was randomized: for a given subject pairing, the order of voice, SMS, and electronic forms was alternated. For the voice interface, the second author acted as the operator and was located outside of the room testing was being conducted in; however, there was always an additional person associated with the experiment inside the room at all times with the subjects.

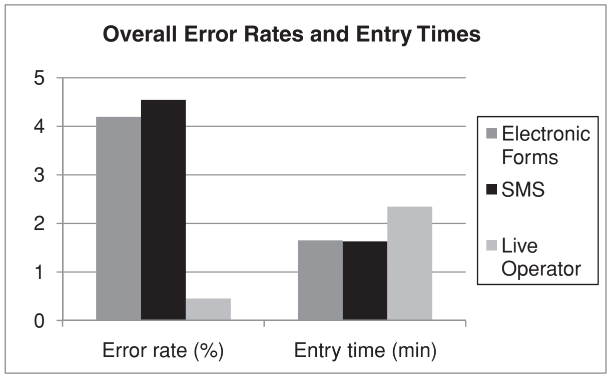


Fig. 12. Overall error rates and entry times for the trial.

During testing, each subject performed two complete patient/worker interactions (in the role of the worker) for each of the forms and SMS interfaces. For the operator interface, the six community health workers completed only one interaction, while others completed two interactions (we did not anticipate that the operator interface would become a focal point of this study until halfway through our experiments).

The lag time between training and testing was exactly one day for seven of the subjects, and ranged between half a day and two days for the remaining subjects. All subjects received a brief refresher and supervised entry session immediately prior to testing.

Device and documentation tools. The device used for experimentation was a low-end Java phone (a Motorola L6i). All interfaces and related tools (cue cards, etc.) were presented in Hindi, and the mobile phones used had dual Hindi menus. To measure outcomes, we inspected the data entered into the phones and also gathered an audio recording of the calls to the live operator.

5.4. Results

The results of the user study are summarized in Figure 12. We present both the accuracy of data entry, as well as the time needed to interview patients and report the data.

On average, electronic forms and SMS offered comparable error rates of 4.2% and 4.5% per entry, respectively. The operator interface proved to be approximately 10× more accurate, with an error rate of 0.45% per entry (corresponding to only a single error across all of our tests). While only one out of thirteen participants performed perfectly on both the forms and SMS interfaces, twelve out of thirteen participants performed perfectly with the operator. A single-factor ANOVA test revealed that operator interface had a significantly lower error rate than electronic forms ($F = 7.38 > F_{crit} = 4.06$, $p = 0.009$) and SMS ($F = 7.49 > F_{crit} = 4.06$, $p = 0.009$); no significant difference was found between the error rates of electronic forms and SMS ($F = 0.042 < F_{crit} = 4.03$, $p = 0.839$).

It is important to note that our results indicate a bimodal distribution of error rates: hospital staff performed notably better than health workers. As summarized in Figure 13, health workers exhibited an error rate of 7.6% for forms and 6.1% for SMS, while hospital staff exhibited an error rate of 1.3% for forms and 3.2% for SMS. In addition, the only operator error occurred with health workers. These differences are discussed in the following section.

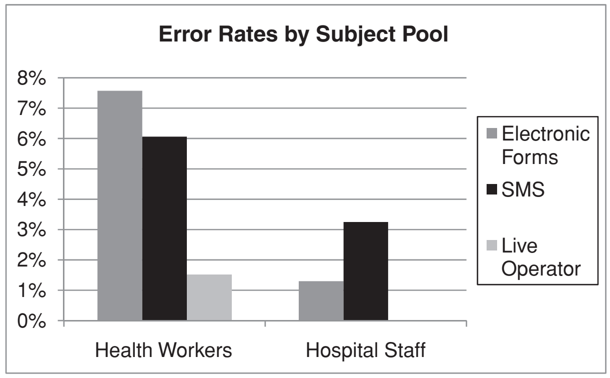


Fig. 13. Breakdown of error rates by subject pool.

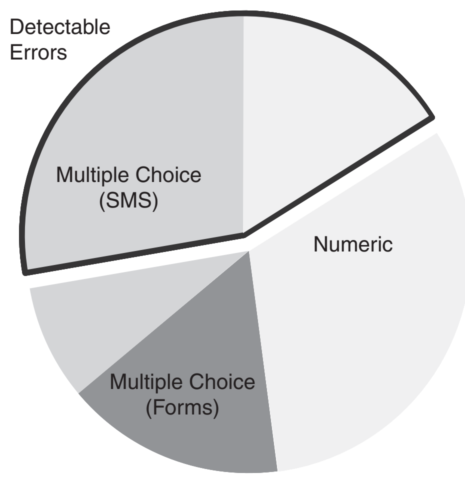


Fig. 14. Breakdown of errors observed by entry type.

