Chapter 7

Assisting Wayfinding in Visually Impaired Travelers

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Human wayfinding, both by sighted and visually impaired people, consists of two very different functions: (1) sensing of the immediate environment, including obstacles and physically defined paths, for the purposes of moving through it and (2) navigating to remote destinations beyond the immediately perceptible environment (Golledge, 1999; Loomis et al., 1993; Rieser, Guth, & Hill, 1982; Strelow, 1985; Welsh & Blasch, 1980).[1] Navigation involves keeping track of one's position and

[1]In connection with wayfinding skills by visually impaired people, the terms "*mobility*" and "*orientation*," respectively, correspond to sensing of the environment and navigation.

orientation during travel with respect to the destination, which can be accomplished using either piloting or path integration (Gallistel, 1990).

Piloting refers to sensing positional information and using it to determine one's location. For example, in natural unaided navigation, one can use visible, auditory, or haptic landmarks to fix one's current position. If only nearby landmarks can be sensed, one usually needs to have an external map or cognitive map to locate oneself relative to the destination. Remotely sensed landmarks that are near the destination can serve as beacons for homing. If there are no such beacons, remotely sensed landmarks can be used in conjunction with triangulation of directions and trilateration of distances to determine one's current location. Remotely sensed landmarks allow one to travel into unfamiliar territory and remain oriented. In radio-based navigation used by aircraft, boats, and now even cars, positional signals from navigation transmitters on land or in space can be used to compute one's position instead of sensed landmarks.

Path integration refers to obtaining information about one's motion (e.g., velocity and acceleration) and then using that information to compute one's displacement and change in orientation with respect to an origin. Pilots and mariners have long used path integration based on velocity, known as "dead reckoning," as a backup when piloting and electronic navigation are not available. Inertial guidance systems for aircraft and spacecraft utilize acceleration alone (i.e., no external sensing) and have been so perfected that they allow extremely accurate position keeping over hours of travel without a position fix.

Obviously, visually impaired people are at a big disadvantage when it comes to wayfinding. Sensing the near environment for obstacles and hazards is effortful and error prone, even with a long cane and auditory cues such as echoes. In particular, blind people are vulnerable to collision with small obstacles above the ground. For navigation, they lack much of the information needed for planning detours around obstacles and hazards and have little information about distant landmarks, heading, and self-velocity, information that is essential when traveling through unfamiliar environments. Still, some blind travelers are superbly able to remain oriented while traveling within large environments. There are individuals, for example, who are able to perform path integration while traveling as a passenger through a familiar environment, like a city grid. Others challenge themselves by using path integration while walking to venture forth into unfamiliar parts of a town or city. And, of course, many blind people are able to use auditory and haptic signals about the near environment to travel along familiar routes.

These examples of success notwithstanding, blind people stand to benefit greatly from electronic devices that augment their senses, greatly improving both the sensing of the immediate environment and providing

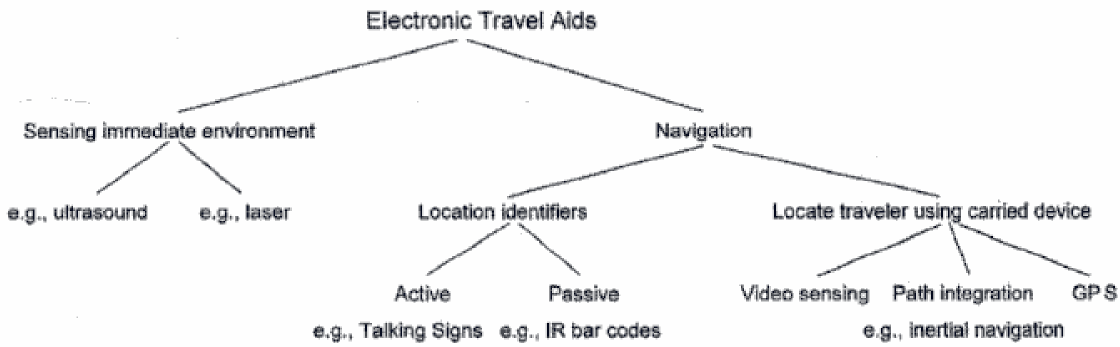

Fig. 7.1.
Types of Electronic Travel Aids (ETAs).

information for navigation. Like many others, we believe that "user-centered design" (Card, Moran, & Newell, 1983; Norman & Draper, 1986) will lead to the most effective wayfinding devices. The research and development we review reflects this commitment to user-centered design.

ELECTRONIC TRAVEL AIDS

Early research and development of Electronic Travel Aids (ETAs) focused on sensing the immediate environment, in efforts to supplement or replace the long cane (Brabyn, 1985; Farmer, 1980). Electronic obstacle avoiders used today include the Sonic Pathfinder, Mowat Sensor, and MiniGuide, which are stand-alone devices that use ultrasonic sensing to detect obstacles and provide auditory or vibratory signals to the user, and modified long canes, such as the LaserCane and Ultracane, which include laser and ultrasonic sensing to provide information about obstacles above the ground (see Fig. 7. 1). Of interest are two technologically sophisticated devices, the NavBelt and the GuideCane, which used ultrasensor sensors to scan the forward environment and algorithms for determining a clear path for the user (Shoval, Ulrich, & Borenstein, 2003). They are apparently no longer under development.

