Indoor Wayfinding: Developing a Functional Interface for Individuals with Cognitive Impairments

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ABSTRACT

Assistive technology for wayfinding will significantly improve the quality of life for many individuals with cognitive impairments. The user interface of such a system is as crucial as the underlying implementation and localization technology. We built a system using the Wizard-of-Oz technique that let us experiment with many guidance strategies and interface modalities. Through user studies, we evaluated various configurations of the user interface for accuracy of route completion, time to completion, and user preferences. We used a counter-balanced design that included different modalities (images, audio, and text) and different routes. We found that although users were able to use all types of modalities to find their way indoors, they varied significantly in their preferred modalities. We also found that timing of directions requires careful attention, as does providing users with confirmation messages at appropriate times. Our findings suggest that the ability to adapt indoor wayfinding devices for specific users' preferences and needs will be particularly important.

Categories and Subject Descriptors: H.5.2 [Information Interfaces and Presentation]: User Interfaces–*Evaluation/methodology, User-centered design, Prototyping, Screen design, Auditory (non-speech) feedback*; K.4.2 [Computers and Society]: Social Issues–*Assistive technologies for persons with disabilities*

General Terms: Design, Human Factors

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1. INTRODUCTION

This paper describes the insights and feedback received from a user study of a wayfinding system prototype that is designed for individuals with cognitive impairments, such as traumatic brain injury, cerebral palsy, mental retardation, and Alzheimer's disease. We are targeting users who are mobile and need to travel through both indoor and outdoor environments for work, shopping, socializing, therapy, and other purposes [1]. The results from our study begin to address the question of what kinds of modalities and direction-giving strategies [10, 19] are effective for individuals with cognitive impairments.

We developed a Wizard-of-Oz infrastructure so that potential users could walk through a realistic experience of using a wayfinding system without all parts of the system being fully implemented. This prototyping approach is particularly important in collaborative, iterative design with individuals with cognitive impairments, because simply "thinking through" designs on paper is rarely effective [8].

2. BACKGROUND AND RELATED WORK

Difficulties in wayfinding diminish the quality of life of many individuals with cognitive impairments who are otherwise physically mobile. For example, an adult with mental retardation may be capable of holding a regular job, but may have difficulty in taking public transit to and from work. Remaining oriented in indoor spaces may also be a challenge, for example, in an office building, a shopping mall, or a hospital. Current methods for aiding people with wayfinding are labor-intensive. For example, a job coach from an employment agency, who works with individuals with cognitive impairments to support them in learning new jobs and maintaining paid employment, may work for months helping a person learn how to travel to and from work, and even then, the individual may at times still require assistance. As a result, the majority of otherwise-employable persons with cognitive impairments remain unemployed [4], rarely access appropriate community services, and are socially isolated [17].

The growing recognition that assistive technology can be developed for cognitive as well as physical impairments [11] has led several research groups to prototype wayfinding systems. The Nursebot project [15] demonstrated a robot that would physically guide an elderly person within an assisted living home. Researchers at the University of Colorado have designed an architecture for delivering just-in-time transit directions to a PDA carried by bus users, using GPS and wireless technology installed on the buses [3]. The Assisted Cognition Project at the University of Washington has developed algorithms that *learn* a user model in order to infer when the user needs help [9]. A prototype system, *Opportunity Knocks*, demonstrated the feasibility of using machine learning in an assisted cognition system, but the parts of the user interface that involved delivering prompts were not well developed [14]. The current paper presents one step in creating a truly usable interface for a system like *Opportunity Knocks*.

Our system's design draws upon psychological models of spatial navigation [6, 12], usability studies of interfaces by people with cognitive impairments [18], and interviews we conducted with individuals with impairments and their caregivers regarding wayfinding [1]. We have also adapted ideas from commercial automobile navigation systems, such as displaying arrows in perspective view (*e.g.*, products by Garmin or Magellan), and GPS systems for blind users that employ voice prompts (*e.g.*, products by VisuAid or Pulse Data). Although this paper focuses on a system for people with cognitive impairments, it is likely that a design that requires low cognitive overhead will also be attractive to many users without impairments. The lessons learned from our study may well be useful, for example, in tour guide systems [5] and general location-aware applications [7].

