Wearable Interfaces for Orientation and Wayfinding

David A. Ross
+1 404 321 6111 x6817
davidross1@mindspring.com

Bruce B. Blasch
+1 404 321 6111 x6277
bearconsel@aol.com

Atlanta VA Rehab R&D Center
1670 Clairmont Road
Decatur, GA 30033 USA

ABSTRACT
People with severe visual impairment need a means of remaining oriented to their environment as they move through it. Three wearable orientation interfaces were developed and evaluated toward this purpose: a stereophonic sonic guide (sonic "carrot"), speech output, and shoulder-tapping system. Street crossing was used as a critical test setting in which to evaluate these interfaces. The shoulder-tapping system was found most universally usable. Considering the great variety of co-morbidities within this population, the authors concluded that a combined tapping/speech interface would provide usability and flexibility to the greatest number of people under the widest range of environmental conditions.

Keywords
Orientation aid, blindness, wayfinding, street crossing.

STATEMENT OF THE PROBLEM
There are approximately 11.4 million visually impaired persons in the United States, ten percent of whom have no usable vision. The literature clearly states that the prevalence of blindness rises steadily with age, and that nearly two-thirds of the visually impaired population is 65 years of age or older [17, 18]. A major shift has occurred in the average age of people with severe visual impairment as a result of both the increase in average age of the general population, and because of the increased prevalence of diabetes and macular degeneration. As a result of these, the majority of people now experiencing the onset of a severe visual impairment are over the age of 60, and the number of people over 65 with a severe visual impairment will continue to rise dramatically [9].

The implication to rehabilitation strategies, and the design of assistive technologies, is that existing strategies and designs must be adapted to suit the needs of an older and much more heterogeneous population in terms of physical, sensory, and cognitive functionality and needs. While functional independence and good quality of life continue to be appropriate rehabilitation goals, the means of achieving these goals may be somewhat different for people aging with and/or into disability.

ASSETS'00, November 13-15, 2000, Arlington, Virginia.
ACM 1-58113-314-8/00/0011

The majority of people in this population are now either retired, or nearing retirement. With aging, many have begun to experience the onset of various co-morbidities including hearing loss, some loss of physical function, some loss of cognitive function, and some loss of sensation (e.g., peripheral neuropathy), as well as a decreased capacity to discern different smells and tastes. Because of this, many may have a diminished interest in learning new skills, and may not be interested in, or capable of learning Braille. It is the wide range and variety of possible co-morbidities that makes the needs of this population so diverse; and it is this diversity that makes the design of easy-to-use interfaces challenging. It is imperative that universal design criteria be employed for evaluating interfaces for this population, and that people representing the diversity of the population be employed in testing rehabilitation interventions and assistive technologies [22, 23].

Maintaining spatial orientation is a major challenge for people with severe visual impairment [6, 24]. Spatial orientation is distinctly different from mobility in that mobility depends on skillfully coordinating actions to avoid obstacles in the immediate path, whereas spatial orientation depends on coordinating ones actions relative to the further-ranging surroundings and the desired destination [13]. Spatial orientation refers to the ability to establish and maintain an awareness of one's position in space relative to landmarks in the surrounding environment and relative to a particular destination [10]. Wayfinding is the means by which a person employs their spatial orientation to maintain a heading toward their destination regardless of the need to avoid or move around obstacles in their path. The successful coordination of actions within the perceived surroundings of a dynamic setting (e.g., a traffic intersection) requires the wayfinding guidance provided by *continuous* feedback from the environment [13, 20].

Cues used to monitor environmental flow comprise the greater and most important part of such feedback. Environmental flow refers to the ordered changes in a pedestrian's distances and directions to things in the surroundings that occur while walking. Maintaining orientation is thus, to a great extent, a matter of keeping track of this environmental flow [13]. The environmental flow of walking can be perceived through a number of senses, though hearing is perhaps the most notable of these. When a person walks in the vicinity of sound-making objects, changes in spatial relationships can be perceived with the shifting of sounds emitted by the objects. Listening to the echoes of object sounds, as well as sounds made by the person themself, can indicate distance to a wall, the presence of a doorway, etc. [10].

The ability to detect heat and to smell are also important. Directionally-specific sources of heat and odor can indicate location and facing direction. The temperature change felt when walking into the shade of a familiar setting is useful, and the door of an air-conditioned bus can be detected by the cool air that flows out when the door is opened [13].

The sensation of walking is also an important source of perceptual input. Skillful travelers keep track of how their walking affects their distances and directions to objects in their surroundings, and use this information to guide them [13]. This type of sensate feedback has both proprioceptive and vestibular components [20].

