INTERNATIONAL JOURNAL OF HUMAN–COMPUTER INTERACTION, *13*(2), 161–186

"You Talking to Me?" Exploring Voice in Self-Service User Interfaces

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Automated teller machines (ATMs) are a classic example of ubiquitous computing as they pervade our everyday life and, for many, are typical artifacts of convenient, modern living. More important, most people are unaware that in using an ATM they are connected via a computer to a powerful network. Through our research reported within this article, we examine the user acceptance and usability aspects of a novel, "contactless" ATM. This prototype ATM has iris identification, speech recognition, speech synthesis, and communication to a user's personal digital assistant (PDA).

In this article, we describe our experiences of and explorations with "Stella," a contactless ATM. First, we briefly discuss the background to the study in terms of technology and trends, and then overview previous usability research in the area. We report our findings from a cognitive walkthrough, the heuristic review of the prototype, focus groups, and a user trial. These results underline the need for multiple evaluation methods for novel concepts. In general, from the findings of this work, consumers believe that speech is a technology that will create more usable applications, even when faced with the relative failure of current technology to live up to their expectations or fulfill their practical needs. People are often initially resistant to the concept of iris identification and the PDA interaction, yet basic experience with a usable prototype quickly overcame people's reservations. Finally, we outline some of the underlying challenges facing voice-based interaction approaches to this form of ubiquitous, public self-service computing.

1. INTRODUCTION

Ubiquitous computing poses a great many challenges and offers a range of opportunity for the disciplines of usability and ergonomics (Baber, Stanton, & Johnson,

We thank the NCR Self-Service Advanced Concepts team for their insight and practical support of this study, especially Steve Swaine for his designs and concept illustrations. We are also grateful for the comments and advice provided by the special issue editor and anonymous reviewers. Note that the views expressed in this article are those of the authors and do not necessarily reflect those of NCR Corp.

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1998). Over the last few years, the concept of ubiquitous computing has grown in stature (Norman, 1999), with the recognition that this field generally refers to machines, networks, and objects embedded within everyday life—information appliances that are not typically perceived as computers. An extension of, or arguably a subset of, ubiquitous computing is the area of public technology. This is commonly conceived as composed of machines such as ticket vending machines, kiosks, and automated teller machines (ATMs), where consumers of all types can "walk up and use"without any training or instruction.

Our focus within this article is on the ATM, which has provided a 24-hr banking service to the public for many years and has witnessed several significant design and technology evolutions to reach its current form. As with so many other domains, the drive to apply the latest is also witnessed in the arena of public technology, and this is also true of self-service epitomized by the ATM. Increasing functionality and service additions are considered, as more becomes possible. Indeed, the convergence of technologies themselves, as a function of an increasingly networked world, means that public technology can form part of a solution involving many other (ubiquitous computing) components, such as handheld devices in the form of a personal digital assistant (PDA) or a mobile (cellular) telephone.

The 1990s saw the great rise of the ATM in popularity as banks found that they could offer a full 24-hr service to their customers, and the variety of locations for ATMs grew. As an example of everyday computing used by young and old alike, there are few rivals. Naturally, service providers and developers have sought to extend the overall set of financial (and other) services on offer via this self-service portal. We now have ATMs that can dispense, apart from the standard notes and coins, a range of paper-based media including checks, stamps, different currencies, forms, and ski passes. Also, the ATM's ability to accept and recognize media continues to grow, and currently checks, money, and passbooks are all possible with recent advances in technology. For some time, touchscreens have been offered as standard, and the World Wide Web has influenced the networked capability of self-service. From a user's perspective, such innovations in public technology can offer great improvements in the variety of services and in the quality of service. At the same time, the end user may also be challenged with new and different ways of carrying out basic tasks, ones that are clearly dependent on an environment that prides itself on speed, reliability, and convenience.

In this article, we describe part of our research that had the dual objectives of (a) gaining an understanding of people's reaction to, and expectations of, a voice-based user interface to an ATM, and (b) exploring the possibilities of broader, less visually dependent, interaction for public, self-service technology. The case study presented centers around a novel ATM, which is "contactless"employing both speech and biometrics technology as well as a "virtual contact"with a consumer's PDA.

Evaluating novel concepts with the general public is particularly problematic, and no one method is adequate. We employed a number of evaluation methods to explore user acceptance and usability of the concept. We conclude the article with a discussion of the usability issues encountered and an identification of challenges in the further development of such concepts. Before describing the main study, we

first outline the previous research in traditional self-service interfaces, speech technologies, and novel self-service interfaces, which provided, in part, a foundation for the evaluation study.

1.1. Previous Research on Traditional Self-Service Interfaces

As a focus for human–computer interaction (HCI) research, the ATM and its usability characteristics have attracted a limited amount of attention (Johnson & Westwater, 1996) when compared with the large and varied body of research addressing the domain of the desktop personal computer (PC) and occupational settings such as control rooms. To some extent, this appears to be due to the narrow task scope, wide user population, and relative operational success of many financial self-service interfaces. Furthermore, the dominant forces within HCI have mirrored the information technology industries' progression, which until recently paid too little attention to the public, domestic, and mobile fields of everyday consumer applications.

Much of the usability and applied psychology research on ATMs tended toward an analysis of the general usage and nonadoption aspects by consumers (see e.g., Adams & Thieben, 1991; Bell & Scobie, 1992; Hatta & Iijama, 1991; Stevens, Warren, & Martin, 1989). As a public technology, the critical issue of adoption, or acceptance, by all has been a central research issue. Others have investigated public conceptions and mental models of the ATM itself (e.g., Henneman, Knutson, & Johnson, 1993; Payne, 1991). As a commonly encountered example of public technology, such an area is ripe for investigation of natural mental models and of the fundamental questions concerning service adoption and end-user comprehension by many unfamiliar with computer-based systems.

There has also been a steady and major stream of ATM-focused research in the United States, mainly centered on the issues concerning older users, their technology use, and training approaches (Jamieson, Cabrera, Mead, & Rousseau, 1995; Jamieson & Rogers, 1998; Mead & Fisk, 1998; Rogers, Cabrera, Walker, Gilbert, & Fisk, 1996; Rogers & Fisk, 1997; Rogers, Fisk, Mead, Walker, & Cabrera, 1996; Rogers, Gilbert, & Cabrera, 1994, 1997; Smither, Braun, & Smither, 1991). In particular, they have studied cognition and aging as it applies to ATMs, and they continue to investigate other common, everyday technologies from the perspective of the older user. Employing both full survey and in-depth interview methods, as well as developing simulation approaches, they have furthered the understanding of self-service technology for and by this often underrepresented segment of the user population.

1.2. Speech Interaction

Speech interaction is often portrayed as the most natural way to interact with a computer system. Television advertisements show a man at ease with controlling his home environment via spoken commands. Visions of the future often involve peo-

ple conversing with their computers as they would a friend. Many people do believe that this is the way forward. The majority of articles on speech technology do not question the underlying assumption of the desirability of this technology; rather, they address the technological feasibility of providing such an experience for the user.

Over the last 40 years, there has been slow and steady progress in speech technology capabilities. There are four interrelated aspects of voice interaction: speaker recognition, natural language understanding, speech recognition, and speech synthesis.

Speaker recognition. This requires the system to recognize who said it rather than what is said. Speaker recognition belongs to two industries: biometrics and speech processing. The recent upsurge in mobile phone usage and the drive to deliver services over this technology has led to renewed interest in voice biometrics (Markowitz, 2000). However, the reliability of this approach is not as high as iris identification, and therefore iris was chosen as the contactless biometric for this research vehicle.