The sources of error are summarized in Figure 14. About half of the errors were in numeric entries (temperature, weight, pulse), even though these accounted for only three of the twelve questions. We attribute these errors to tactile difficulties in pressing the number keys, to difficulty in correcting mistakes (even though we demonstrated how to use the backspace key, subjects had trouble doing so), and trouble entering the correct location of the decimal point in the temperature entry (though the decimal symbol was automatically inserted, subjects needed to enter the correct number of digits, for example, “1006” for a temperature of “100.6”). In the electronic forms interface, there was difficulty understanding the concept of scrolling and selection for the multiple-choice entries. And for the SMS interface, the complexity of the numeric encoding often led to errors.

In addition to the sources of error, we determined which errors could be detected by a trained eye using the submitted data only. In the future, such errors could potentially be flagged or automatically fixed using self-correcting forms. Over one-third of the errors fall into this category, including certain numeric entries (numbers that are out of range) and certain multiple-choice entries in the SMS interface (choices which were encoded in an invalid way). Unfortunately, errors in multiple-choice fields using the electronic forms interface bypass detection, because all entries appear valid.

We also determined whether each error is potentially dangerous with respect to the health outcome of the patient. For example, a severe cough reported as mild is a dangerous error, because it could prevent a physician from delivering needed care. Out of the 26 total errors observed, 12 were dangerous. Only one of the dangerous errors was detectable. A complete listing of the errors observed is available elsewhere [Patnaik et al. 2009].

The operator interface witnessed only a single error for the entire duration of the trial. We consulted a videotaped record of the interaction in question (we taped one interaction for each participant), and found that the error was incurred by the operator in translating the participant's report into a spreadsheet. While such transcription errors could indeed occur in practice, it is encouraging that the participants were not responsible for any errors on the operator interface.

While the operator interface offered the lowest error rates, it also led to the longest entry times. Electronic forms and SMS averaged 1:39 and 1:37 (min:sec) per interaction, respectively, while the operator interface required 2:20 on average ($1.43\times$ higher than forms and SMS). One factor that contributed to the slower entry rates with the operator was the cellular coverage in our study area; the connection between participants and the operator was highly unreliable. The audio quality was frequently degraded beyond recognition, and calls were occasionally dropped and restarted. While many resource-poor environments have excellent cellular coverage (including the area of Bihar, India that our partners are planning to target with their treatment program), the weak coverage in our study area nonetheless reflects a realistic hazard of employing an operator in some environments.

In addition to quantitative results, we also solicited qualitative feedback from each participant, asking them to rank the interfaces by their order of personal preference. The forms and SMS interfaces were most popular amongst the participants, with each receiving six votes as the most popular interface. Only one participant preferred the operator interface to the others. This feedback is indicative of the poor phone connections experienced during the trial; many found conversations with the operator to be frustrating due to the bad call quality. We were surprised that any participants preferred the SMS interface, given the relatively cryptic message that is produced in the end; however, participants noted that fewer keys are required under SMS than under electronic forms (which requires scrolling and selection). We also note that 8 of the 13 participants preferred the interface on which they demonstrated the fastest entry time.

5.5. Discussion

Our results indicate a bimodal distribution in error rates, where hospital staff performed notably better than health workers. Unfortunately, our data are insufficient to explain the differences observed between these two groups of participants. On average, the hospital staff were older, more educated, and more likely to own a cell phone than the health workers. It is plausible to suspect that these factors contributed to the higher accuracy achieved by hospital staff. However, due to logistical reasons, our training procedure also differed between the two groups: health workers were trained in a large group for 6–8 hours, while hospital staff were trained in small groups for 1–2 hours. Our trainers were also somewhat more experienced when working with hospital staff, as health workers were trained first. We reiterate, however, that training continued until all participants were able to complete two perfect trials on forms and SMS, and one perfect trial with the operator.

Perhaps the most important result of this study is the identification of the live operator as a highly accurate and flexible interface for mobile data collection. We were surprised and alarmed that the textual interfaces resulted in error rates as much as $10\times$ higher than the live operator. In collaboration with community partners, our original intent was to utilize electronic forms in an upcoming tuberculosis treatment program. However, we consider it to be an unacceptable risk that 38% of submitted forms (containing critical health information) may contain errors. For this reason, we have overhauled our plans and will pursue a treatment program using a live operator rather than forms or SMS. While the cost of a live operator may be prohibitive in many countries, in India it proves to be very cost effective. The increased cost of a human operator is more than compensated by the decreased cost of voice-only handsets, voice-only cellular plans, decreased training time, and decreased literacy requirements for health workers [Patnaik et al. 2009].