Orientation and Mobility (O&M) instructors train their students to make use of all the above, and more, in learning the skills needed for traveling independently. Even for young students with acute senses, acquiring the perceptual awareness and needed skills is not easy, and comes only with much practice, patience and experience [8]. For the older adult with some hearing loss, and perhaps other sensate losses as well, it simply may not be possible to acquire all the orientation and wayfinding skills taught by an O&M instructor. For example, with a hearing impairment it may not be possible to learn to judge object distances by becoming aware of the loudness of sound sources and how loudness varies with distance [13]. As a result, many older students may be warned by their instructor not to attempt independent travel in unfamiliar environments.

With regard to wayfinding, the tendency to veer from a straight path is a major problem. Even if the individual is initially oriented to the environment, starts out facing their destination, and encounters no obstacles; problems with veering make it necessary to re-orient often. A large body of research documents the inability of blind pedestrians to maintain a straight line path (i.e., not veer) in the absence of external guidance [7, 12, 21]. Even highly experienced blind pedestrians exhibit variable error sufficient to result in their veering into a parallel street when crossing at an unfamiliar intersection [13].

LIMITATIONS OF EXISTING DEVICES

Existing orientation and wayfinding aids are limited by: 1) the types, amounts, and accuracy of information they can provide; 2) the types of environments in which they can function, and 3) their user interface structure/operating procedures. One of the reasons for these limitations is that while there has been a great deal of research in the area of electronic travel aids for obstacle avoidance [2], there has been little comparable research and development of orientation and wayfinding devices.

Based on the needs and diversity of the potential user population as described above, and the previous research of the authors (See Previous Research below), a well designed orientation and wayfinding aid should ideally be able to provide the user with: 1) their current location and heading relative to known landmarks and the desired destination, 2) descriptions of prominent surrounding features and the general layout of the greater surrounding environment, and 3) things of interest to the user in the greater surrounding environment. Further, location information should be accurate to within one meter, and be provided in a fashion that can be clearly comprehended regardless of location or type of environment. Finally, the system should be usable by people with a variety of age-related co-morbidities. In other words, the interface must meet established universal design criteria [22, 23].

Braille labels have been used as orientation aids for decades. They have been used to label prominent objects, such as doors, pedestrian light poles, and information kiosks, and to describe the layout of a surrounding area. However, in a generalized setting, there is an access problem in that there is no means of knowing when and where a Braille label might be found and what information it might contain.

Tactile maps with Braille identifiers are also available to a limited extent. These provide overview information about an area along with walking routes. However, there is a usability issue in that these maps are too bulky to easily carry around for reference, and some people have difficulty translating tactile maps into meaningful cognitive maps that help them mentally maintain their orientation to the physical environment as they travel through it [2]. Also, the use of such maps may be particularly difficult for older people experiencing some cognitive loss or loss of touch sensitivity.

Talking Signs®, developed by the Smith-Kettlewell Eye Research Institute, and similar devices developed by others, provide the equivalent of visual signage orientation information [3, 6]. These devices employ either Infra-Red (IR), or visible light, to silently transmit a message recorded in the "sign." This message can be heard via the use of a special hand-held receiver. These "signs" require a power source, but otherwise can be installed in a variety of outdoor and indoor locations. The light beamed from these "signs" can be used as a "beacon," enabling the user to orient themselves and walk in a desired direction. Specialized versions of these "signs" have been integrated into pedestrian crossing signals to provide "Walk," "Don't Walk," and "Don't Start" information to the user, as well as a light beam that can be used to line-up with the cross-walk [3, 6].

Certainly these "signs" are an advantage over Braille labels in that they provide information at a distance along with a means of orienting to the physical setting. However, the procedures for operating the receiver do not make this device as simple and easy to use as it might be. The trained procedure is paraphrased as follows: upon entering an area with installed Talking Signs®, 1) stand still, 2) take out the receiver and switch it on, 3) extend the hand holding the receiver and scan your arm about the area before you until the desired message is heard, 4) turn and face your body in the direction your arm is pointing, 5) switch off the receiver and put it away, and 6) walk a straight path in the direction you are facing until you need further assistance from this or another "sign" [6].

This procedure is both awkward and time-consuming, especially if the user is carrying something. It also assumes that the user is capable of walking a straight path, which research has shown is rarely the case. Further, if a series of "signs" were installed to guide people through a setting like a transit station, a person would most likely need to be trained in the structured sequential use of the "signs" at that particular station. For unfamiliar settings there is an access problem similar to that for Braille labels, as there is no means of discovering these signs without actively searching for them. A more usable receiver interface would not need to be held or scanned about to determine the presence or location of Talking Sign® transmitters. Further, it would provide *continuous* feedback to help the user follow a straight line path to their intended destination.