Within the last decade and a half, research and development of ETAs has shifted from obstacle avoidance to the navigation function. There are basically two approaches: modify the environment with electronic location identifiers or provide the traveler with an electronic device that locates the traveler within a global or local coordinate system (see Fig. 7.1). Examples of the first approach are three systems of active signage called Talking Signs®, Talking Lights, and Verbal Landmark.

In the Talking Signs® system, based on Remote Infrared Audible Signage (RIAS), infrared transmitters are installed throughout the environment,

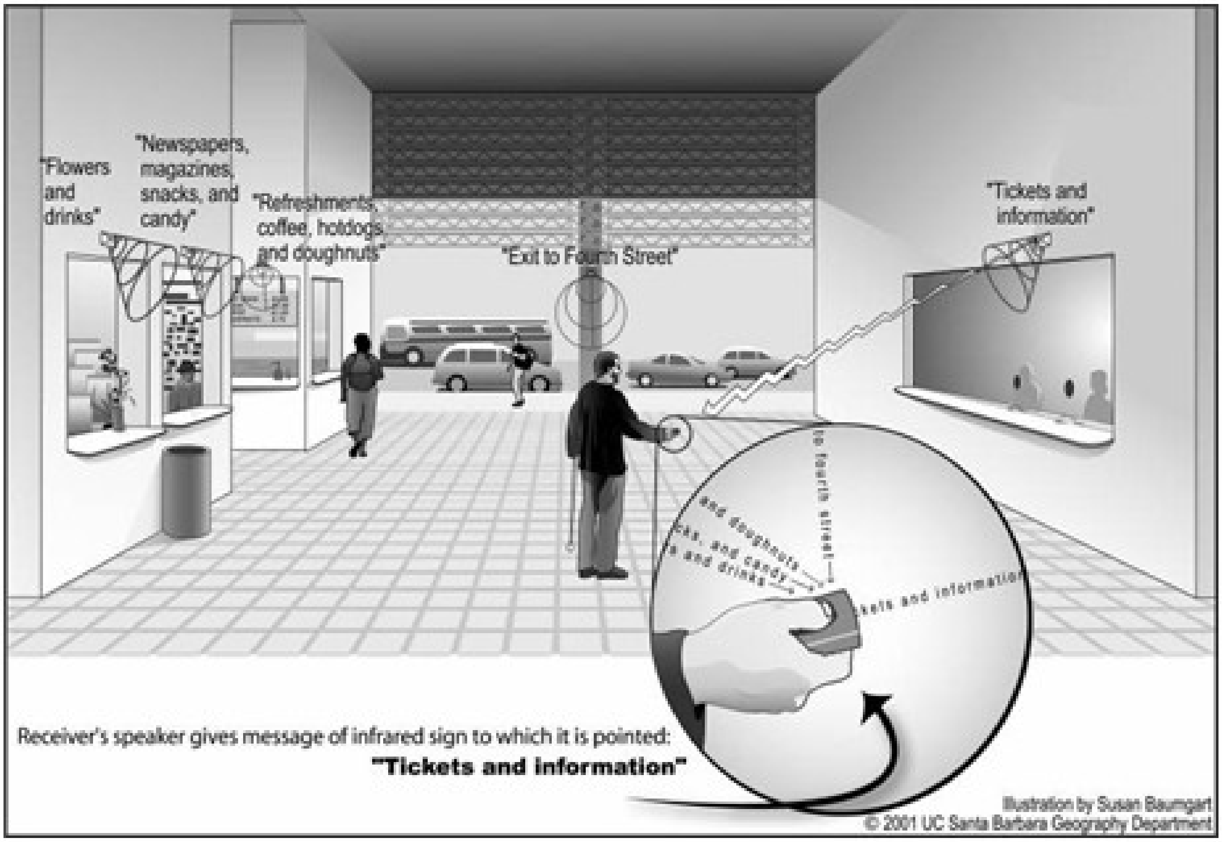

Fig. 7.2.
The Talking Signs® system of Remote Infrared Audible Signage (RIAS). Infrared transmitters are installed near important environmental entities. Each transmitter continuously sends out a digitally encoded utterance about the nearby entity. A person holding an RIAS receiver hears the utterance when pointing the receiver in the direction of the transmitter. From *Towards an Accessible City: Empirical Measurement and Modeling of Access to Urban Opportunities for Those With Vision Impairments, Using Remote Infrared Audible Signage*, by J. R. Marston, 2002, unpublished dissertation, Department of Geography, University of California, Santa Barbara. Copyright©2002 by J. R. Marston. Reprinted with permission.

such as in shopping centers, hotels, airports, and public transportation terminals (see Fig. 7.2); (Golledge & Marston, 1999; Marston & Golledge, 2003; Bentzen & Mitchell, 1995; Crandall, Gerry, & Alden, 1993; Hatakeyama et al., 2004). The infrared radiation (IR) from the transmitters carries encoded information, including speech, about the identity of the location or vehicle to which the transmitter is attached. The IR signal from the transmitter is highly directional, which makes the transmitter serve as a beacon. A visually impaired traveler with an IR receiver picks up the encoded speech signal usually within a range of 30 m outdoors, with the maximum depending on the environment (e.g., less for indoors); directional localization of the transmitter is accomplished by aiming the hand-held receiver to obtain maximum signal strength. RIAS transmitters have been installed in large numbers around the world. They provide permanent messages for building entrances, restrooms, etcetera and variable messages, such as destination signs on buses and Walk/Wait signs at pedestrian crossings.