3. PROTOTYPE DESIGN

We designed an interface suitable for use on a handheld device, such as a PDA, to send directions and prompts to the user. We will use the term *messages* to describe any information that the interface intends to convey to the user, *directions* to describe messages that guide the user through some path, and the term *prompts* to describe messages that are triggered in order to help the user return to a path.

Both directions and prompts consist of a subset of images, audio, and text messages. The design was a result of several rounds of pilot testing involving members of our research group and job coaches from a community based rehabilitation program. Job coaches were able to consider the needs of their clients when evaluating the system. Based on the pilot tests, we refined the types of images presented and the wording of the audio and text messages.

Images: We use four types of images: photos, arrows and other generic symbols, photos with overlaid arrows, and photos with an outlined area (See Figure 1). Photos are of landmarks and other interesting features. Arrows and other generic symbols are used to tell a user to turn or stop, which can be used at times when appropriate photos are not available or distinctive enough. Overlaid arrows on photos are intended to disambiguate where to go as well as provide additional indication of where a user should go next. Some photos contain a highlighted area (*e.g.*, a room number or elevator button). The need to include arrows and outlines became clear as a result of our pilot testing. In particular, with small images of indoor landmarks, it can be difficult for a user to know where to focus.

Audio and text messages: Text messages are brief messages displayed in large font. The text and audio messages have the same wording, in order to minimize the complexity

Figure 1: Sample images used in the interface. *Clockwise from top-left:* plain photographs, directional symbols, photographs with highlighted areas (*e.g.*, room number), and photographs with overlaid arrows.

of directions with both text and audio. See Figure 2 for an example direction.

New message alert: An alert chime precedes new messages and prompts to get the user's attention, alerting the user that a next step was being indicated.

Acknowledgment message: Besides directions and prompts, the interface also has a simple message "Good," which is intended to tell the user when a prior direction is completed successfully and has been cleared from the screen. The device does not play an alert chime before this message because there is no need for participants to switch their focus to the device. This addressed an issue in our pilot testing where users would check their display and see prior, irrelevant messages that they had already followed.

3.1 Prototype Implementation

Our prototype is implemented in Java and SWT and runs under Windows Pocket PC 2003 on a HP iPAQ handheld with a 802.11 (wi-fi) adapter. The software supports display of images up to 240x320 resolution. We use images with 240x180 resolution in order to leave room for text to be displayed as well. Users can choose to use headphones or the built-in speaker to hear the audio. Figure 2 shows the device displaying a sample direction with image and text.

Arrows and highlighted regions are overlaid on the photos manually. One could imagine automating this process but we wanted to first understand which modalities would work best for directions before tackling this complex image processing problem.

The device acts as a client to a remote server controlled by the *navigation wizard* who sends instructions to the client on what to display and play, based on the participant's location and heading. To gather location and orientation information, we use a *location wizard* who follows study participants and transmits their location and orientation to the navigation wizard in real-time using a simple map-based GUI that runs on a Tablet PC. Figure 3 shows the system diagram. Current wi-fi-based localization systems are close to providing the resolution that we need [7], but we also re-

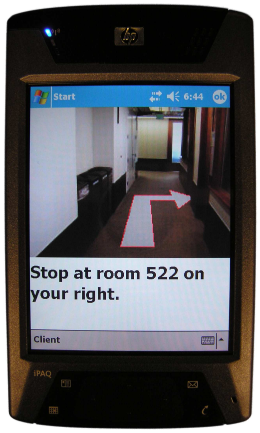

Figure 2: Sample iPAQ display. Participants get a combination of image, text, and audio directions to follow when navigating a route.

quire orientation, which would necessitate a separate sensor. Therefore, we chose to use a location wizard as a substitute for now. Figure 4 shows the server control program and the map GUI. We divide study responsibilities between two wizards (in addition to other observers) in order to more effectively operate our multi-modal simulations [16].