Recognizing the need for a general purpose orientation device, researchers at Arkenstone, Inc., developed Atlas Speaks® and Strider®. Atlas Speaks® is a talking map for personal computers that can be used to orient to a setting prior to venturing out into it. Strider® employs a laptop computer in a back-pack, and integrates Atlas Speaks®, a Global Positioning System (GPS) receiver, and a digital compass into a portable system the can provide *in situ* orientation information including the user's current location and heading, the direction of a particular destination, and some information about what's in the surrounding environment [4].

However, while the introduction of Strider® was a major step forward in the development of a general purpose orientation and wayfinding aid, the current realization of this device has many limitations: 1) it can only function outdoors, 2) it does not provide temporal information (e.g., the state of a traffic light), 3) it lacks sufficient accuracy to guide a person across the street to the opposite curb, 4) the information it can provide about the surrounding environment is limited; and 5) it employs speech output only, which is not necessarily suitable for every setting (e.g., a city intersection where traffic is so loud that one must shout to be heard), nor is speech most suited to the needs of every potential user.

The authors suggest that two major things must occur for the development of a truly general purpose orientation and wayfinding aid: 1) an integration of all applicable indoor and outdoor locator/orientation/wayfinding technologies, and 2) the design of a "hands-free," universally-usable interface [22, 23].

It was the limitations of the devices described above, and the realization that better user interface design could reduce these limitations, that was the impetus for the authors' herein described research.

PREVIOUS WORK

In 1991 Blasch completed a study of "environmental information needs for orientation and wayfinding." The results of this study described the most usable form and content for orientation and wayfinding information, and showed the importance of presenting information to the subject *in situ*. It also showed the importance of presenting information on a timely, "as needed" basis, and in a concise and unobtrusive manner [1].

In a follow-up project, "Cyber Crumbs: Subject Testing An Orientation Aid for Veterans with a Visual Disability," completed by Ross in 1997, three orientation device designs were developed and evaluated for use indoors: 1) a system employing passive Radio Frequency Identification (RFID) tags, 2) a system employing powered RFID tags, and 3) a system employing localized Infra-Red (IR) tags. Results showed that IR tags placed at hallway inter-sections, most reliably provided wayfinding information as it was needed. Twenty older adults with severe visual impairments were tested during this research. Interestingly, the majority of these subjects' comments were directed at the user interfaces rather than the type of technology employed. It was these results, specifically subject critiques and suggestions, that led to the research that is the topic of this article: the development and evaluation of three wearable orientation and wayfinding interfaces.

Also, research in the area of virtual sonic environments by Jack Loomis, Ph.D., has lead to initial prototypes and tests of an orientation/guidance system for the visually impaired [16].

RESEARCH OBJECTIVES

Given a list of user interface recommendations provided by subjects in previous studies, the investigators had the following research objectives:

1. To evaluate the three types of interfaces suggested by subjects, namely (a) the sonic guide or "carrot", (b) a speech interface giving verbal directions, and (c) an shoulder-tapping interface;
2. To determine if the most naturally perceived direction information is obtained when (a) referenced to the person's head orientation, or (b) referenced to the person's body orientation.

METHODOLOGY

Wearable Interface Prototype Construction

Wearable interface prototypes were designed using a wearable computer as a base from which to control the interfaces. This was done with the full expectation that any general purpose orientation and wayfinding aid would of necessity integrate the appropriate technology (i.e., GPS receiver, dead-reckoning hardware, cellular triangulation hardware, wireless data links, etc.) into a wearable computer platform..

The wearable computer base was constructed from four 2.5-inch by 5-inch boards manufactured by Adaptive Systems, Inc. These included a 66 MHz 486 processor board with 16 Meg of RAM, an I/O board with two serial ports and hard-drive controller, a SoundBlaster® board for stereo sound presentations, and a "back-plane" board with a 200 megabyte hard drive attached. The Windows 95 operating system was used to take advantage of its 3D sound modules. Software was written to interpret incoming directional data, drive the three interfaces, and implement testing procedures.

Orientation input to the wearable was to be provided by a pedestrian signal system designed by Relume Corp. This special system superimposes a digital transmission on the visible light signal. A detector for this system was developed to be worn by the user and provide directional data to the wearable. For reasons related to county versus city jurisdiction over traffic lights, however, the authors were not able to install this system for testing. Thus, in order to complete testing of the developed interfaces, a simulation of directional input was devised employing a digital compass. It is not suggested that a digital compass actually ever be used by itself in an orientation system.

The two orientation modes tested (Objective 2) were implemented via placement of the digital compass on either the shoulder (for producing body-referenced output), or in a hat (for producing head-referenced output). This compass was re-calibrated at the start of each street-crossing event.