Natural language understanding. Natural language understanding requires free-form speech input and the computer to have the ability to understand what is said (White, 1990). Comfortable and natural communication in a general setting is regarded as beyond the capabilities of current technologies (Caulton, 2000; Peacocke & Graaf, 1990). Fortunately, the problem can be simplified into speech recognition.

Speech recognition. There are five factors that can be used to control and simplify the speech recognition task.

1. Isolated words: The recognizer recognizes whole, individual words. This may require the user to slow down speech, which can be problematic in applications such as word processing but may be acceptable in command-type setting. This approach was adopted by the contactless ATM concept.
2. Single speaker: These speaker-dependent systems can be five times more accurate than speaker-independent systems. The system has pattern-matching templates created to a specific voice in a training phase. However, this is not appropriate for a public access system, and therefore a speaker-independent approach was taken.
3. Vocabulary size: The smaller the vocabulary the easier and faster the recognition task. However, the vocabulary set produced must be unambiguous. This can be quite difficult if we take the *E* set, where sounds such as *B, C, D, E, G, P, T, V, Z,* and *three* are potentially ambiguous.
4. Grammar: This defines the allowable set of words and the order in which they appear within a linguistic structure. The constraint placed on a gram-

mar is known as the perplexity of the grammar—the greater the perplexity the higher the accuracy—and it increases the learning task for the user.

Speech synthesis. This is the conversion of linguistic information stored as data or text to speech. There has been rapid expansion of the application of speech synthesis, out of the realms of disabled access and into areas such as document processing and telephone-based applications. Word pronunciation, intelligibility, and accuracy are key issues. Far more gains have been made in speech synthesis than speech recognition in the last 30 years. However, there are still unrealistic expectations for dramatic improvements in text-to-speech technology, sometimes arising from an unsophisticated view of the complex linguistic information involved (O'Malley, 1990).

In the field of human factors of interactive speech technology and voice recognition applications, there is a relative abundance of literature (e.g., Baber & Noyes, 1993). The main areas to adopt speech are desktop applications such as word processing and spreadsheets (Caulton, 2000; Karl, Pettey, & Schneiderman, 1993; Rudnicky et al., 1990). There has been mixed success with such applications, with users requiring training to operate such systems effectively. Some of this can be applied to the domain of self-service. Nevertheless, the user, task, and environmental aspects that characterize ATM usage make this situation potentially very different from others that employ speech.

A number of studies (Baber, Johnson, & Cleaver, 1997; Hone, Graham, Maguire, Baber, & Johnson, 1998; Manzke, Egan, Felix, & Krueger, 1998) have addressed various research questions covering speech within an ATM user interface. Here, researchers are primarily concerned with the augmentation and overall enhancement of the user experience via the technologies of speech verification and voice recognition. Baber et al. (1997) studied the factors influencing users' word choice. Adopting a "Wizard of Oz" approach, with studies of unconstrained and constrained word use, they looked at those specific words and forms that were used to express the requests at an ATM, as well as the degree of consistency across speakers. Key factors to emerge from these vocabulary-definition studies were the design of feedback, nature of the tasks being performed, and the nature of the speech recognizer. These findings have been incorporated in the design of the operational prototype presented in this case study.

The use of the ATM by visually impaired users was investigated by Manzke et al. (1998) in which the use of speech output was evaluated. For these users, compared to those with unimpaired or corrected vision, significant performance benefits of a speech output ATM were demonstrated using time-log data, although participants in these trials sometimes felt hindered by the speech. Hone et al. (1998) reported several studies examining the deployment of speech technology at the self-service (ATM) interface. The first study, carried out in the United States and United Kingdom, surveyed nearly 900 people on the potential for speech in this self-service context. A number were skeptical, although many felt that a multimodal interface would have real benefits. Dealing with the consumer issue of privacy in speech-based transactions, a simple experimental study was conducted to look at design options for en-

closure and microphone setting. Finally, focus groups with visual impairments and users without visual impairments were carried out, revealing some concerns, but also revealing a clear interest from those with visual impairments.

1.3. Previous Research on Novel Self-Service Interfaces

Novel interfaces to financial services and ATMs have also been the subject of usability research. For example, Burford and Baber (1994) reported their experiments using simulation, tackling the issues concerning adaptive user interfaces for ATMs, and assessing user reactions. Similarly, interfaces for consumer banking via games' consoles and television have also been investigated (Johnson, 1996a) revealing new avenues, or channels, for tasks commonly perceived as mundane. From the perspective of contemporary interaction design, the ATM user interface has acted as the stimulus for many innovative design approaches, using such concepts as persuasion and personalization to drive new designs and examine the nature of the consumer's communication with ATMs as everyday artifacts (see e.g., Boyarski & Buchanan, 1994; Fogg, 1999; Riecken, 2000). Consumer-driven research on future financial and retail interfaces, and those technologies that enable them, continues to be the focus of innovative approaches (see e.g., Lynch, Emmott, & Johnson, 1999) as the scope of everyday, ubiquitous computing increases.

More recently, the biometrics technologies that seek to verify the identity of a user—such as fingerprint, face recognition, and hand geometry—their introduction to the ATM user interface, and the associated usability aspects have formed the focus for several studies. The use of biometrics technologies within self-service, of course, requires that they be simple to use, reliable, and do not intimidate consumers. Coventry and Johnson (1999) reported on the technology of iris verification that added to the ATM user interface to speed and ease the verification of a consumer, in principle avoiding the need for a personal identification number (PIN). This research utilized a number of evaluation approaches at different stages of the concept development to discover real acceptance and usability issues with the introduction of iris verification. Despite many reservations about the technology disclosed in early focus group and survey studies, consumers were quick to appreciate the utility of iris verification once they had practical experience of operational prototypes. User reactions to this significant change within the standard self-service scenario were extremely positive when used in an operational ATM. This highlighted the role of usability in forming user acceptance of new technology.

1.4. Human Qualities in an Interface

Recently there has been much interest in the role of a computer as a social actor, exploring the relation between humans and computers (Reeves & Nass, 1996). Studies report a relation between speech and human traits (see e.g., Nass & Lee, 2000). Even without creating humanlike speech, the nature of what is said during the interaction

is often sufficient for users to attribute "personality" and to react to the computer artifact in the same way as they would to a person displaying personality traits such as introversion and extroversion.

As well as speech, embedded synthetic characters, or avatars, have been explored. However, the balance between costs and benefits when implementing an avatar or deliberately introducing these qualities are not yet well understood. The behavior of any avatar must be consistent with the personality attributes communicated by the speech patterns, requiring further understanding of communication. Avatars, although having some value in terms of novelty and amusement, and serving as an excellent attraction, can also potentially distract from the purpose of the application or irritate the user. Christian and Avery (2000) reported on their recent experiences with an intelligent information kiosk that incorporated synthesized speech, touchscreen input, and a "talking head" as an avatar. This avatar has a basic awareness of the location of users and the head tracks the user, although many users were unaware of this. People enjoyed poking the talking head and seeing the reaction; the creators had coded in a series of reactions to these pokes. Other authors, such as Lai, Wood, and Considine (2000), reported that the behavior of an avatar can also create anxiety in users, especially if the avatar appears to monitor the activities of the user. It is interesting to speculate how this would be perceived in a financial environment: How would such monitoring effect user's perception of, say, security? Cassell (2000) went further and presented a fully embodied behavioral character, which uses gestures and nonverbal cues to facilitate the interaction experience, although she did point out the lack of user evaluations of such systems.