Talking Lights, which are still under development, rely on computer chips that are connected to the ballasts of fluorescent lamps and modulate the emitted light at frequencies too high to be visible. The modulating signal consists of digitally encoded utterances or other information. The traveler carries a receiver that decodes the signal and displays the encoded utterance by speaker or earphone. Talking Lights are obviously well suited to indoor environments, although their directionality is not as precise as that of RIAS.

The Verbal Landmark system, developed in 1992 but no longer in use, employed radio frequencies (RF) instead of infrared light as the carrier signal. The RF transmitter had a more limited range (2 m) and was omnidirectional, making precise localization impossible. Thus, rather than being used as a beacon to represent a location, the Verbal Landmark transmitter typically sent out verbal instructions to the travelers, who had to orient on their own. A study sponsored by the American Council of the Blind evaluated the relative merits of this system (Verbal Landmark) and the Talking Signs® RIAS system. The study (Bentzen & Mitchell, 1995) determined the efficiency in completing travel tasks (objective measures) and preference of users (subjective measures) using the two systems. Results of both measures showed superior performance and satisfaction with the information provided by the RIAS system.

An alternative to electronic signs that emit IR or RF, but still exemplifying the environmental modification approach, are passive tags posted in the surroundings, which reflect energy from a device carried by the traveler and impose signals on the reflected energy. Ogata, Makino, Ishii, and Nakashizuka (1997) have experimented with IR bar code labels that appear as uniformly colored strips and can be attached to objects and wall surfaces within a building; IR video sensing and computer processing provide the traveler with locational speech information encoded on the labels. A second type of environmental marker involves RF identification tags (RFIDs) (e.g. Kulyukin, Gharpure, Nicholson, & Pavithran, 2004) that reflect RF signals from a low-power transmitter worn or carried by the traveler.

The obvious drawback of placing a network of location identifiers within the environment is the cost of installing and maintaining the network relative to the coverage achieved. The second general approach to aiding navigation, using an electronic device to locate the traveler, potentially overcomes this drawback. Within this second approach, there are many methods, which vary in the extent to which they require sensing of the environment, reception of signals provided by external positioning systems, and stored information about the environment (see Fig. 7.1). Inertial navigation is attractive, for it requires neither external sensing nor stored information about the environment; unfortunately, there are as yet no accelerometers of sufficiently high sensitivity and low noise to allow for inertial navigation as the primary basis for pedestrian travel (Ladetto & Merminod, 2002). However, an inertial navigation unit is being developed by Leica Vectronix as an adjunct to other means of pedestrian navigation. Another method is path integration using velocity, by way of a downward-pointing camera to sense the traveler's velocity (Loomis, Golledge, Klatzky, Speigle, & Tietz, 1994; Nistér, Naroditsky, & Bergen, 2004). We are not aware of any efforts exploring the feasibility of this method for pedestrian use. Still another approach is using video sensing in conjunction with map correlation (e.g., Campbell, Sukthankar, & Nourbakhsh, 2004; Ulrich & Nourbakhsh, 2000). Here, video images of the environment are matched to images or models of the environment stored in memory.

Most common are methods that rely on radio signals received by the traveler and processed by computer. Preeminent is the Global Positioning System (GPS), in which satellites continually send out signals indicating their exact locations (Parkinson & Spilker, 1996). A GPS receiver uses these signals to compute its position. GPS provides high-positional accuracy, wide signal coverage, and easy accessibility for many outdoor environments. Even inexpensive GPS receivers with differential correction will routinely allow positional accuracy of several meters or better, provided that enough satellites are in view. The downside of GPS (and GLONASS, its Russian equivalent) is that positioning is degraded or eliminated by buildings or dense foliage, etcetera that block the satellite signals. In these environments, GPS needs to be supplanted or supplemented by some other means of navigation, such as inertial navigation or RIAS. For indoor environments, the future holds the possibility of local positioning systems analogous to GPS or GLONASS. Here, triangulation or trilateration of signals from a set of high-frequency stationary transmitters called *pseudolites* will enable precise positioning of the receiver (e.g., Kee et al., 2001). Another approach to indoor navigation will be to exploit the widely deployed WiFi and Bluetooth transmitters used in wireless digital communication.

GPS-BASED NAVIGATION AIDS FOR THE VISUALLY IMPAIRED

The idea of using GPS to assist with navigation by the visually impaired goes back two decades (Collins, 1985; Loomis, 1985). Since then, there have been a multitude of research projects investigating GPS-based navigation systems for visually impaired travelers, besides our own (e.g., Brusnighan, Strauss, Floyd, & Wheeler, 1989; Fruchterman, 1996; Helal, Moore, & Ramachandran, 2001; Holland, Morse, & Gedenryd, 2002; LaPierre, 1998; Makino, Ishii, & Nakashizuka, 1996; Petrie et al., 1996; Talkenberg, 1996). There are now several commercial products being widely used by visually impaired people (Trekker and BrailleNote GPS), with more on the way.