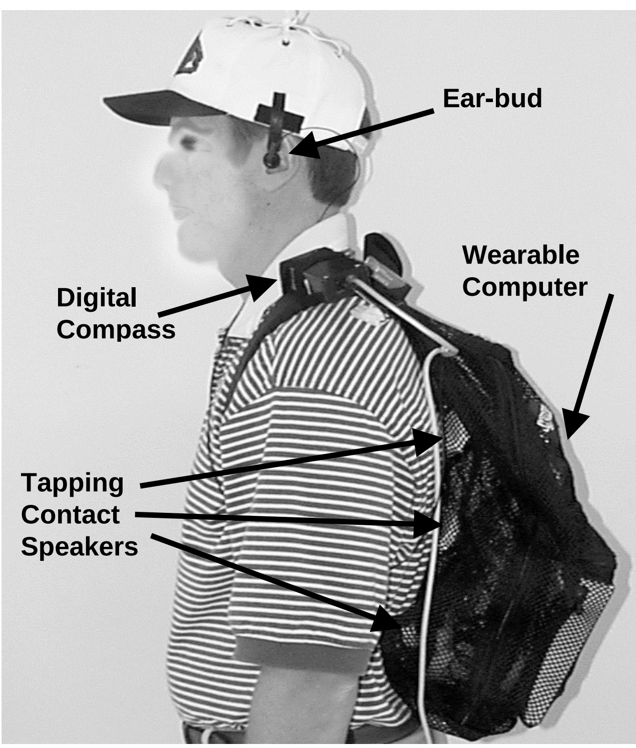

Fig. 1. Picture of person wearing the prototype interfaces.

The Sonic "Carrot"

The Sonic Carrot presentation was accomplished via use of Windows sound modules and SoundBlaster® card. The sound produced by the Carrot was a digitally encoded bell-like tone. The direction of the Carrot relative to the user's head (or body) position was calculated by a routine that employed data from the digital compass. Carrot location values were updated approximately 30 times per second, so that perceptual latency was minimal. The Carrot sounded only once every 1.5 seconds, but moved in space while the Carrot was sounding if the person changed their position relative to the target during this time. Presentation of stereo output to the user was accomplished via a pair of ear-buds mounted on a cap worn by the user. These were adjustable so they could be positioned just in front of the ear canal at a distance of about half an inch from the ear canal. This was done so as not to interfere with the user's ability to easily, and naturally hear subtle environmental sounds.

The Speech Interface

Speech presentation was accomplished with digitized speech played via the SoundBlaster® board. Developed software converted digital compass data into either target location clock-face directions relative to the user's current heading, or degrees left or right of the user's current heading. The user was given the option of using whichever directional system they preferred. The relative position of the destination was announced once every 2 seconds (e.g., "one o' clock"… "one o' clock"…, etc.). Speech was presented to the user as a monaural signal via the cap-mounted ear buds.

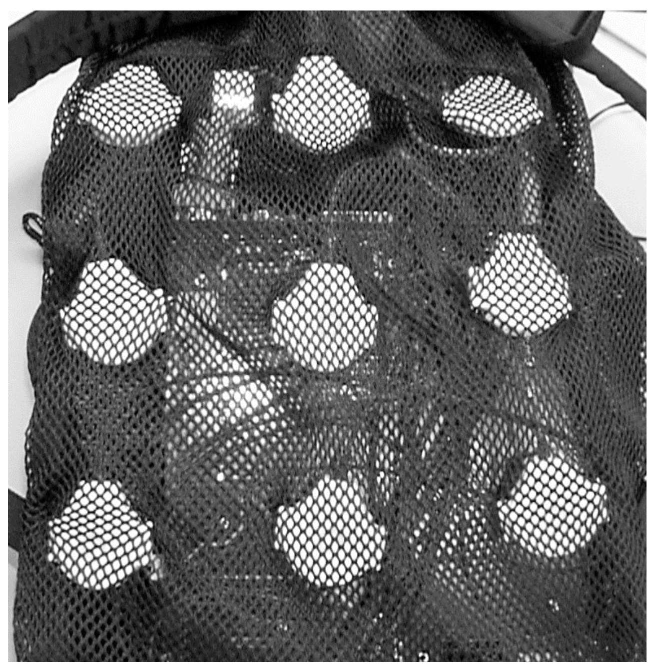

Fig. 2. Picture of the original 3x3 tapping interface grid.