1.5. Evaluation Approaches

For the last 20 years there have been disagreements within the usability community as to the relative effectiveness of different evaluation methods. Karat, Campbell, and Fiegell (1992) compared empirical usability testing with individual and team walkthroughs. A finding of this research was that only one third of usability problems were found by all three methods. Most problems were found during empirical usability testing, but effective usability testing requires working models, particularly when the concept being tested is novel. There is also great debate about expert involvement, be it to evaluate against guidelines or partake in cognitive walkthroughs. With such techniques, the quality of the evaluation is very dependent on the skills of the evaluator. Thus, to fully understand consumer acceptance and potential usability problems with new technology, it is essential to utilize more than one method of evaluation during concept exploration. Public technology, especially ATMs and financial user interfaces, has been the focus of many usability evaluation methods, their development and their application, such as checklist and heuristic approaches (Johnson, 1996b; Westwater & Johnson, 1995) and operational sequence methods (Johnson, 1993). Less conventional approaches to the appraisal of usability and requirements gathering have been explored—for example, innovative behavioral techniques using eye-position tracking in the use of ATMs (e.g., Hide, Hasle-

grave, Hopkinson, Robertson, & Johnson, 1999), as well as more qualitative evaluation approaches (Johnson & Briggs, 1996) using verbal protocols.

In the following section we describe the novel, contactless, voice-based ATM (named *Stella*) and provide a brief background to the concept.

2. STELLA: A CONTACTLESS, VOICE-BASED ATM

The exploration, via user-centered studies, of the potential of future technologies to create a more "friendly" and humanlike interaction within a self-service environment led to the emergence of a series of concepts for a futuristic ATM, one of which was a contactless ATM, labelled *Stella.* The initial objectives of this ATM prototype, Stella, were to

1. Explore the utilization of future technologies and design ideas that "break the mold"of traditional ATM design.
2. Demonstrate possibilities for new humanlike interaction paradigms for consumers achievable with current technology.
3. Investigate the physical and interaction designs, which would be viewed as personal, engaging, friendly, private, and effective.

A number of concept vehicles have been created to explore how best to achieve these objectives, deriving their thinking and approach from contemporary and retro design trends. Figure 1 shows two of the initial concepts considered.

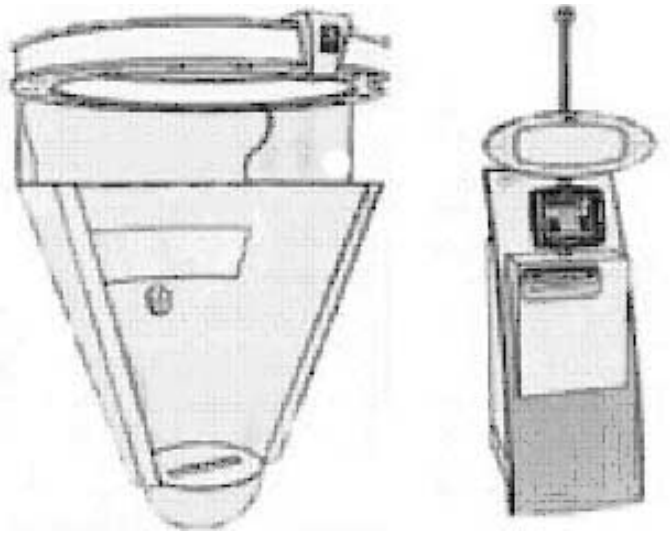

FIGURE 1 Concept designs for futuristic ATMs (sketched by Steve Swaine, NCR Corp.).

Stella was created with a number of deliberate attributes, which differentiated "her" from conventional ATMs. The notion was that we would not only be able to demonstrate this futuristic self-service device but ensure evaluation via a fully operational prototype.

2.1. Iris Identification

First, consumer recognition was based on an iris identification (biometrics verification) system integrated within the ATM itself. In this scenario the customer walked up to the ATM and looked into the recognition panel, cued by the flashing indicator. A proximity sensor noted the user approach and began the dialogue, addressing the specific user. This was created to demonstrate that an ATM interaction could be achieved by the customer without any form of token such as a (bank) card and the associated key—the PIN (Personal Identification Number).

2.2. Speech Recognition and Synthesis

Second, and the main focus of this article, was the novel interaction embraced by the ATM concept. To demonstrate an alternative, humanlike interaction, speech synthesis and speech recognition were used for the interaction rather than a standard keypad or touchscreen. Speech recognition and the majority of speech synthesis were implemented with IBM Via Voice®. The actual female voice was implemented with Microsoft Whisper®. A small grammar was created that was thought to best match predictions of how a user may speak to Stella (see Figure 2).

Stella grammar is restrictive; to facilitate users following this grammar, the interaction is led by Stella in the hope that users will respond to the question. An advanced microphone was used that provided noise cancellation. No user "barge in" was allowed, as Stella could not speak and listen at the same time.

To complement the transient nature of the speech interaction, a commonly available PDA was utilized to send permanent, private information (in this case, a transaction receipt) directly to the user via an infrared link, continuing the contactless theme throughout the interaction.

2.3. Personalization and Visual Form

Simple personalization was included within the concept. Given the increase in services and information available to financial consumers today, and the likely increase in the future, it was important to introduce a more personal environment for self-service. Personalization was achieved in two ways: addressing the user by name and offering the transactions in a manner that reflects the users' previous self-service transaction history.

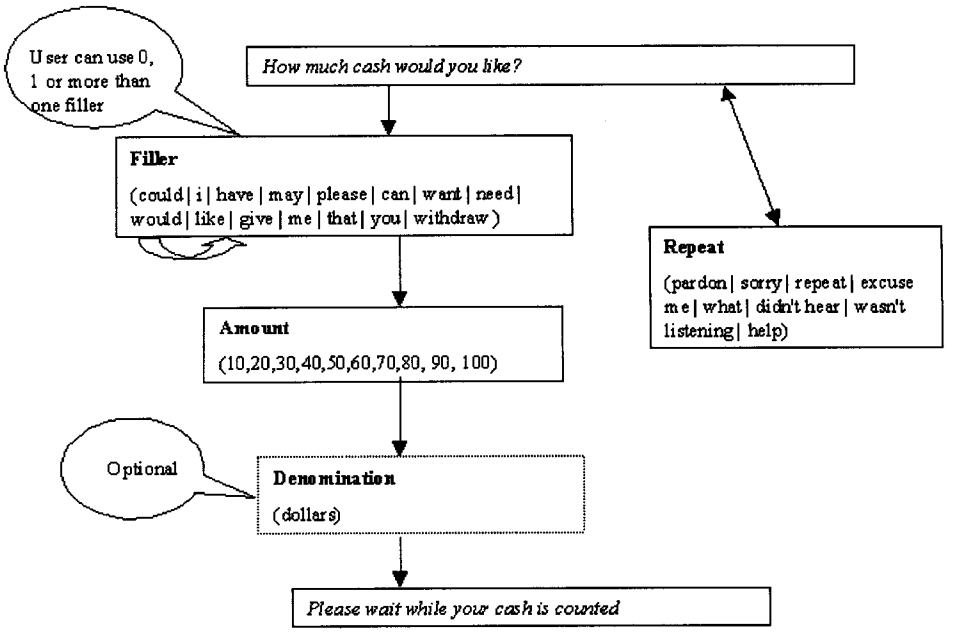

FIGURE 2 Grammar for cash withdraw transaction.

Finally, a more contemporary and innovative design approach was taken, using less geometric and more organic forms and contemporary colors, to the physical structure of the machine itself. Figure 3 shows Stella being used.