The system our group has developed, the Personal Guidance System, has been and is currently being used only as a research test bed (Golledge, Klatzky, Loomis, Speigle, & Tietz, 1998; Loomis et al., 1994; Loomis, Golledge, & Klatzky, 1998, Golledge, Loomis, Klatzky, Flury, & Yang, 1991). Our long-term goal has been to contribute to the development of a portable, self-contained system that will allow visually impaired individuals to travel through familiar and unfamiliar environments without the assistance of guides. Now that commercially available systems exist, our primary effort is directed toward the user interface, especially the development and evaluation of spatial displays. Nonvisual spatial displays use hearing or touch to provide direct perceptual information about important locations in the environment; auditory or haptic information specifies both distance and direction to each location or just direction alone. The user experiences these locations from a first-person perspective, as if surrounded by the displayed locations. Spatial displays contrast with synthesized speech, which is used by most other research projects and commercial products (e.g., Gaunet & Briffault, 2005). We are hoping that our research, which already has shown the effectiveness of spatial displays, will lead developers and producers of navigation systems for the visually impaired to provide spatial displays as options for commercial products.

Our interest in spatial displays goes back to the very beginning of our project. At that time, we contemplated using a virtual acoustic display as part of the user interface (Loomis, 1985), but we are now doing research on other interfaces as well. A virtual acoustic display takes a monaural audio signal (e.g., speech or environmental sound) and transforms it into a binaural signal delivered by earphones, the result being a sound that appears to emanate from a given environmental location (Begault, 1994; Gilkey & Anderson, 1997; Loomis, Hebert, & Cicinelli, 1990). The original idea was that as the visually impaired person travels through the environment, he or she hears the names of buildings, street intersections, etcetera spoken by a speech synthesizer, coming from the appropriate locations in auditory space, as if they were coming from loudspeakers at those locations (Fig. 7.3).

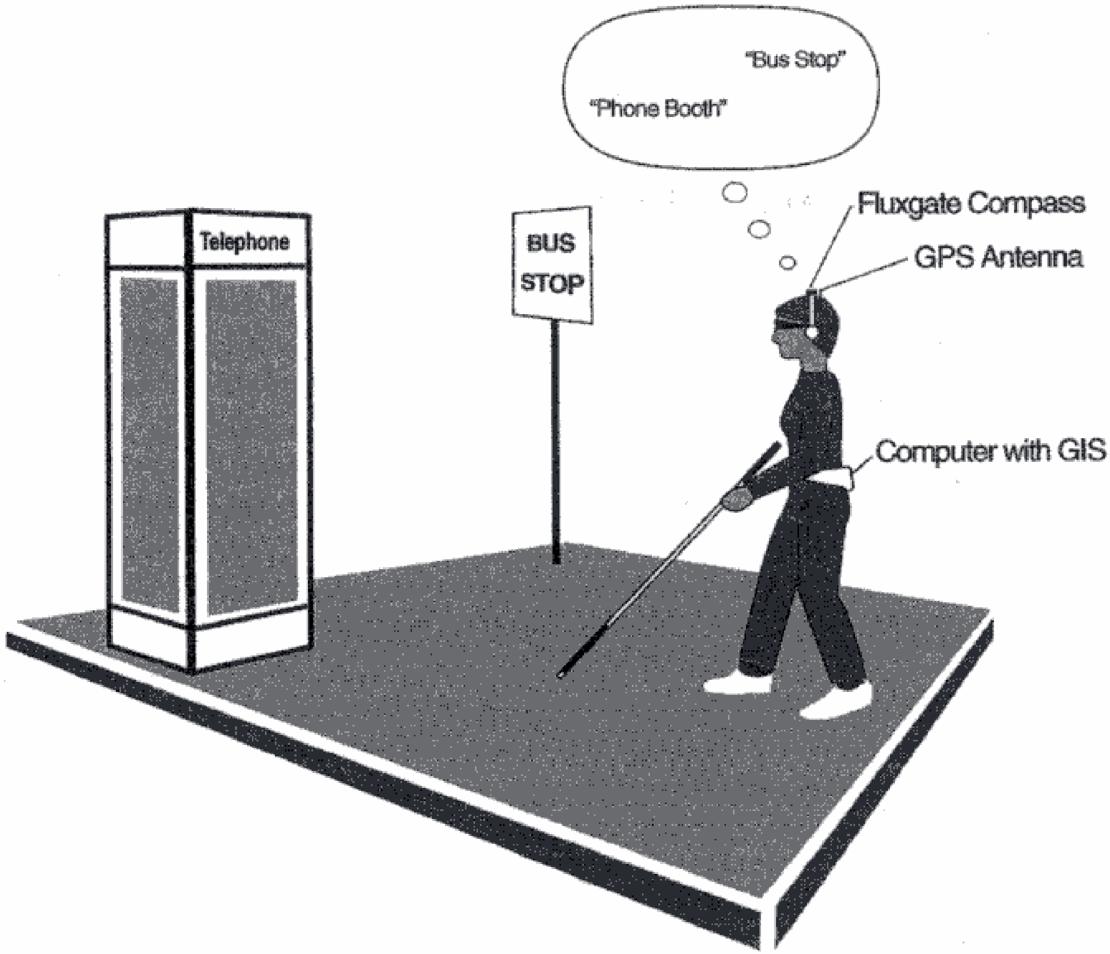

Fig. 7.3.
Early conception of the Personal Guidance System. From "GPS-Based Navigation Systems for the Visually Impaired," by J. M. Loomis, R. G. Golledge, and R. L. Klatzy, 2001. In W. T. Barfield and T. Caudell (Eds.), *Fundamentals of Wearable Computers and Augmented Reality* (pp. 429–446). Mahwah, Erlbaum. Reprinted with permission.