The Shoulder-Tapping Interface

The shoulder-tapping interface was a modification of a sensory saltation interface developed by MIT investigators as a means of helping drivers follow a map without distracting their visual attention. As designed by the MIT investigators [19], this device was comprised of a three by three array of small "contact" speakers that lightly thumped the person's back in sequences of three "taps" up the back. This was experienced by the user as something moving up their back in a specific direction. Movement straight up the back indicated the person should move straight forward. Movement from lower left to upper right indicated the user should angle to the right; and movement from the left to right side of the back indicated a right turn.

After building and testing this device, the investigators reduced it to three shoulder tappers. This was done because the investigators found it difficult to keep all nine "tappers" in solid contact with the user's back as the user moved about. The investigators found that when worn under the shirt across the top of the shoulders that solid contact could be maintained, and that tapping these locations was perfectly adequate for presenting directional information to the user. Software was written to convert compass output to shoulder taps as follows. If the user was on target, the center tapper will produce a double-tap once every two seconds. If the user was off-target by 7.5 degrees right or left, then the left or right tapper respectively would tap in addition to the center tapper. If the user was off-target by 15 degrees or more, only the left or right tapper respectively would tap in response.

Selection of a Critical Test Setting

Of all the orientation and wayfinding tasks taught by O&M instructors, street crossing has been found to be the most critical and demanding in terms of both the complexity of the task and the complexity of the environment [11]. Street crossing also encompasses the most difficult orientation and wayfinding aspects of moving through most indoor and outdoor environments, including: establishing and maintaining an awareness of position in space relative to a particular destination, and keeping track of environmental flow.

To cross a street, one actually performs four critical tasks: (1) detecting the street or curb, (2) aligning the body with the edge of the curb facing the opposite corner, (3) initiating crossing at the proper time, and (4) walking a straight path across the street to the opposite corner [13]. All four of these tasks have become more problematic in recent years. The advent of curb ramps has made it easy to unknowingly walk out into the street. These ramps also make it difficult to orient properly to the intersection. [6, 24].

Traffic sounds provide many orientation cues. However, when Chew [5], and Guth, Hill, and Rieser [11], assessed the skill with which experienced blind pedestrians aligned themselves parallel to and perpendicular to traffic, they found trial-to-trial variability large enough that every subject would have eventually walked out into the center of an intersection [11].

Thus, of all the tasks one might select for testing an orientation and wayfinding aid, street crossing was selected as *the* most difficult, hazardous, critical and crucial. If a subject feels confident and safe in the use of an orientation and wayfinding aid for street crossing, then this same aid would most likely suit their needs in most other less crucial settings as well.

Subject Testing Protocols

A total of 15 subjects were recruited and tested. When the subjects presented themselves their visual pathology, along with any age-related co-morbid pathologies, were recorded. Testing took place at three intersections (A, B, and C) near the Atlanta VA Medical Center. Pre and post baseline (device not used) measures were taken of subject performance crossing over all three intersections (A, B, C) and then back (-C, -B, -A). During these tests, subjects were allowed to use their cane, but not a dog guide.

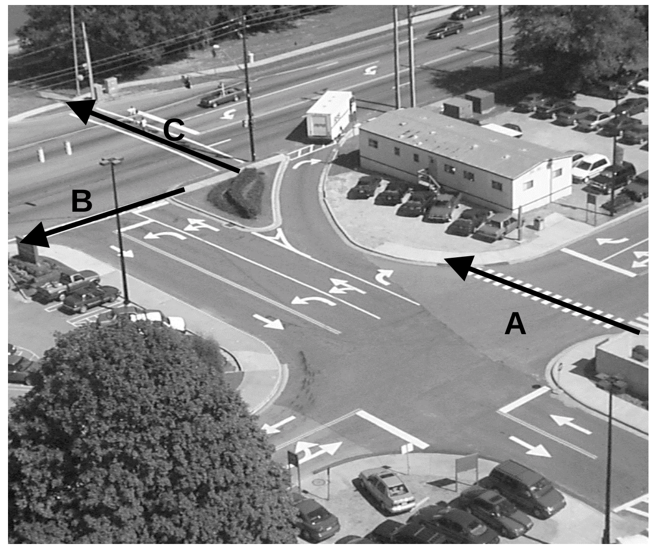

Fig. 3. Picture of the test-site intersections (A, B, C).

After the pre-test baseline measures, each subject was fitted with the wearable device and trained in its use. In an outdoor courtyard, some distance from intersections and noisy traffic, investigators explained how each of the three interfaces functioned, and subjects practiced two trial runs across the courtyard using each interface. The order in which they learned to use each of the three interfaces was randomized across subjects.