The use of Stella, from a consumer's point of view, is summarized in Figure 4, which depicts the key steps in usage as a storyboard. The brevity of the task and the simplicity of the dialogue are key characteristics of the self-service environment.

3. EVALUATION APPROACH

To ensure a full exploration of users' issues with this approach, our evaluation of Stella utilized four methods. We, the authors, carried out these evaluations. First, a cognitive walkthrough similar to Lewis, Polson, Wharton, and Rieman (1990) was conducted. The evaluators walked through three tasks understanding what the user's goal was, if sufficient information was available at every step for the user to know what action was required and how to execute it. This task was carried out independently by each evaluator, and then the findings discussed.

Second, after walking through the tasks a number of times and understanding where problems may arise, we categorized our issues in terms of usability heuristics (see Nielsen, 1993; Ravden & Johnson, 1989). Evaluators were given a series of questions for each of the usability heuristics. These questions served to focus the evaluators on the types of issues related to each of the heuristics.

FIGURE 3 Stella: Prototype contactless ATM.

Third, focus groups were held to discuss users' views of an ideal future ATM and their thoughts about the Stella concept. Last, users were asked to complete two transactions with Stella to assess how well Stella could perform.

3.1. Usability Heuristics

The usability heuristics, used in the assessment of the Stella prototype, are listed next with examples of the questions used to explore compliance to the heuristic.

- Compatibility between the system and the real world: Does the language use match users' expectations? Do the users know how to behave and what is expected of them? Does the system work the way a user would expect? Does it look like an ATM?

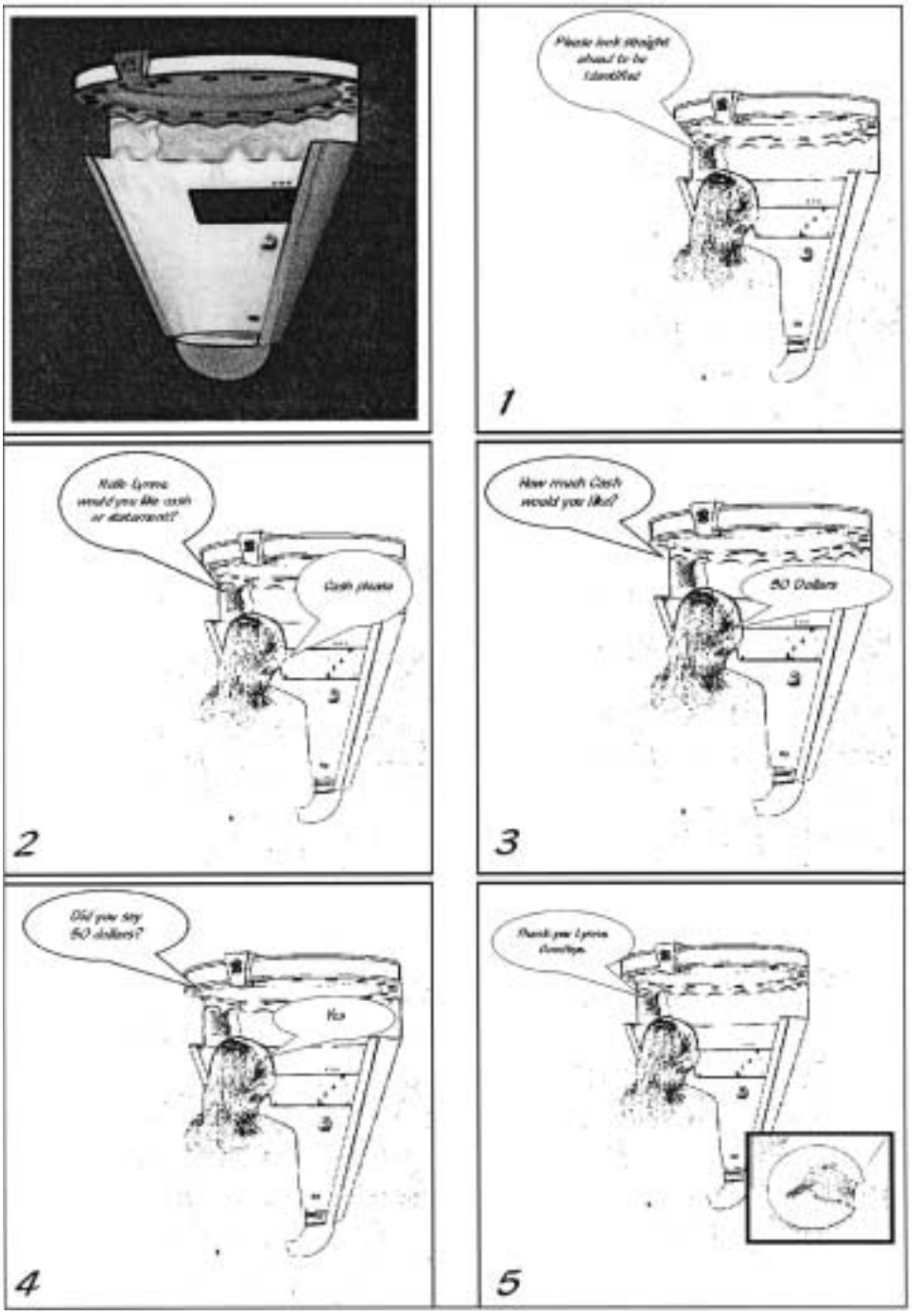

FIGURE 4 Using Stella.

- Appropriate functionality: Is the functionality appropriate to the task, and is the way information is presented appropriate to the task?
- Visibility of system status: Is it clear where the user is within the application? Is the user made aware of what is happening? Is the task structure simple?
- User control and freedom: Is "undo" available? How many ways can the user complete the task? Does the user have shortcuts? Does the user have sufficient time to respond?
- Consistency: Is the same information presented in the same way? Are the required user responses similar in similar situations?
- Error protection: Are users prevented from errors? Is it easy to recover from errors? Can the user cancel or undo at any point? Is the user given clear instructions about how to recover from errors?
- Flexibility and efficiency of use: Are universally recognized commands used? Is it as fast to use this system as a standard ATM? Is anything slowing down the interaction?

In addition to these accepted usability criteria, the review included two further dimensions: (a)"Aesthetics," by which we meant the general appearance of the concept model and the effectiveness of the aesthetics in communicating function and promoting user acceptance and satisfaction, and (b) access for disabled and impaired users.

3.2. Focus Groups and User Trials

The second, and main part of the evaluation, was a series of in-depth focus groups and user trials, centered on the concept ATM, Stella. The location of the focus groups and user trials was within central Toronto. All participants in the group sessions were customers from two of Canada's leading banks.

Participants. A total of 80 participants took part in this study. Participants were selected on the basis of gender, age, and use of banking technology. Ten groups were formed with 6 to 10 participants in each group. The groups were split by gender and age. The age groups were 18 to 34, 35 to 54, and over 54. Within each group was a spread of technology users. All participants were regular ATM users and credit or debit card users. At least two members of each group used telephone banking. At least two members of each group used Internet banking services. Despite not being selected on the basis of PC usage, only one or two members of each group had never used e-mail or the Internet, and only one participant did not regularly use a PC.

Procedure. For each of the four groups, the following procedure was followed:

1. A general discussion of current technology used by participants, their likes and dislikes.

2. Discussion of participants' vision of an ideal future technology and what benefits it would or could bring.
3. The Stella concept was presented and the participants' feelings toward this particular vision of the future were discussed.
4. User trial.
5. Questionnaire completion: Each participant filled in individual questionnaires on the Stella concept and the potential users and their characteristics while waiting; when they came back from using Stella, they filled in a questionnaire about the experience while waiting for the group to reform.
6. General group discussion of the experiences of using Stella.