Our system, like other GPS navigation systems for visually impaired people, is not intended to provide the visually impaired person with detailed information about the most immediate environment (e.g. obstacles); thus, the traveler still has to rely on the long cane, guide dog, or ultrasonic sensing devices for this information.

We have developed various versions of the Personal Guidance System. The initial version was bulky and heavy and carried in a backpack. We have also developed a very lightweight version carried in a small pack over the shoulder. We are less concerned about size and weight because commercial products are already very acceptable in this regard and will only get better. Instead, because our goal is to investigate different designs for the user interface, we have opted to use a version that is easy to work with and has a high-quality GPS receiver. Consequently, our formal research in the past several years has used a version worn in a backpack and weighing 2.3 kg. For details on the hardware of this system, see the paper by Loomis, Marston, Golledge, and Klatzky (2005).

In what follows, we describe research our group has done on two distinct projects, one the user interface for GPS-based navigation systems and the other on RIAS.

RESEARCH ON THE USER INTERFACE FOR A NAVIGATION SYSTEM

The user interface involves both input and output. On the input side, the traveler enters data into the system (like the destination) and controls the various modes of operation. On the output side, the system provides information about the environment, the traveler's location and orientation within it, and the status of the system (e.g. malfunctions). The usual input interfaces for the commercial products are the Qwerty keyboard and braille chording keyboard. Speech input via microphone and speech recognition software seems promising, but the problem of ambient noise must be overcome. In our lab, we have shown that a throat microphone (which increases the signal to noise ratio for speech) can be used effectively with speech recognition software (Dragon Naturally Speaking 7.0), and we are currently investigating other noise canceling microphones. We are unaware of any user studies comparing the different types of input interface, but Golledge, Marston, Loomis, and Klatzky (2004) have conducted survey research on user opinions about different options.

In this survey, participants were asked for their preferences for alternative ways to input destination, the best ways to start a trip, and how best to get en-route information to a traveler. Prior to requesting their preferences, participants were read a detailed description of a new device, labeled a Personal Guidance System (PGS) and were asked to consider their responses both with respect to their initial knowledge base about ETAs (both obstacle avoiders and navigation systems) and the new technology that was described to them. A final set of questions probed participants' perceptions of any expected changes in trip frequency and exploratory behavior if the PGS were to become readily available. Results showed that there was a favorable disposition towards the new technology, that speech input and output interfaces were markedly preferred over other interfaces (including braille), that there was a positive attitude towards experimenting with the described PGS technology, and that there was the expectation of more trips if such a guidance device were to become available. A key part of this survey aimed at defining preferences for types of input interfaces. The alternatives offered were speech, a QWERTY keyboard, a telephone keypad, and a braille keypad. On a 5-point rating scale, (1 = very unacceptable to 5 = very acceptable), speech scored an average of 4.8, with all 30 participants rating it as Very Acceptable or Acceptable (Golledge et al., 2004).

The display interface for a navigation system provides at least two types of information useful in navigation. The first is route guidance information, which leads the traveler from the origin to the destination. The second is off-route information, which can both help the traveller keep oriented and develop better mental representations of the environment over multiple trips though it. Most evaluation of navigation systems for visually impaired people has been concerned with route guidance.

As mentioned, most research and commercial navigation systems for visually impaired people use synthesized speech. In a typical usage, the traveler inputs the destination and is informed where he or she is on the street grid and then given progressive instructions on how to travel to the destination. The commercial products are quite effective, as judged by the sales volumes and positive comments by users. Our own research on displays continues because we have long thought that visually impaired people too will want to have spatial displays at least some of the time, just as car drivers and aircraft pilots prefer to have visual spatial displays in addition to speech and text. Because spatial displays provide a direct perceptual pathway to the experience of location, they have advantages in ease of understanding and precision.

The survey research by Golledge et al. (2004) confirms that there is indeed interest among the blind community in such displays for providing guidance information. The respondents were told that some of these devices would give textual route information alone whereas others would also give directional cues to locations. Options to be considered included speech (from a speaker location on the head, neck, shoulder, or collar), a tactile raised dot display, braille output, or speech delivered by earphones. The most preferred output device was a collar- or shoulder-mounted speech or tone-emitting display (Golledge et. al., 2004). The most preferred directional device was a hand-held unit that the traveler would use to scan the environment to get directional information to a destination. There remained some hesitation about the use of the stereo earphones required for a spatialized speech interface.

We have conducted many informal demonstrations of the Personal Guidance System at our test site, the University of California at Santa Barbara campus. With these demonstrations, we have shown the capability of the system to guide an unsighted person to some specified destination using a sequence of waypoints; under conditions of good satellite availability with differential correction, we now routinely obtain GPS mean absolute error considerably less than 1 m.

We have completed three formal experimental studies on the display interface in connection with route guidance (Loomis et al., 1998; Loomis et al., 2005; Marston, Loomis, Klatzky, Golledge, & Smith, in press). The first study compared four different auditory displays, one of which was a spatial display using virtual sound. Our primary interest was in determining whether speech presented as virtual sound resulted in better or worse route-following performance than verbal guidance commands provided by conventional synthesized speech. Of secondary interest was a comparison of guidance with and without heading information, as provided by an electronic compass.