We preloaded all images and audio on the client device to maximize responsiveness of our initial prototype. With the high bandwidth of wi-fi connectivity, these objects could be easily transferred in real-time from a locally-deployed server with negligible latency. However, we also want to support caching on the client for those situations where wi-fi is not available. Audio messages were pre-recorded to match text directions although, in the future, audio could be automatically generated using text-to-speech converters.

4. EVALUATION

4.1 Method

We used a within-subjects, counterbalanced study design where the interface guided every participant through three routes of differing complexity using three different subsets of modalities. We varied the order of both routes and modalities presented to each participant. The studies were done in our Computer Science and Engineering building, which was unfamiliar to all participants. Two of our researchers from the Department of Rehabilitation Medicine followed each participant in order to take notes, get feedback from the participant, and provide assistance in case the participant became confused or uncomfortable. All participants gave permission to audio record their session.

At the end of each study, we asked participants a series of questions about what they thought of the interface and how they navigate when in unfamiliar locations. We also asked them to look at alternative interfaces that displayed maps with arrows, identify where they would be, according to the map, (*e.g.*, in a room or a hallway), and explain what the map was telling them to do (*e.g.*, move forward and turn right).

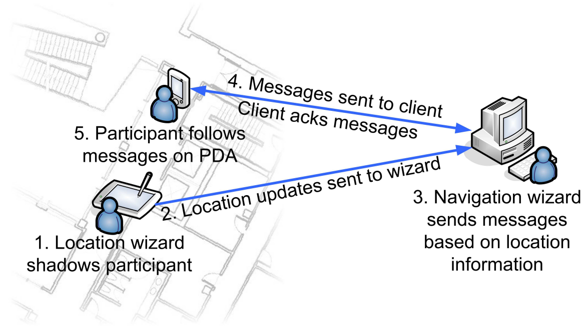

Figure 3: System interaction diagram. Location wizard provides location information on the participant (x, y, floor, and orientation) (1) sent over wi-fi (2), while the navigation wizard uses that location information to decide which messages to send (3). Messages (to display images, text, and play audio) are sent to the client device over wi-fi and acknowledged for robustness (4). Participant then follows the direction or prompt displayed on device (5).

4.2 Materials and tasks

Participants were shown the device and given examples of each of the subset of modalities. They were led to the starting location of each route by the location wizard and given the task of following the device's directions to a set destination. Participants were told their destination and what modalities would be used for that route.

Routes: We chose three routes that traversed through different parts of the building in order to minimize any learned familiarity. Route 1 involved no floor changes, while Route 2 involved using an elevator, and Route 3 involved taking the stairs down one flight. Each route involved five turns, but differed in the number and type of intersections along the route. See Table 1 for a breakdown of route features.

Modalities: We used three combinations of modalities to get feedback on which combinations participants preferred and to gain insight into how effective they were for navigation. Combination 1 used all three modalities for messages (*all*). Combination 2 used only text and audio (*-images*). Combination 3 used text and images (*-audio*).

4.3 Participants

The selection criterion for participants was purposive. We recruited a pool of adults with cognitive impairments who were receiving employment services from a community-based

Table 1: Route features. *Turns:* intersections along the route where participants had to change their heading. *Intersections:* all intersections along path.

		Route 1	Route 2	Route 3
Multi-floor?		none	elevator	stairs
Turns		5	5	5
Intersections	2-way	0	1	0
	3-way	5	4	3
	4-way	2	0	3
	Total	7	5	6

Figure 4: *Left:* Screen shot of the navigation wizard GUI running on a desktop. Green marks on the map show where pictures were taken from, and are used to send prompts to client. Solid red mark shows information from location wizard. *Right:* Location wizard GUI running on a tablet PC. Red mark shows participant location and orientation.