The subjects then used each of the interfaces in two different modes (head-referenced and body-referenced feedback) to cross the three intersections in either the forward or backward directions. The order of testing the three interfaces, as well as the mode of operation, was randomized for each subject. In this way subjects tested each of the three interfaces in each of two orientation modes of operation while crossing over either the "A, B, C" sequence of intersections, or the "-C, -B, -A" sequence of intersections. Following the device tests, the subjects removed the prototype and crossed each of the three intersections both forward and back in post baseline tests. Measures recorded were crossing time, off target error, out of crosswalk errors, hesitations, and any apparent subject confusion.

Following these tests, subjects were asked to rank order the interfaces and modes of operation from the most useful to the least useful. Then they were asked if any of the interfaces/modes helped them find their way across the street better than using their cane or dog; and if so, how it was better; and if not so, what it was about each interface that made it difficult to use. Finally, they were each asked for ideas on how each interface and orientation mode of operation might be improved to become more useful; and, given this improvement, what interface they would then prefer.

RESULTS

Data Analysis

Street crossing times were converted to walking pace in feet per second. Target errors were converted to inches of veer per foot forward. Average "normal" pace and veer for each subject were calculated from pre and post baseline measures. The ratio of prototype performance (pace and veer) to baseline performance was calculated for each subject for each interface and mode of operation. These ratios were used as relative indicators of performance improvement for each subject. Standard t-tests were performed to determine significance of performance improvements for each interface and mode of operation. Subject rankings were used to produce weighted "votes" for each interface/mode. T-tests were used to identify significant differences in the "vote" tallies. Finally, subject critiques and comments were grouped by type of comment/criticism/improvement idea and tallied.

Demographics

Subjects ranged in age from 62 to 80, with the average age being 68. Their condition ranged from totally blind for over 40 years to partially sighted with the best acuity being 20/300. Over half the subjects were totally blind. Four of the subjects had hearing deficits, and two of these wore hearing aids. Four other subjects were physically frail to the point that two had to sit down and rest after each series of three street crossings. Subject history of activity in street crossings ranged from a few street crossings a week to several street crossings a day. Type of streets crossed ranged from local low volume streets close to home to high-traffic streets some distance from home. Independence ranged from almost always crossing with someone else, to almost always crossing streets on their own. Two of the subjects had dog guides; the others consistently used a cane.

Objective Data

Performance using the various modes of operation for each subject varied widely and some quite significantly. For most subjects, the best performance was achieved using one particular mode of operation of the prototype. The mode of operation that resulted in the best performance varied from person to person. However, using the mode of operation where the subject showed the most improvement in performance, a comparison of performance with and without the prototype (obtained by dividing the prototype performance score by the baseline performance score), gave the following:

Measure:	Change:	Significance:
Walking Pace	1.04	No Sig.
Veering	0.31	.001

The above indicates that there was no significant improvement in walking pace when each person used the interface/mode that helped them perform their best. However, a very significant improvement in veering performance was achieved when subjects used the best interface/mode. On average, veer was reduced to 31% of baseline veer. This was not only statistically significant, it was quite meaningful, considering that average baseline veer was around 10 feet when crossing the street. This was often enough veering to cause the person to completely miss detection of the opposite curb and walk into the parallel street. However, when veer was reduced to 3 feet, each person was able to detect the opposite curb and step up onto it.

Further, when each subject used their "best" interface/mode, the number of subject "hesitations," "confusions," and movement out of the crosswalk as compared with baseline measures was:

Measure:	Change:	Significance:
Hesitations	0.33	.001
Confusion Episodes	1.00	No Sig.
"Out of Crosswalk"	0.24	.01

Thus, using their "best" interface/mode, subjects hesitated only one-third of the time and tended to wander out of the crosswalk only one-fourth the time. There were not enough confusing events noted to make any conclusions about improvements in this regard.

There were also interfaces/modes that seriously degraded subject performance. The following lists degraded subject performance for the interface/mode where each subject performed their worst:

Measure:	Change:	Significance:
Walking Pace:	0.71	.03
Veering:	21.4	.000
Hesitations	10.0	.005
Confusion Episodes	9.0	.001
"Out of Crosswalk"	1.18	No Sig.

To indicate which interfaces/modes were best, two types of ranking were done: one for actual performance, and one for expressed subject preferences. In these rankings, 2 points were assigned for best performance (first choice preference) and 1 point for second best performance (second choice preference). The totals were:

	SCt/h	SCt/b	Sp/h	Sp/b	Tap/h	Tap/b
Performance:	13	9	0	1	2	20
Preference:	5	15	2	5	2	16

In the above table "SCt" stands for Sonic Carrot, "Sp" stands for speech interface, "Tap" stands for the tapping interface, "/h" stands for head oriented feedback, and "/b" stands for body oriented feedback. From this it is clear that in terms of actual performance, as well as subject preferences, that the tapping interface used in a body-oriented mode was "best." However, the Sonic Carrot was a very close second, especially in terms of subject preferences. In fact, there was no significant difference between these two when evaluated by subject preference alone.