In the experiment, the participant was led along one of four paths, each 71 m long and consisting of 9 straight segments defined by 10 waypoints. These were situated within a large open grassy field on campus. The navigation system computer constantly updated the distance and relative bearing of the next waypoint relative to the participant. When the subject arrived within 1.5 m of the waypoint, the computer triggered the next waypoint in sequence. Auditory guidance information was given at two intermittency rates: once every 1.5 sec (fast) or once every 5.0 sec (slow).

We evaluated four display modes in the experiment; three involving a conventional speech display and the fourth involving speech presented as a virtual sound. In the Virtual mode, the person heard the number of the next waypoint spoken by a speech synthesizer and then rendered as a virtual sound at the location of the waypoint. In the Left/Right mode, the speech synthesizer provided information about the bearing of the next waypoint ("left," "straight," "right") relative to the participant's heading. The Bearing mode was similar except that the relative bearing between the participant and the next waypoint, rounded to the nearest 10 deg, was spoken (e.g., "left 80"). Finally, the No Compass mode was like the Bearing mode, in that the participant received the same type of verbal command from the computer (e.g., "left 80"). However, the relative bearing of the next waypoint relative to the participant's direction of travel (based on two successive GPS fixes) was given as output. If the subject stopped moving, travel direction was not defined, and the computer stopped issuing commands.

We obtained two performance measures—travel distance and completion time—and subjective ratings from each of the 10 blind participants. Because the two performance measures were highly correlated, Fig. 7.4 gives just completion times. Judging from the two performance measures and the ratings, the Virtual mode was only slightly better than the next best mode, Bearing. The No Compass mode was definitely the poorest, as

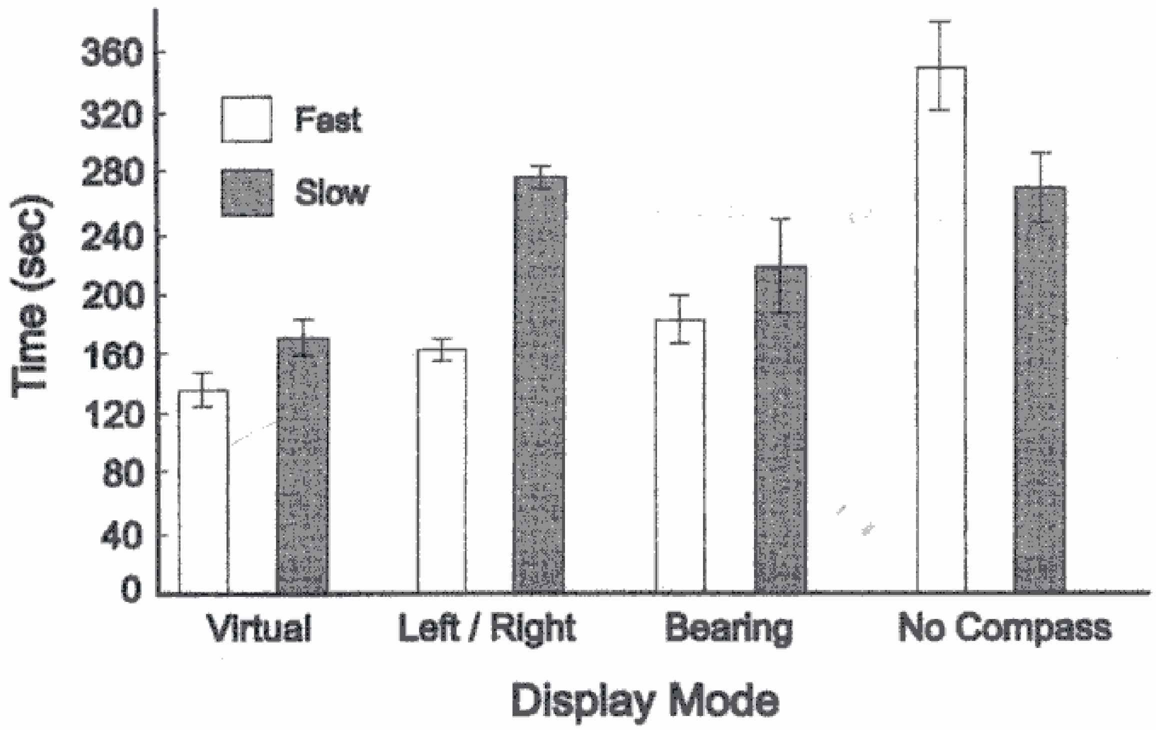

Fig. 7.4.
Results of experiment on route guidance using 4 auditory display modes. Time to finish walking the 71 m path is given as a function of display mode and rate at which information was given to the subject (once every 1.5 sec or every 5.0 sec). From "Navigation system for the blind: Auditory Display Modes and Guidance," by: J. M., Loomis, R. G., Golledge, and R. L., Klatzky, (1998). *Presence: Teleoperators and Virtual Environments, 7,* pp. 193–203. Copyright © 1998 by MIT Press. Reprinted with permission.

judged in terms of both performance and ratings. The experimental findings show the importance of using a compass to provide heading information for route guidance and the value of using spatialized virtual sound over conventional speech information.