Table 2: Participant demographics. *CP:* cerebral palsy, *TBI:* traumatic brain injury, *DS:* Downs Syndrome, *PDD:* pervasive developmental disorder.

Participant	Gender	Age	Primary Disability	Computer Use
1	Male	32	CP	none
2	Male	40	TBI	email
3	Female	29	DS	rare
4	Female	36	DS	rare
5	Male	26	PDD	extensive
6	Male	36	PDD	none
7	Male	46	TBI	extensive

rehabilitation provider. From the pool of interested participants, we selected two individuals whose primary disability is traumatic brain injury (TBI), two participants whose primary disability is mental retardation (Downs Syndrome), two diagnosed with Pervasive Developmental Disorder (PDD), and one with cerebral palsy (CP) with cognitive impact, ranging in age from 26 to 46. See Table 2 for more participant demographics.

Participant 1 has a mobility impairment requiring the use of a power wheelchair and was unable to complete the route that involved stairs, so his route was slightly modified. Participant 4 has a hearing impairment and prefers not to use hearing aids. She also required a different and relatively minor modification because she could not reliably distinguish right from left. We taped a small note to her right hand as a reminder. However, she only completed two routes because she struggled with the modality that included only audio and text.

Of the participants, only two (Participants 5 and 6) had some experience using a device similar to ours. Participant 5 uses a smart phone and a computer on a regular basis but does not use a PDA. Participant 6 uses a computer on a regular basis. Both use computers in their work and personal life; Participant 5 also uses a computer to plan routes prior to making trips into the community. Participant 6 uses the computer routinely for email and is familiar with several search engines but does not use the computer for navigation.

Participant 1 uses a mobile phone on occasion; he does not own nor use a computer. Participant 2 uses a computer at home for email; he also uses a mobile phone with preprogrammed phone numbers. Participants 3 and 4 rarely use a computer (Participant 3 uses a computer in the library for email on occasion); neither use mobile phones. Participant 7 does not use a computer and does not have a mobile phone.

5. RESULTS

All participants were able to follow the directions to their destinations. Table 3 summarizes the performance of each participant. Since the intent of our study was to learn how suitable the directions were for our target user-base, we encouraged feedback from participants as they were following the directions. Thus, the measured times includes the times when participants were showing researchers what was on their screen, and are provided only to give a general idea of the how long each participant took.

5.1 Participants' Modality Preferences

Participants varied widely in their preferences of modalities, but found the combination of modalities useful. Some participants found text most useful, while others found images more helpful. Details of these ratings are shown in Table 4. Participants gave different reasons for their rankings. Text was highly rated because it let participants process messages at their own pace, and refer back to them as necessary. Some participants said audio was useful in combination with other modalities, but audio by itself was not preferred (probably due to its fleeting nature), although all participants said the audio was of good quality and clear. Images were reviewed positively because they also gave the participants more time to consider the message and make the visual associations. Several participants noted the ar-

Table 3: User study results. *Modalities* are the subset of image, audio, and text used for that route. *Time* is duration of task with elevator wait times omitted. *Errors* are situations when participant took a wrong turn or passed their destination. *Directions*, *Prompts*, and *Good* are the types of messages as described in Section 3. Routes are ordered consistently for the table, although participants did not perform them in the same order. See Section 4.3 for details on participants and special cases marked with asterisks (*).