Subjective Data

Subjective data was comprised of the responses to the questions asked and comments offered. Thirteen of the 15 subjects said that at least one interface helped them cross the street more easily and with more confidence than with their cane alone. The reasons subjects preferred each particular interface is summarized as follows:

Sonic Carrot: **"**It didn't cause me to overcorrect like the others;" "I didn't have to concentrate to use it ... I could hear where the tone was and follow it."

Speech Interface: "Very easy and simple to respond to the voice."

Tapping interface: "It doesn't stand out like having on a headset, and doesn't cover ears or make it hard to hear traffic sounds;" "I can feel it even when I can't hear anything else because of the traffic noise;" "Natural and easy to know which way to turn or move to go straight."

Ways offered to improve each interface are summarized as follows:

Sonic Carrot: "Make the bell-sound higher, louder and more distinctive;" "Make it adjustable so I can set the volume and turn it off," "Make it usable with a hearing aid."

Speech Interface: "Make it repeat less often when going correct direction, and tell me more quickly when I get off track;" "Make it louder so I can hear it over traffic."

Tapping Interface: "Make it tap slower in middle for OK, and faster on the side to get attention right away when I start to veer;" "Make it tap harder and not buzz;" "Make it like a collar or neck band small enough to wear under a shirt and not show."

Comments for improving the overall device included: "Make it wireless and put compass in a belt or lapel pin;" "Make it smaller, with not so many wires;" "Needs to be tied into traffic information and tell me where the cars are;" "Make more adaptable to each person, especially people with hearing aids."

When asked which interface they would prefer if their suggested improvements were made, six of the subjects chose the speech interface, five chose the tapping interface, and four chose the Sonic Carrot. In addition to answering this question, four people volunteered the suggestion that a combination of speech and tapping interfaces would be ideal; and two volunteered that a combination of speech and Sonic Carrot interfaces would be ideal.

DISCUSSION

Given the above subject comments, there is no clear interface "winner." While the objective results clearly show that of the three interface designs tested, the tapping interface resulted in the best performance and was preferred by the majority of subjects; the constructed interfaces were not necessarily the best possible realization of each type of interface. This was obvious from the subject suggestions for improvements. Most of the subject suggestions were very reasonable and can be accomplished using existing technology. The timing of orientation feedback was perceived as very important for all the interfaces. Subjects emphasized that the speech interface, as well as the others, should respond immediately when they start to veer, but only occasionally tell them they are on track.

Perhaps the question should not be "which interface is ultimately the best," but rather, "how can these interfaces be optimized and modularized so that users can easily assemble an overall interface that best suits their own needs and preferences?" Given the heterogeneity of the target population, it certainly may be true that each person within the population might obtain optimal usability when a customized combination of these interfaces is designed for their specific needs and environment.

It should also be noted that different subjects came to this research from different street crossing experiences and community environments. Some were from more rural communities and some from very urban communities, so it is likely that subject comments varied relative to these different settings. For instance, subjects living in communities where traffic is light may not have been concerned with noise being a problem for the virtual beacon and speech interfaces; where those living in a very urban environment may have considered this a great concern. Further, for those with some hearing impairment, there was certainly a concern that operability with hearing aids be addressed.

CONCLUSIONS

First, the investigators conclude that each of the developed interfaces can clearly play a role in assisting people with severe visual disabilities in walking a much straighter path across the street. The most statistically significant result showed that on average the amount of veer to left or right was reduced to 30% of what it had been. In the majority of cases, this made the difference between finding the opposite curb and walking out into the parallel street.

Second, the investigators conclude that of the interfaces tested, the one that gave the best results in terms of subject performance and subject preferences was the tapping interface. Third, the investigators conclude, based upon subject comments, that the speech interfaces can be considerably improved by optimizing the timing of feedback. Given such improvement, speech may be as usable as the tapping interface.

Finally, the investigators suspect that a tapping interface combined with an improved speech interface may become the most usable and flexible interface combination for orientation aids that suit the needs of the majority of the target population. It may also be the case, as indicated in the work of Loomis, that a virtual sound environment combined with speech output would be best for some people in the target population [16].

The authors therefore recommend the further optimization of the speech and tapping interfaces and the implementation of a combination of these. They also suggest that the potential of Sonic Carrots and virtual sound environments be further investigated for use by people who do not have a hearing impairment.