In this way, the participants in the focus groups had the opportunity to discuss the general attributes of current and possible future technology, express specific views before using Stella, and then actually use the prototype for common banking tasks. The last part followed tasks with the prototype in which participants discussed their views with each other in their groups.

Participants left the focus group room individually and took part in the user trial. Participants were enrolled for iris identification and were asked to then attempt to withdraw money from Stella and collect a statement on a PDA. The basic way to operate the PDA was explained. The only instruction in the use of Stella was not to interrupt but to wait until Stella finished speaking before they responded. If the user was struggling to complete the transaction, the evaluator would provide an appropriate prompt to the user. The use of the prototype during these sessions was, with permission, videotaped and timed.

4. GENERAL RESULTS

4.1. Cognitive Walkthrough

The walkthrough of the task raised a number of issues to the evaluators. There was general agreement about the problems, but the female evaluator had more problems completing the task than the male evaluator did. The major concerns identified were the following:

- Unnaturalness of the timing of the response to the question; one evaluator repeatedly responded too quickly.
- The inability of Stella to recognize the female voice input.
- The concave shape amplified the sound and so may raise privacy fears.

The evaluators were unable to determine if the general public would accept the concept, or whether the technical restrictions would place too high a demand on the user for a successful transaction to occur, or if it would be possible to achieve the same speed of transaction as with a traditional interface. The findings of this were recorded against usability heuristics and each heuristic explored in more detail.

4.2. Heuristic Results

The findings from the heuristic evaluation were useful in the generation of discussion points for the later focus groups and user trials. This part of the evaluation quickly highlighted a number of key areas for further consideration in contactless self-service. It was noticeable that the heuristics themselves in the face of such a novel concept were easily questioned, as their origin and general application concerns were conventional screen-based, often desktop, interaction.

Real-world compatibility. When looking at compatibility issues, we found that there were set expectations associated with a menu-driven, voice-based interface. Although some of the timing aspects seemed problematic, it was difficult to gauge just how (quickly) consumers would answer specific questions posed by Stella. In the overall lead through of the transaction, the user is prompted with questions (such as "How much cash would you like?"); however, there are several spots in the interaction wherein the system status is unclear. This is normally when a "window" occurs in anticipation of a response from a consumer. One of the main issues identified with this part of the heuristic evaluation is just how well this approach would scale up when more functionality is added. One can imagine, from experience with telephone-based solutions, the navigation issues that may occur when the system grows in terms of the services offered.

Visibility of system status. Again, within the system status part of this evaluation, from a consumer's perspective there is an apparent lack of feedback when using the PDA link to Stella. The system also fails to respond if the system does not understand an input; the system waits until an appropriate response is heard. A general iteration of the dialogue with attention to non-verbal audio signals was recommended.

User control and freedom. With respect to user control and freedom, another category within the structured expert evaluation, the user is well supported in what is a relatively simple set of interactions. This iteration of the dialogue involves the user in only moving forward, and the need for a back, cancel, and so forth would be an issue in a larger application. Similarly, experienced users may require shortcuts, with barge in an obvious option.

Consistency, flexibility, and efficiency of use. Consistency and flexibility faired well in our evaluation. However, user expectations of the speed of transaction may be an issue as the overall system's impression of a futuristic and advanced system.

Disabled access. As we reviewed the prototype against our criteria concerning disability, it was obvious that those with visual impairments would most

likely benefit from the voice-led approach. In so doing, this approach also places a heavier load on those users without visual impairment as they must remember and listen according to the menu-driven interaction. Removing the touch inputs within the interface reduces issues of physical reach for all, including those with mobility impairments and those who are wheelchair bound. Of course, users with speech and hearing impairments are not accommodated by this concept. Also, application of this approach to nonnative speakers, and their speech recognition, raises possible issues.

Aesthetics. Finally, our heuristic review of Stella centered on the aesthetic qualities promoted by the design. The main objective of presenting a concept that appears futuristic and novel, in terms of overall form, look, and feel, was achieved. The unusual concave form, driven by the need to enhance privacy, however, may lead to issues with consumers appreciating its overall self-service function. It remained to be seen, within the user-centered investigation, whether people would easily understand the purpose of the concept and whether they would find the design welcoming, private, and engaging. At this stage of the heuristic evaluation, a number of queries were also raised about the way in which the (female) voice of Stella would be perceived, and whether or not this would communicate self-service functionality to the consumer.

4.3. Focus Group Results

Focus group discussions were based around thoughts on current technology, the views of a useful future technology, and opinions of Stella before and after use.

Current technology. In general, the groups made few comments about current ATMs other than they were seen as quick, relatively easy to use, and reliable, offering a real benefit to the consumer. Negative comments tended to center around fee structures and uncertainty about how up-to-date balance information may be. Comments on contemporary telephone-based banking systems were mixed, although many recognized the convenience of the system being "location free." Several commented on how useful the system is when used with a screen phone, allowing for option viewing and confirmation of numbers.

Future technology. The majority of participants felt the use of technology in banking would increase and could be made more useful than it is currently. Participants discussed home-based banking, more secure identification, use of speech to control computers that would make them easier to use, and the use of videoconferencing to talk to bank managers to negotiate loans, and so forth.

Stella—before use. Participants mentioned concerns about the identification technology, primarily worried about how it worked and how well it worked, a find-

ing that ties in well with previous studies of iris-based verification (Coventry & Johnson, 1999). There was little understanding of the PDA or its role in the overall usage scenario. Concerning the speech-driven aspects of Stella, many were interested, although several doubted whether it would be able to recognize their own voices and accents. They did believe that speech interfaces may attract technophobes and make an ATM easier to use. Some participants expressed fears about the general privacy of the transaction, in that the design of Stella appeared very open.

Stella—after use. Following actual usage of Stella, individual responses to questionnaires were completed. In answer to the question, "What words best describe how you felt when using Stella?," a range of adjectives, forming both positive and negative comments, was proposed. Typical responses (by frequency) were the following:

- Positive category: *Convenient, eager, simplicity, streamlined, interested, polite, fast, curious, awe, comfortable, amused.*
- Negative category: *Loud, impatient, stupid, awkward, intimidated, apprehensive, nervous, frustration.*

Overall reactions, gathered via the question "What words would you use to describe Stella?" resulted in a split opinion. Words such as *spacey, high-tech,* and *different* were scored as neutral, as it was unclear whether these were intended as positive or negative. An extreme range of answers was elicited with many opposites noted: for instance, *slow* and *fast, friendly* and *unfriendly, simple* and *difficult.* These comments seemed, understandably, to reflect the individual's particular experience with the Stella prototype.

Stella's voice provoked several reactions from the participants. Users were keen to suggest how her voice could be improved. More interesting, over half the participants did not perceive Stella as having a female voice. Only a small number of users felt that the voice was adequate. Most were of the view that there should be a range of voices from which a favorite could be selected. Others pointed out that Stella's voice was very metallic, almost robotlike. Several commented that it was too slow, indistinct yet loud, and far too unnatural. Following use, some participants thought that the voice would quickly become irritating with repeated usage.