Participant	Route	Modalities	Time	Errors	Directions	Prompts	Good
1	1	all	2:23	0	10	0	2
	2	-audio	2:05	0	11	0	0
	3*	-images	2:34	1	11	3	4
2	1	-audio	1:33	0	10	0	2
	2	-images	1:46	2	15	3	2
	3	all	3:37	1	17	3	4
3	1	-images	1:56	0	9	0	3
	2	all	1:54	2	15	4	2
	3	-audio	3:28	2	14	3	5
4	1	all	2:16	0	10	0	3
	2	-audio*	3:05	1	15	4	2
5	1	-audio	1:56	0	11	0	1
	2	all	1:21	0	12	0	1
	3	-images	3:06	0	13	0	3
6	1	-images	2:45	0	12	2	4
	2	all	3:13	0	17	4	4
	3	-audio	4:18	0	14	1	4
7	1	all	1:10	0	9	0	0
	2	-audio	1:14	1	13	2	0
	3	-images	2:13	0	12	0	3

rows overlaid on the images were helpful because they "tell you where you're going" (Participant 7). Only Participant 2 stated he preferred images the least, because he had concerns that photos might not always be clear and accurate in a real setting.

5.2 Analysis of Modalities

Images: Images were helpful for disambiguation when the text and audio messages were inadequate at describing directions. It was important to keep images simple and give participants more time to study them by sending directions earlier. Participant 4, who was unable to reliably differentiate the audio/text messages "Turn left" and "Turn right," also had difficulty with the left/right turn arrows, but was not able to complete a route when given messages that contained no images. Most participants were able to follow the arrows on photos and reported that they were useful. Participant 1 had difficulty interpreting an arrow at an atypical orientation (see Figure 5, left). Another arrow containing a series of turns, meant to show where participants were to go once they took the stairs down a floor, caused several participants to hesitate (see Figure 6, left).

Directions with photos increased the cognitive load on participants, who needed to interpret features in the photos, which were small and of a relatively uniform building environment. Participants suggested that photos might be more useful if they showed more easily seen landmarks and objects, such as bright red fire extinguishers. Some noted during the study that they liked when landmarks, such as a painting, appeared in the photos.

Text: Text was a well-liked modality for providing messages due to the lower cognitive load associated with reading. It was important to use familiar vocabulary. This was evident with the use of the word "walkway" to describe the catwalk structure that was part of Route 1. Participants who were unfamiliar with the term or unsure that it applied to the catwalk asked for confirmation from researchers.

Audio: Although the wording of audio messages were the same as complementary text messages, they were not as useful as text for participants. Audio messages were better when used in conjunction with messages in other modalities when participants wanted to check against the others, provided they were delivered inconspicuously and at an appropriate (and possibly adjustable) rate. Participant 6, after receiving directions, would pause often in the middle of intersections and only proceed when sent short prompts, but indicated that he preferred taking his time with directions containing text and images at his own pace as the audio "went a little too fast."

Table 4: Modality preference by participant.

Participant	First Preference	Second Preference	Third Preference
1	Images	Audio	Text
2	Text and Audio (tie)		Images
3	Text	Images	Audio
4	Images	Audio	Text
5	Text	Images	Audio
6	Text	Images	Audio
7	Images	Text	Audio

5.3 Timing of Directions

Participants liked directions that communicated a sense of responsiveness by the system. The system needed accurate location information in order to send directions at appropriate times. Those directions also needed to convey a sense of how long they were applicable, otherwise participants could get confused.

One situation where the timeliness was important to participants was during the elevator-riding portion of Route 2. Participants could not receive messages while they were in the elevator because the device would disconnect from the wi-fi network and lose the ability to receive messages from the navigation wizard. Our pilot testing discovered that this gap was problematic, so we implemented delayed message handling so the navigation wizard could send a message to the device before losing connectivity, and have the device process the message after a fixed delay. We could then send a direction reminding participants to exit the elevator on their destination floor. However, this work-around was not entirely successful. Participant 3, clearly having difficulty determining when to exit the elevator when other riders were exiting on different floors, reported that, "It was confusing; I wasn't sure what to do." Additional sensors (*e.g.*, barom-