ACKNOWLEDGMENTS

The Department of Veterans Affairs, Rehabilitation Research and Development Service provided funding for this work. The Atlanta VA Rehabilitation R&D Center is part of the Atlanta VA Medical Center Research Service, which provides laboratory space and equipment, administrative support and staff resources for this research.

REFERENCES

1. Blasch, B. Environmental information needs for wayfinding. *VA RR&D Final Reports* (Atlanta VA Rehab R&D Center), 1991.
2. Blasch, B.; Wiener, W.; Welsh, R. *Foundations of Orientation and Mobility, Second Edition*. American Foundation for the Blind, New York, NY, pp. 291-293, 1997.
3. Bond, Y.M. Parking and Traffic. *Proceedings of a symposium of consumer, user agency, researcher, and commercial experience with talking signs and related technologies*, San Francisco, CA. Smith-Kettlewell Eye Research Institute, 1995.
4. Busboom, M.; May, M. Mobile navigation for the blind. *Proceeding of the International Conference on Wearable Computing*, Vienna, Austria, 1999.
5. Chew, S. The use of traffic sounds by blind pedestrians. *Dissertation Abstracts International*, 47, 08B. (University Microfilms No. AAG8627007), 1986.
6. Crandall, W.; Bentzen, B.L.; Myers, L.; Mitchel, P. *Transit accessibility improvement through talking signs remote infrared signage: A demonstration and evaluation*. Smith-Kettlewell Eye Research Institute RERC, San Francisco, CA, 1995.
7. Cratty, B.J.; Williams, H. (1966) *Perceptual thresholds of nonvisual locomotion (Part 2)*. Los Angeles: University of California, 1966.
8. Gibson, E.J. (1969) *Principles of perceptual learning and development*. New York: Appleton-Century-Crofts, 1969.
9. Goodrich, G.L. *Growth in a Shrinking Population: 1995-2010*. Palo Alto Health Care System. Palo Alto, CA, 1997.
10. Grantham, D.W. Spatial hearing and related phenomena. In E. Carterette & M. Friedman (Series Eds.) & B. Moore (Vol. Ed.), *Handbook of perception and cognition: Hearing (2nd ed.)*, New York: Academic Press, pp. 297-345, 1995.
11. Guth, D.A.; Hill, E.W.; Rieser, J.J. Tests of blind pedestrians' use of traffic sounds for street-crossing alignment. *Journal of Visual Impairment & Blindness*, 83(9), 461-468, 1989.
12. Guth, D.; LaDuke, R. Veering by blind pedestrians: Individual differences and their implications for instruction. *Journal of Visual Impairment & Blindness*, 89(1), 28-37, 1995.
13. Guth, D.A.; Rieser, J.J. Perception and the control of locomotion by blind and visually impaired pedestrians. *Foundations of Orientation and Mobility, (Second Edition)*, AFB Press, pp. 9-38, 1997.
14. Institute of Transportation Engineers. *Improving traffic signal operations: A primer*. Washington, DC, 1995.
15. LaGrow, S. LaGrow, M. Weessies *Orientation and Mobility: Techniques for Independence*. Royal New Zealand Foundation for the Blind, Dunmore Press, pp. 9-30, 1994.
16. Loomis, J. M., Golledge, R. G., & Klatzky, R. L. (1998). Navigation system for the blind: Auditory display modes and guidance. *Presence: Teleoperators and Virtual Environments*, 7, 193-203.
17. National Center for Veteran Analysis and Statistics. *National Survey of Veterans*. Assistant Secretary for Policy and Planning, Department of Veterans Affairs, Gov't Printing Office, 1994.
18. National Society to Prevent Blindness. *Estimated statistics on blindness and vision problems*. New York: National Society to Prevent Blindness, 1979.
19. Pentland, A.; Tan, H. Tactual displays for wearable computing. *International Symposium on Wearable Computers*. Cambridge, MA, Oct '97. IEEE Press.
20. Pick, Jr., H.L. Perception, locomotion and orientation. In R. L. Welsh & B.B.Blasch (Eds.), *Foundations of orientation and mobility*. New York: American Foundation for the Blind. Chapter 5, pp. 73-88, 1980.
21. Rouse, D.; Worchel, D. Veering tendency in the blind. *New Outlook for the Blind*, 49, 115-119, 1955.
22. Vanderheiden, G.C. Accessible design: A handbook for more universal product design. Madison, WI: Trace Research and Development Center, 1993.
23. Vanderheiden, G.C. Universal design…What it is and what it isn't. Madison, WI: Trace Research and Development Center, 1996.
24. Welsh, R.; Blasch, B. *Foundations of Orientation and Mobility, Second Edition*. American Foundation for the Blind, New York, NY, pp. 291-293, 1997.