In our second experiment on route guidance (Loomis et al., 2005), we introduced a new interface, which we call the Haptic Pointer Interface (HPI); It emulates an RIAS receiver. Whereas the traveler localizes an RIAS transmitter by aiming the hand-held receiver towards the transmitter until obtaining a maximum audible signal, with the new HPI interface, the traveler holds a small box similar to an RIAS receiver, to which is attached an electronic compass. When the hand is pointing within 10° of the direction to the next waypoint along the route, the computer sends an audible signal to a speaker within the box or worn on the person's upper torso. For this experiment, we used the torso speaker and a rectangular block instead of a box with speaker (see Fig. 7.5).

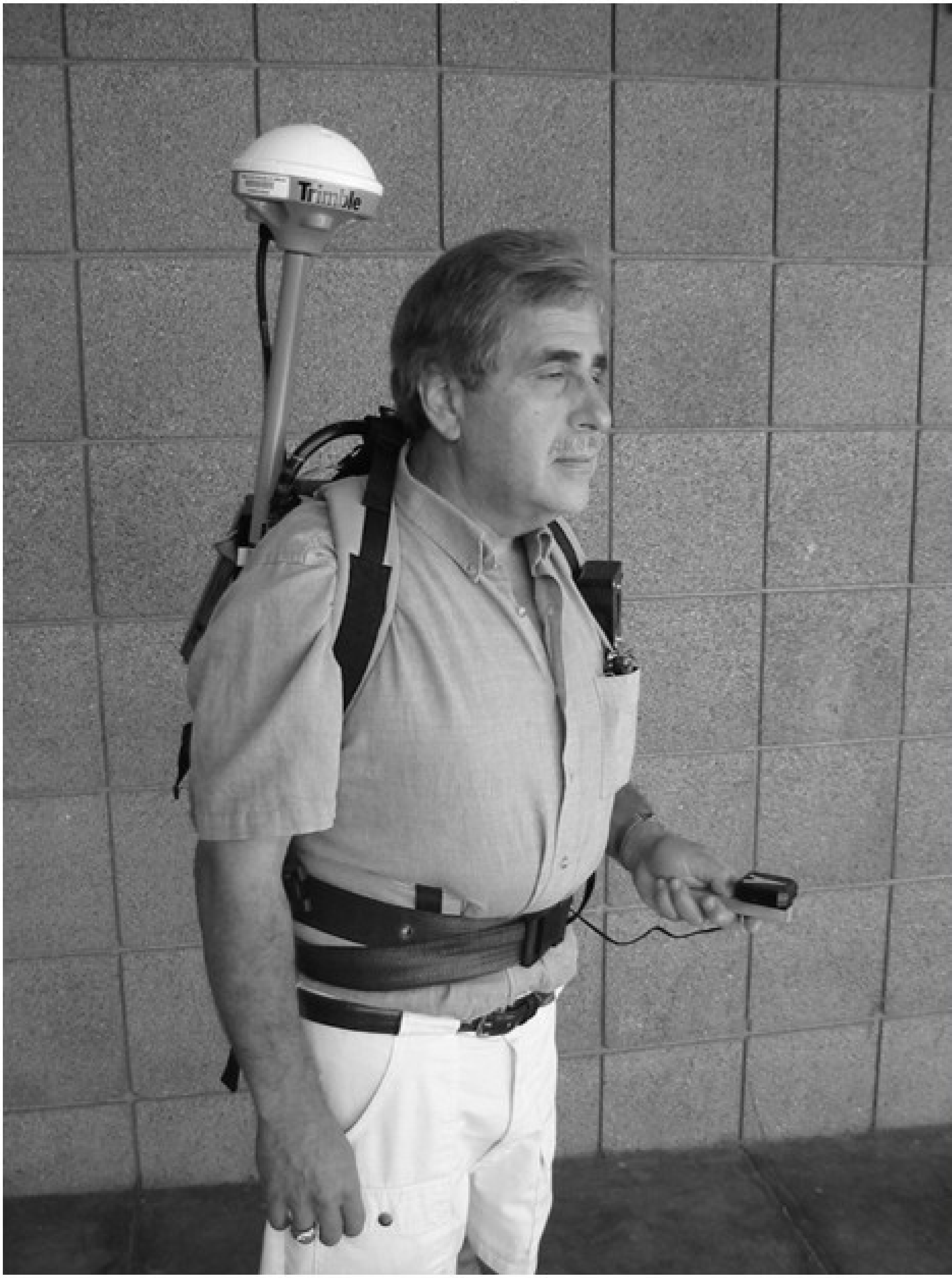

Fig. 7.5.
The fourth author illustrating the Haptic Pointer Interface. The electronic compass is mounted on the small block held in the hand, and the sound was delivered by the speaker mounted in front of the author's left shoulder. From research by Loomis, Marston, Golledge, and Klatzky (2005)

This experiment compared five different display modes for specifying the bearing to the current waypoint; distance was also provided. The paths were 50 m and consisted of 7 straight segments. The Virtual Speech mode was the same as the Virtual mode of the earlier experiment except that the synthesized speech, while conveying the current bearing with binaural auditory cues, did so by speaking the distance to the next waypoint instead of the waypoint number. The second mode, Virtual Tone, was similar to Virtual Speech mode, except that the bearing to the next waypoint was represented by the perceived direction of virtual tones instead of virtual speech. In the third mode, HPI Tone, the participant held the haptic pointer in one hand. Whenever the hand was nearly aligned with bearing to the next waypoint, the computer issued a rapid sequence of beeping tones to the shoulder-mounted speaker. The fourth mode, HPI Speech, was similar to the previous mode, except that synthesized speech was presented instead of tones. If the bearing to the next waypoint was within 10°, the word "straight" was presented. For relative bearings greater than 10°, "left" and "right" signaled the direction to turn. The fifth and final mode, Body Pointing, was similar to the HPI Tone mode except that the person's body, rather than hand, had to be within 10° of alignment with the next waypoint for tones to be heard. In all modes except Virtual Speech (which specified distance integrally with bearing), distance to the next waypoint was announced every 8 sec.