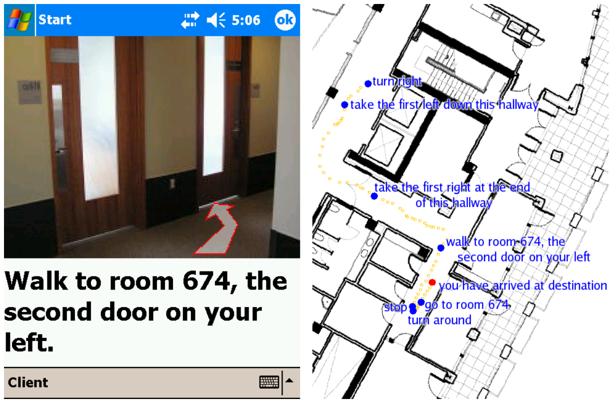

Figure 5: *Left:* Direction telling users to proceed to their destination and stop. This direction very closely followed the direction to turn right, and sometimes came late. In addition, one participant thought the skewed arrow was confusing. *Right:* Map showing spacing of turns and the path of a participant with difficulty locating the destination. Small yellow dots indicate participant's path, red dot indicates the final destination reached.

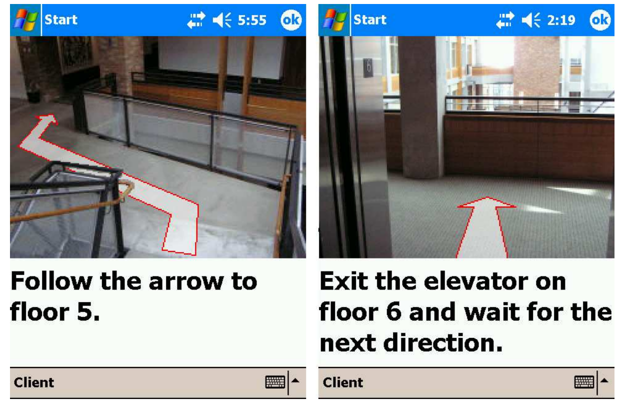

Figure 6: *Left:* A detailed but complex arrow guiding the participant off the staircase. This confused participants more than simple directional arrows. *Right:* Direction telling the participant to exit the elevator and wait for the next direction. This helped overcome confusion from delays in wi-fi outages in the elevator.

eter) could aid in determining where participants were and when they should exit the elevator.

Directions containing more information would have been beneficial to our participants in some situations. The destination in Route 2 was close to a previous turn and caused two participants to walk by, because they received the direction telling them to stop at their destination room (see Figure 5) only after they had already passed by at their normal walking pace. The system should have informed them earlier that the destination was close. A challenge would be simplifying longer directions containing both the turn and the destination. We tried an alternative method for informing participants to expect additional directions by adding a message to wait (see Figure 6, right). Some participants commented that it was helpful to them. However, some participants did not wait and began walking or looking around after exiting the elevator. When the next direction finally arrived, Participant 3 had just turned away from the orientation that the direction was meant for, which caused her to go the wrong way. Some participants also wanted to know when to expect subsequent directions when given directions such as "Walk down" or "Walk to the end of" a hallway or walkway. When given the latter, some participants were unsure whether they should walk past intermediate intersections. Participant 7 asked, "All the way? Part of the way-walk down this hallway?"

5.4 Confirmation

We found that the navigation wizard intuitively began sending more "Good" messages after participants followed correction
prompts correctly, and used them less when standard directions were followed. Sending feedback rather than simply the next direction when participants were on path tended to slow down the pace. When the "Good" feedback was received, Participant 5 even replied out loud [whimsically], "of course." When participants were less sure and had to take more care to follow directions, this feedback became more important. Several participants thought this message was helpful because they received important feedback when trying to make corrections to get back on path. Participant 1 even stated his preference for the audio modality because the text-only version of the "Good" feedback was less noticeable when it occurred, as it did not have an audio alert preceding it.