The identification part of Stella, which employed the iris verification technology, had been raised in the pre-use groups as a concern for several reasons. However, following use of the prototype, the majority of views of this aspect of Stella had changed. They found this form of identification acceptable and were able to articulate the benefits. The enrollment process, involving the recording of a digital template of their individual, unique iris patterns, seemed to dismiss the concerns some had about the overall security and speed of the system. Participants liked the idea of the ATM recognizing them rather than having to identify themselves to the machine. Furthermore, the absence of card and PIN was seen positively. Several users said that they could easily imagine themselves using a conventional ATM with this iris verification feature when it becomes available. It was noticeable that many us-

ers were making the assumption that because Stella had identified them from their eyes, the voice system would only recognize their voice. Several participants also believed that during the transaction Stella was constantly identifying them as a particular user (which was not the case) and often users would direct their gaze toward the integrated iris system.

On the question of personalization, most users found the idea of being addressed by name (via Stella's voice) very appealing, with only two conditions. Naturally, Stella must be able to pronounce their name perfectly. Secondly, the participants were keen to be able to direct the system in how it should address them. One user commented, "It is an attempt to be more personal, but it seems caught between a person and a machine—a very odd combination."

The second aspect of personalization introduced by Stella was in basic adaptation to individual users' previous transaction behavior. However, the use of "your usual" in this context did surprise most participants, and some commented that they would not necessarily have a usual transaction. Others noted that it would have been more usefully termed "same as last time," or more specifically the function combination itself.

As far as the PDA involvement was concerned, there were few strong views on this concept of "transmitting" receipts and related information between Stella and the handheld device. Note that many participants had no real experience and very little exposure to this kind of handheld computing. Many made the point that this would be an extra thing to carry around. Following use of the PDA, several views changed, and many were interested in the potential. They quickly saw the possibilities for using the PDA between the Stella ATM and a PC, say as an intelligent wallet, able to ensure account balancing. Of course, the fact that the PDA could be used to display private information or allow for the download of other information types from Stella also featured in their feedback.

Participants were of quite different opinions when quizzed about the visual design of Stella. Although some felt it was really visually appealing, modern, and simple, others felt it was overpowering and daunting. In general, the physical design of Stella did not put their minds at rest about the privacy of the transaction. The lights built in the upper part of Stella that gradually came on after an individual was identified and the transaction commenced were, according to some participants, disconcerting as they felt like they were suddenly on a stage. Reactions to the physical and visual design were modified by the success or otherwise of individuals' use of Stella. One comment sums this up: "A beautiful setting, I loved it. But, I was disappointed when I tried it."

When the participants were asked about whom they saw as the most likely user group for this type of ATM, there was an overall consensus about the group. Their judgment about the main potential user group tended toward a typical early-adopter profile. These characteristics reported across all groups were young (probably in the age range 18 to 34 years), interested in trying out new technology, already computer literate, time poor, and regular ATM users. The pre-use notion that this form of ATM may appeal to those with no real computer experience, with Stella avoiding the keyboard and screen style of user interface, was not borne out by the participants' views after they had tried to use Stella.

4.4. User Trial Results

The main objective for the user trial was to collect observational data of real users using Stella. The study was formative in nature as we had predicted that users would have difficulties using Stella, but we had to learn more about the actual difficulties within the ATM context. Observational data are always useful with a prototype of such a novel system, especially one at an early stage. This proved to be the case with Stella, as many of the user observations shed light on the interaction difficulties at key stages. For instance, the frustration was evident with several participants who were unable to make themselves understood, or rather recognized, by Stella. Similarly, timing and feedback issues cropped up at certain points, as participants waited for Stella or were unsure whether their own answer had been recognized.

It proved not to be possible for a user to complete the task without prompting from the evaluator. A sample of 50 participants was used to generate some metrics. Due to the lack of success of users to interact with Stella, qualitative findings are reported rather than any quantitative statistics. Behavioral findings focused mainly on the transaction when using Stella. With these caveats, the general findings can be summarized as follows:

- All users were successfully identified by the iris identification technology. Successful identification took less than 10 sec.
- The evaluator had to prompt every user to repeat what the user had said, or to respond with "yes" to a question, or not to speak too early.
- 20% of the sample ($N = 50$) were able to carry out their transactions as quickly as with a conventional ATM. These people required the prompt to repeat what they had said as they had spoken too soon.
- The mean time taken to complete the cash withdrawal transaction was 65 sec, and the maximum time taken by any user was 158 sec. This does not include time before a user failed and walked away (see Figure 5).

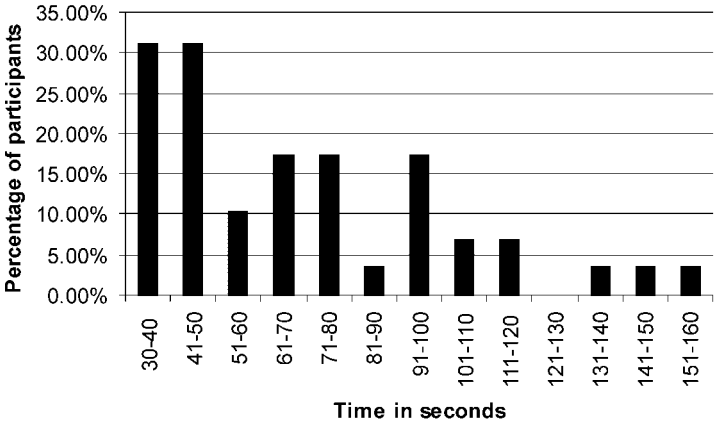

FIGURE 5 Time to complete transaction.

- Ninety-four percent of the sample managed to fully complete the transaction, although only 90% received the correct amount of money (due to recognition failure of amount). The general point of failure was failing to have the amount of money recognized.

5. DISCUSSION AND CONCLUSIONS

5.1. Performance of Speech in Stella

Stella did eventually understand 90% of the input from a wide range of users. However, this involved many users experiencing extreme frustration, having to continually repeat what they said. Users assumed that Stella could not understand what they had said and so would adopt different voices the more their response was not recognized. The lack of feedback from Stella and lack of tools to debug Stella meant that it was not clear whether timing of response, pronunciation of words, lack of user synchronization with the grammar, or inappropriate noise cancellation by the microphone was to blame for the failures. Ten percent of users failed to complete the transaction; this was actually less than we had anticipated from our heuristic review but would have been much higher if participants had not received external help.

Although the desire for speech recognition is quite prevalent among consumers, the ability of speaker-independent systems in busy public environments does not appear to be sufficiently robust, accurate, or intuitive. Speaker-independent recognition is most reliable with a small vocabulary and clear audio. Although the vocabulary for a correct path through the transaction was sufficient, the Stella system failed to deal well with users who strayed from the path. Users' reactions to mistakes were not predictable. Although the prompts in the dialogue did serve the purpose of limiting user responses, without the user feeling restricted, this would not necessarily work in more open responsive-type environments. Speech interfaces have weaknesses, which can be accommodated by the appropriate mixing of other forms (modalities) of interaction. The key is finding the correct match of interaction with the nature of the task. This balance has been explored in other contexts such as medicine as reported by Grasso, Ebert, and Finin (1998).

5.2. The Role of Prototypes in Evaluations

The ability of the users to interact with Stella was extremely varied, and this is reflected in the dichotomy of views about the concept expressed after use. This dichotomy was not present before use of the system. The inability of the current implementation to allow a barge in and provide well-timed feedback to the user about the current system status was particularly problematic. Another influencing factor was the quality of the microphone and the acoustics. Clearly, high-quality directional embedded microphones are required, as is attention to the acoustical environment.

The study supported the role of working prototypes in providing users with concrete experiences and real interactions on which to base comments about acceptance of technologies. Experience with the prototype can turn positive expectations into negative, as was illustrated in general with the speech interaction, and conversely, negative expectations into positive, as was illustrated with iris identification and PDA functions.