A second noteworthy result of the study is that the overall error rates observed for SMS are not significantly higher than that of electronic forms, even when our electronic forms solution was iteratively designed in collaboration with the target community. This suggests that it might be viable to consider a simple SMS reporting system in cases where it is too complex or costly to develop an electronic forms solution.

While the results of this study have changed our own approach to implementing mobile data collection, we caution the reader in extending the results of the study beyond its original context. Our sample size is very small, encompassing only 13 users and observing only 26 errors in total. Clearly a larger study is needed to obtain a more precise estimate of the error rates, particularly in the case of a live operator (where we observed only 1 error during our trials). In addition, we are focused on the scenario in which users have limited cell phone familiarity and there is limited time to perform training. If either of these variables changes, it may be possible to implement high-accuracy mobile data collection with electronic forms or SMS. Also, while the error rates that we report on mobile phones are $3-8\times$ higher than those previously reported for PDAs, our data are unable to distinguish whether this difference is due to the devices or due to other aspects of the study demographics, training, and evaluation. A future study could address this question directly by evaluating both phones and PDAs in the same context.

6. CONCLUSIONS AND FUTURE WORK

Given the widespread excitement in using mobile phones for providing services in the developing world, it is important to establish that the data entered on these devices meets the strict accuracy requirements of health, finance, and other applications. In this article, we explore the usability of mobile interfaces for novice and low-literacy users via three in-depth studies: an ethnographic investigation of 90 subjects in India, Kenya, the Philippines, and South Africa; a quantitative evaluation of text, spoken dialog, and graphical interfaces across 58 first-time low-literacy subjects in southern India; and a quantitative evaluation of electronic forms, SMS, and live operator interfaces across 13 novice but literate users in northern India.

Our results confirm that textual interfaces are unusable by low-literacy users and difficult to use accurately by novice users. In the context of mobile banking, not a single low-literacy user was able to complete tasks in existing text-based UIs. In the context of healthcare, we observed approximately a 5% error rate amongst novice users (intolerable for many health applications) using an SMS or electronic forms interface. Our ethnographic investigation points to many usability barriers to traditional textual interfaces, including difficulty in scrolling and hierarchical navigation, soft-key mapping, nonnumeric input, and understanding technical language. Our general guidelines are to minimize use of these elements, while providing voice and graphical cues.

What interfaces are usable by low-literacy users? Perhaps our most positive result is that of a live operator: novice users can dictate patient health information with 99.5% accuracy for real-time transcription by an operator. In India, a live operator is a cost-effective solution for reporting small amounts of data, and we advocate its use over SMS or electronic forms. However, for environments or applications that cannot support an operator, an automated interface is needed. Though it remains an open research problem to develop a fully automatic interface that allows first-time nonliterate users to complete tasks without assistance, our studies advance the state-of-the-art in this area by identifying effective design elements as well as usability bottlenecks that can be targeted in future work.

In the case of the voice UI, most users were comfortable with the spoken interface, but some users (28%) encountered roadblocks that prevented them from completing the task. Before deploying a spoken interface for novice and first-time users, it would be critical to ensure that they are familiar with the language, concepts, and terms that are used in the application. It would also be critical for them to understand the general concept of interacting with a spoken dialog system. If these hurdles can be overcome, the voice UI offers a platform that is relatively familiar and natural to users, allowing them to complete tasks more quickly and with less assistance than on the graphical UI. A practical means of leveraging the voice UI could be as part of a hybrid interface, where users first attempt a spoken dialog system, but are referred to a live operator if they experience problems. Introducing the operator could boost the rate of task completion while also leveraging the automated interface in cases where it is effective. In order to further inform this trade-off, in future research it will be valuable to rigorously assess the accuracy and usability of a spoken dialog system relative to a live operator.

In the case of the graphical UI, all of our subjects completed the task, but only with extensive prompting and encouragement. While the number of prompts needed may decrease with further practice or coaching, the current interface is not suitable for independent use by first-time users. In order to make users more autonomous, it will be necessary to decrease their anxiety about pressing keys and “breaking” the device. It will also be helpful to decrease the mental burden of mapping keys to abstract functions. One promising avenue for addressing both of these challenges is to explore a new design point that augments the graphical UI with spoken input. By integrating a spoken dialog system with graphical cues, one could potentially leverage the best aspects of both interfaces.

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