5.5 Device Usage and Form Factor

Our pool of participants had three general ways that they used the device. The most common was to keep the device visible at chest level for the whole session, and switch their attention between the device and their surroundings as needed, walking at a consistent pace and only altering course when they received directions. To keep the screen at a visible angle for the wheelchair user, we attached the device dock to his wheelchair tray. Participant 3 gave the device the majority of her attention, and would walk briskly after receiving a direction until she reached an intersection where she would stop and wait for more directions. Participant 2 kept the device at his side the majority of the time, and only look at the screen occasionally. He would listen to the audio first and then check the screen, though at times he missed the audio cues.

Although the other two modes are reasonable for short routes, Participant 2's mode of occasionally referring to the device seems more practical for routes of a larger scale. Using vibration feedback in addition to audio could help avoid missed messages, and address one of the participants request for a 'silent mode.' One participant also expressed a preference for a wireless headset, saying he would be less self-conscious. Although none of the participants had complaints about the size of the iPAQ, one thought it was too heavy, and another was concerned there would be a social stigma attached to using one. When asked whether they would prefer using a mobile phone instead of a PDA, some participants felt the text may be harder to read, but that images would probably be large enough.

6. DISCUSSION

Many factors come into play when evaluating appropriate interface modalities for individuals with cognitive impairments. First, developers must consider comorbid impairments. For example, in our group two of our participants had other impairments that impacted their ability to use the system. One participant used a wheelchair and was unable to hold the device. The other user had a hearing impairment and preferred to not use hearing aids, thus making the auditory prompting more difficult to use. In addition, cognitive impairments are not a uniform construct. For example, individuals with acquired brain injury may have patterns of specific and global deficits based on their specific type of injury and very specific cognitive losses related to the location of trauma, whereas individuals with mental retardation will commonly have more generalized deficits. As a result of the differing etiologies of cognitive impairments and varying functional limitations, we assume individuals will possess different prerequisite skills and knowledge that might impact the use of assisted cognition devices. For example, individuals with acquired brain injury may have been proficient technology users prior to the onset of their condition and may be able to learn to use new technology with more ease than individuals with mental retardation who might not have previous experience.

Second, in our work there were differences between how individuals used the system. Some users were systematic in their use of the device. They followed each direction, and then halted waiting for the next direction. Sometimes these individuals indicated frustration when the system prompted too slowly. For example, Participant 3 said "Come on now!" to the device when it failed to give a prompt at the expected time. Other individuals were less systematic, more distractible, and lost focus on the device and its directions. Participants' executive function, receptive language, attention to detail, and memory capacity no doubt impact their performance with our system. In addition, participant's performance will differ based upon the cognitive demand of the task being attempted and individuals who function quite well under some conditions will function less well when the demands of the task or environment change. Cognitive load theory acknowledges that the "cognitive architecture" of the brain (*e.g.*, working and long-term memory, attention) has limits that can be overloaded [13]. For example, working memory can handle only a small number of interactions at one time. When cognitive limits are reached, an individual becomes overloaded and unable to process more information.

Third, individuals had definite preferences about the modalities in which they wanted to receive information and there was little agreement in their ratings. Preferences are likely a result of the two issues discussed in the paragraphs above, but may be a result of familiarity with a modality as well. In other words, text may be a more common form of receiving directions for some of our participants. And it should be noted that all participants were at least basic readers.

7. FUTURE WORK

Our future work will pursue four main directions:

User Interface Improvements. We will investigate a greater use of visually distinct *landmarks* for giving directions, particularly for outdoor navigation. Psychological evidence suggests that landmarks play a crucial role in spatial understanding [12].

We will study the effectiveness of *maps* for conveying complex routes to more spatially-aware individuals. In our study, when asked to interpret a map shown on the iPAQ screen, four of the seven participants were able to successfully complete the task. A participant with acquired brain injury particularly liked the map, because he felt that it gave him more information about where he was going and a greater sense of independence.