5.3. The Need for Multiple Evaluations

This research highlights the need to adopt multiple methods when researching novel concepts. The expert evaluation highlighted the majority of issues that caused usability problems during the user trial, however it did not predict the problems when the system misheard an amount of money and the user had to respond to the question "Did you say *X* dollars?" The correct answer is "no," and then wait for a follow on the question. Users did not respond in this manner and therefore could not recover from this point. The grammar must be altered to deal with this aspect of the interaction.

As mentioned previously, the interaction with the prototype also colored users' opinions to a differing degree depending on their previous acceptance of the concept. This highlights the need for multiple early evaluations to understand underlying users' acceptance and resistance before they come into contact with the technology.

5.4. Social Interaction With Computers

In attempting to create a natural interaction, user expectations of the whole interaction are increased. Users were quick to attribute negative traits to Stella because of their experiences. Even with basic speech facilities and a machinelike interaction, the users did react to Stella as if she were humanlike, supporting the computers as social actors view of Reeves and Nass (1996). Attempting to provide the ATM user interface with a more"humanistic"quality, to make it more appealing, or to allow for personalization possibilities seems to have some merit. The"personification"of Stella in terms of form, voice, and interaction style was clearly a basic attempt, and one that received a mixed response within the study. However, it does serve to illustrate several points about humanistic interfaces concerning avatars, personality, and adaptive interfaces. We concluded immediately from this study that an avatar is not necessarily required for users to attribute personality to the ATM. Both the physical design and the quality of the speech interaction within the prototype introduced as Stella contributed to users attributing humanlike characteristics to the machine. Participants' comments such as "she's deaf" and "she wouldn't listen to me" were made after using the system.

However, it may be possible to take an alternative approach to providing these cues and investigating how nonverbal signals can be communicated without requiring a gesturing character. Would a simple light flashing to signal that Stella is

listening be a sufficient cue? How could you subtly design such visual and tactile interactive elements in an ATM concept to enhance the overall usability?

Even the simple task adaptations and personalization within the Stella interface surprised the users. Many did not know what to expect from a usual transaction, and some users disliked the assumption made by the system that they would like to be addressed by their first name, particularly the older participants. Participants felt that they should be able to instruct the system how they preferred to be addressed. How to best facilitate personalization in terms of control of changes, informing the user, and the nature of the change or adaptation over time is an area we are currently investigating further.

5.5. Privacy

A major current concern for users is their personal security when completing ATM transactions. This concern is present with current ATM designs, and users react to this by demanding at least speed and privacy. Given the private nature of the financial transactions facilitated by most ATMs, general acceptance of a speech interface will always be difficult to achieve in this self-service environment (Hone et al., 1998). A minority of users managed to complete their first transactions with Stella in a comparable time to a standard ATM, but for the rest the speed of the transaction seemed to further exaggerate their need for privacy. Even though the design attempted to create a private environment, the participants in the study did not perceive it as such. Although the design attempted to"wrap the design around the user," the use of concave surfaces actually serve to amplify the sound and present some additional problems. Further work on the physical design of self-service environments to facilitate banking and personal information tasks while enhancing perceived privacy for consumers is planned.

5.6. Acceptance of Biometrics

The consumers' real experiences of the biometrics technology, in this case iris identification, served to overcome a great many of their anxieties about the new technology. The technology itself was seen as having value to the consumer in eliminating the need for cards and PINs, and in being fast and easy. Users in this study made an interesting assumption about recognition; they assumed that if it was their eye that was identified, it would only be their own voice that could control the self-service interaction. This assumption, although wrong, could have served to increase their feelings of transaction security.

5.7. Linking Public With Personal Technology

The link between the PDA, which ensured permanence and privacy of information, is a good start in exploring just how different modes and aspects of interaction can

be combined. The role of the screen to display information and speech to complement the visual information in the form of further information and assistance requires in-depth investigation, as the number of combinations with regard to tasks and environments is huge.

5.8. Future Research

Future research on novel interaction is required to investigate how to best facilitate personalization in terms of control of changes, informing the user, and the nature of the change or adaptation over time, and is an area we are currently investigating further.

Our future research will also address the issues of privacy through kiosk design, through the use of highly directional speakers to create private audio zones that do not require physical barriers; the quality of speech input through utilizing highly directional microphones; and introducing other modalities to create a more balanced approach with complementary interaction devices.

In summary, the results from this study highlighted the anticipation felt by the general public of the role of speech to improve interaction with technology. It also served to underline the current inability of commonly available technology to live up to the high expectations of a voice interaction. Despite technology claims, based on this study speaker-independent voice systems do not seem to be able to deal well with the demands of the range of general public in this self-service situation. The sample used within this study tested Stella and the speech recognition system to the limit, presenting many varied accents with the extreme case being a high-pitched female with a distinctive Chinese-Canadian accent.

In conclusion, this case study has explored the nature of a contactless, speech-driven ATM from a user perspective. Our objectives, outlined earlier, have been met in that we have gained an understanding of people's reaction to, and expectations of, a voice-based ATM, and we also explored the possibilities for a less visually dependent, contactless self-service concept. Our future work will focus on the possibilities for avatar-based and multimodal systems providing personalized self-service functions, adopting a pragmatic user-centered research, design, and evaluation approach.

REFERENCES

Adams, A. S., & Thieben, K. A. (1991). Automatic teller machines and the older population. *Applied Ergonomics, 22,* 85–90.

Baber, C., Johnson, G. I., & Cleaver, D. (1997). Factors affecting users' choice of words in speech-based interaction with public technology. *International Journal of Speech Technology, 2,* 45–59.

Baber, C., & Noyes, J. M. (Eds.). (1993). *Interactive speech technology.* London: Taylor & Francis.

Baber, C., Stanton, N. A., & Johnson, G. I. (1998). From public technology to ubiquitous computing: Implication for ergonomics. *Ergonomics , 41,* 921–926.

Bell, K. R., & Scobie, G. E. W. (1992). Multimedia technology: Banks and their customers. *International Journal of Bank Marketing, 10*(2), 3–9.

Boyarski, D., & Buchanan, R. (1994, April). Computers and communication design: Exploring the rhetoric of HCI. *Interactions, 1*(2), 24–35.

Burford, B. C., & Baber, C. (1994). A user-centered evaluation of a simulated adaptive autoteller. In S. A. Robertson (Ed.), *Contemporary ergonomics 1994* (pp. 454–459). London: Taylor & Francis.

Cassell, J. (2000). Embodied conversational interface agents. *Communications of the ACM, 43*(4), 70–78.

Caulton, D. (2000). Can voice recognition work for computer users? The effects of training and voice commands. In *Proceedings of the BCS SIG Human Computer Interaction 2000 Conference* (Vol. 2, pp. 77–81). London: Springer.

Christian, A. D., & Avery B. L. (2000). Speak out and annoy someone: Experiences with intelligent kiosks. *CHI 2000—Proceedings of Conference on Human Factors in Computing Systems* (pp. 313–320). New York: ACM.

Coventry, L., & Johnson, G. I. (1999). More than meets the eye! Usability and iris verification at the ATM interface. In S. Brewster, A. Cawsey, & G. Cockton (Eds.), *Human–Computer Interaction—Interact '99* (Vol. 2, pp. 151–156). Swindon, England: British Computer Society.

Fogg, B. J. (1999). Persuasive technologies. *Communications of the ACM, 42*(5), 27–28.

Grasso, M. A., Ebert, D. S., & Finin, T. W. (1998). The integrality of speech in multimodal interfaces. *ACM Transactions on Computer–Human Interaction, 5,* 303–325.