Our next user interface will support greater interactivity. This will include methods for the user or caregivers to input destinations in a simple manner as, for example, using the method proposed in [14], where the system displays photographs of the most likely destinations based on a learned model of the user's day-to-day movements, and asks the user to confirm the correct choice. The user interface will also include methods for user-initiated feedback to the system, including explicitly asking for the instruction, indicating that the user does not understand the system, or requires more time.

Further User Studies. We will expand our user studies in several ways. First, we believe it is important to more accurately measure "baseline" performance, that is, non-assisted wayfinding. Baseline information is useful both for evaluating the impact of the system and for determining the kinds of individuals who could potentially benefit from automated wayfinding technology. Second, we will study a wider variety of more realistic, purposeful tasks. For example, a task may be to enter a building, find a particular office, and deliver a package. By implementing more naturalistic routes, we expect participants to be more active and intentional in route-finding, and expect to learn more about how individuals might use the system in their daily lives. Third, the studies will include outdoor routes. Outdoor challenges include the difficulty of viewing the screen in bright sun, hearing the audio in a noisy environment, the distraction and danger of pedestrian and automobile traffic, and using public transit. On the other hand, participants in our pre-study interviews have indicated that outdoor navigation can be easier than indoor navigation when distinctive outdoor landmarks are visible [1].

Better Correction Strategies. We will investigate improved ways of determining *when* the user should be corrected, as well as *how* the corrective prompts should be delivered. It is not always easy to determine when the user actually needs help; for example, the user may stop moving because she is confused, or because she is carefully looking around to orient herself. In the latter case, a premature prompt may actually create confusion. This suggests that the system be designed to adapt to the user. Our earlier work [14] argued that confusion is often signaled when the user's behavior does not fit with her "normal" pattern. Such methods for automatically inferring the need for help can be combined with explicit user feedback about the need for help (and whether the system's prompts are understandable) as described above. We will also systematically examine a range of correction strategies. For example, the wizard in our study most commonly prompted users to retrace their steps when they missed a turn. Retracing, however, can be slow; in some cases it was much more effective to send directions that were specific to the user's new location.

Implementation Issues. We will be working to reimplement our system on a mobile phone. Today's mobile phones have enough computational power and bandwidth (including wi-fi) to implement all of our functions. In addition, they can be easily connected (over Bluetooth) to other sensors carried by the person (*e.g.*, barometer). We also plan to integrate a wi-fi-based location system on that platform and augment it with a digital compass to provide approximate location and orientation (we will need 3-4m resolution with 30-45° angle accuracy) [2, 7].

8. CONCLUSIONS

We believe that assistive technology for wayfinding can and will significantly improve the quality of life for many individuals with cognitive impairments. The user interface of such a system is as crucial as the underlying implementation and localization technology. To this end we built a sophisticated system using the Wizard-of-Oz technique that let us experiment with many guidance strategies and interface modalities. After several iterations of user-centered design, we evaluated several configurations of the user interface with a group of users who had various kinds cognitive impairments – including mental retardation, acquired brain injury, and cerebral palsy – on indoor navigation tasks. This small study has laid the groundwork for future studies we will perform with larger groups of users on both indoor and outdoor navigation problems.

Our study showed that there is no "one size fits all" solution, and that arguably the most important aspect of a guidance system for persons with cognitive impairments is that it be widely customizable and adaptive. More specifically, our results indicate that an effective user interface should support multiple modalities (text, audio, graphics, and photographs), because no one modality or set of modalities was best for all users; that timeliness of prompts is crucial, as well as providing appropriate confirmations to the user; and that the way a user *carries* a wayfinding system has a significant effect on how such a system is used. Finally, our experiments suggested important directions for future work on improvements to the user interface, estimating the cognitive state of the user, adaptive correction strategies, and the physical form factor of the guidance system.

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