Hatta, K., & Iijama, Y. (1991). Ergonomics study of automatic teller machine operability. *International Journal of Human–Computer Interaction, 3,* 295–309.

Henneman, R. L., Knutson, M., & Johnson, G. I. (1993). Users' mental models of automated teller machines: An exploratory study. *Proceedings of the Annual AT&T Human Factors and Behavioral Sciences Symposium, '93* (pp. 53–57). Holmdel, NJ: AT&T Bell Laboratories.

Hide, S., Haslegrave, C. M., Hopkinson, N., Robertson, D., & Johnson, G. I. (1999, May). *Tracking eye positions during the use of an Automated Teller Machine (ATM).* Presented at CAES '99 4th International Computer-Aided Ergonomics and Safety Conference, Barcelona, Spain.

Hone, K., Graham, R., Maguire, M. C., Baber, C., & Johnson, G. I. (1998). Speech technology for automatic teller machines: An investigation of user attitude and performance. *Ergonomics, 41,* 962–981.

Jamieson, B. A., Cabrera, E. F., Mead, S. E., & Rousseau, G. K. (1995). Training new technology: Automatic teller machines and older adults. *Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting* (Vol 1., pp. 153–157). Santa Monica, CA: Human Factors and Ergonomics Society.

Jamieson, B. A., & Rogers, W. A. (1998). Age-related differences in the acquisition, transfer, and retention of using an automatic teller machine. *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting* (Vol. 1, pp. 156–160). Santa Monica, CA: Human Factors and Ergonomics Society.

Johnson, G. I. (1993). Spatial operational sequence diagrams in usability investigations. In E. J. Lovesey (Ed.), *Contemporary ergonomics 1993* (pp. 435–440). London: Taylor & Francis.

Johnson, G. I. (1996a, April). *Exploring novel banking user interfaces: Usability challenges in design and evaluation*. Paper presented at IEEE Colloquium "Interfaces - The Leading edge," University of Abertay, Dundee, Scotland.

Johnson, G. I. (1996b). The usability checklist approach revisited. In P. W. Jordan, I. Thomas, B. A. Weerdemeester, & I. L. McClelland (Eds.), *Usability evaluation in industry* (pp. 179–188). London: Taylor & Francis.

Johnson, G. I., & Briggs, P. (1996). Question-asking and verbal protocols: Qualitative methods of usability. In C. Cassell & G. Symon (Eds.), *Qualitative methods in organisational research: A practical guide* (pp. 55–72). London: Sage.

Johnson, G. I., & Westwater, M. G. (1996). Usability and self-service information technology: Cognitive engineering in product design and evaluation. *AT&T Technical Journal, 75*(1), 64–73.

Karat, C., Campbell, R., & Fiegell, T. (1992). Comparison of empirical testing and walkthrough methods in user interface evaluation. *CHI 1992—Proceedings of Conference on Human Factors in Computing Systems* (pp. 397–404). New York: ACM.

Karl, L., Pettey, M., & Schneiderman, B. (1993). Speech versus mouse commands for word processing: An empirical evaluation. *International Journal of Man–Machine Interfaces, 39,* 667–687.

Lai, J., Wood, D., & Considine, M. (2000). The effect of task conditions on comprehensibility of synthetic speech. *CHI 2000—Proceedings of Conference on Human Factors in Computing Systems* (pp. 321–328). New York: ACM.

Lewis, C., Polson, P., Wharton, C., & Rieman, J. (1990). Testing a walkthrough methodology for theory based design of walk up and use interfaces. *CHI 1990—Proceedings of Conference on Human Factors in Computing Systems* (pp. 235–242). New York: ACM.

Lynch, P., Emmott, S. E., & Johnson, G. I. (1999). The NCR knowledge lab. In S. Brewster, A. Cawsey, & G. Cockton (Eds.), *Human–Computer Interaction—Interact '99* (Vol. 2, pp. 229–230). Swindon, England: British Computer Society.

Manzke, J. M., Egan, D. H., Felix, D., & Krueger, H. (1998). What makes an automated teller machine usable by blind users? *Ergonomics, 41,* 982–999.

Markowitz, J. A. (2000). Voice biometrics. *Communications of the ACM, 43*(9), 66–73.

Mead, S. E., & Fisk, A. D. (1998). Measuring skill acquisition and retention with an ATM simulator: The need for age-specific training. *Human Factors, 40,* 516–523.

Nass, C., & Lee, K. M. (2000). Does computer-generated speech manifest personality? An experimental test of similarity-attraction. *CHI 2000—Proceedings of Conference on Human Factors in Computing Systems* (pp. 329–336). New York: ACM.

Nielsen, J. (1993). *Usability engineering.* San Diego, CA: Academic.

Norman, D. A. (1999). *The invisible computer: Why good products can fail, the personal computer is so complex, and information appliances are the solution.* Cambridge, MA: MIT Press.

O'Malley, M. H. (1990). Text to speech conversion technology. *IEEE Computer, 23*(8), 17–23.

Payne, S. J. (1991). A descriptive study of mental models. *Behaviour and Information Technology, 10,* 3–21.

Peacocke, R. D., & Graaf, D. H. (1990). An introduction to speech and speaker recognition. *IEEE Computer, 23*(8), 26–33.

Ravden, S., & Johnson, G. I. (1989). *Evaluating usability of human-computer interfaces: A practical method.* Chichester, England: Ellis Horwood.

Reeves, B., & Nass, C. (1996). *The media equation*. New York: Cambridge University Press.

Riecken, D. (Ed.). (2000). Personalization [Special issue]. *Communications of the ACM, 43*(8).

Rogers, W. A., Cabrera, E. F., Walker, N., Gilbert, D. K., & Fisk, A. D. (1996). A survey of automatic teller machine usage across the adult lifespan. *Human Factors, 38,* 156–186.

Rogers, W. A., & Fisk, A. D. (1997). Automatic teller machines: Design and training issues. *Ergonomics in Design, 5,* 4–9.

Rogers, W. A., Fisk, A. D., Mead, S. E., Walker, N., & Cabrera, E. F. (1996). Training older adults to use automatic teller machines. *Human Factors, 38,* 425–433.

Rogers, W. A., Gilbert, D. K., & Cabrera, E. F. (1994). An in-depth analysis of automatic teller machine usage by older adults. *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting* (pp. 142–146). Santa Monica, CA: Human Factors and Ergonomics Society.

Rogers, W. A., Gilbert, D. K., & Cabrera, E. F. (1997). An analysis of automatic teller machine usage by older adults: A structured interview approach. *Applied Ergonomics, 28,* 173–180.

Rudnicky A., Hauptmann, A., & Leek, D. (1990). Survey of current speech technology. *Communications of the ACM, 37*(3), 52–57.

Smither, J. A. A., Braun, C. C., & Smither, R. D. (1991). Adoption of ATM technology by elderly users. *Proceedings of the Human Factors Society 35th Annual Meeting* (Vol. 1, pp. 177–179). Santa Monica, CA: Human Factors and Ergonomics Society.

Stevens, R. E., Warren, W. E., & Martin, R. T. (1989). A comparative analysis of users and non-users of automatic teller machines. *Journal of Retail Banking, 8*(1), 71–78.

Westwater, M. G., & Johnson, G. I. (1995). Comparing heuristic, user-centered and checklist-based evaluation approaches. In S. A. Robertson (Ed.), *Contemporary ergonomics 1995* (pp. 538–543). London: Taylor & Francis.

White, G. M. (1990). Natural language understanding and speech recognition. *Communications of the ACM, 33*(8), 72–82.