As in the earlier experiment, the two performance measures were travel distance and completion time. Figure. 7.6 gives the results for 15 blind participants. Subjective ratings and rankings of the different modes were also obtained. The two virtual displays led to the fastest mean travel times, replicating the result of the earlier experiment. The probable reason for the advantage in the current experiment is that when the participant arrived at a waypoint, the direction to the next waypoint was immediately apparent through auditory perceptual localization. For the other displays, the hand or body needed to rotate into alignment with the direction of the next waypoint before its direction could be known precisely. The finding that distance did not vary significantly across displays further indicates that the time differences are attributable to the turns rather than the straight segments of the path.

The subjective evaluations indicated that Virtual Speech was judged best, but part of the reason might be that this mode gave information about distance continually; whereas, the other modes gave a distance readout only every 8 sec. After Virtual Speech, Body Pointing was preferred over both the HPI Tone and HPI Speech. Virtual Tone was least preferred but still rated quite highly. User comments indicated that the "off-course tone" was annoying, and different audio tones might likely influence their opinion.

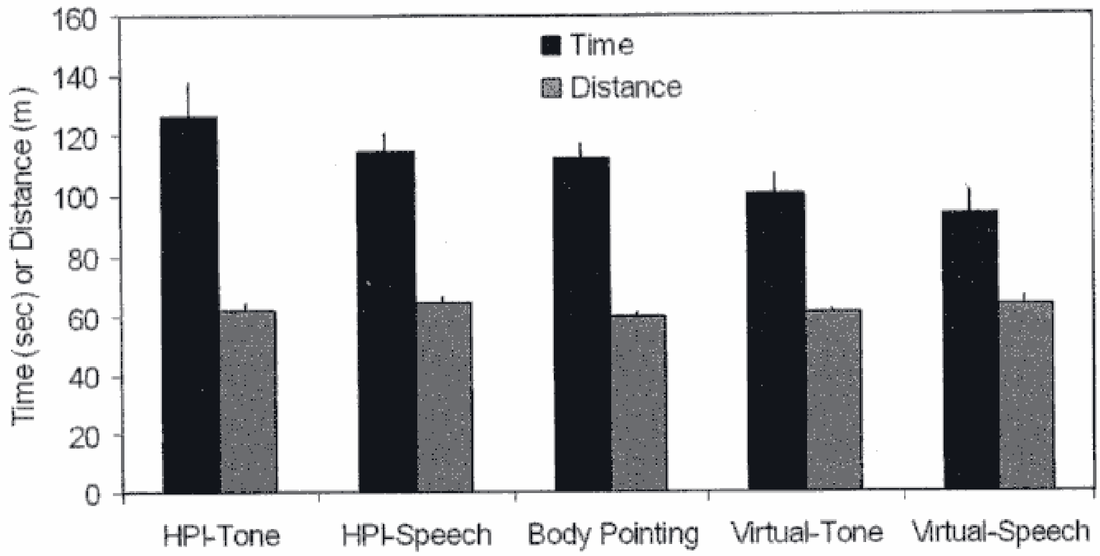

Fig. 7.6

Results of experiment on route guidance using 5 display modes. From "Personal Guidance System for People With Visual Impairment: Comparison of Spatial Displays for Route Guidance," by J. M. Loomis, J. R. Marston, R. G. Golledge, and R. L. Klatzky, 2002, *Journal of Visual Impairment & Blindness*, *99*, 219–232, Copyright © by AFB Press. Reprinted with permission.

The third experiment on route guidance (Marston et al., in press) took our evaluation research from open unobstructed test areas on the UCSB campus out into the surrounding community. This time, we compared just the Virtual Tone and HPI Tone interfaces, with a few modifications. The most notable was that the Virtual Tone interface used air tube earphones that did not block environmental sounds to any extent. Two paths were used, one along urban sidewalks and the other over trails in a city park. Eight visually impaired travelers were tested with both interfaces—four of the participants used one pairing of the two interfaces with the two paths and the other four used the other pairing. On average the 8 participants took about twice as long to complete the paths as three project personnel who walked the same paths using both vision and guidance information from the system. One blind participant was only about 20% slower than the three sighted travelers, an impressive result showing how effective a GPS navigation system with a spatial display can be. Based on pathway completion times and user evaluations, the Virtual Tone display was marginally superior to the HPI Tone display. In addition, the participants judged that the air tube earphones did not block environmental sounds (4.5 rating on a scale of 1 to 5) and were enthusiastic about using them as part of the user interface of a commercially available system.

The three experiments together indicate considerable promise of spatial displays, whether virtual sound, body pointing, or haptic pointing, as part of the interface for a navigation system used in route guidance. (For other work on virtual sound as an interface, see Walker & Lindsay, in press.) Because existing commercially available systems use only synthesized speech, our research indicates that providing spatial displays as options will likely result in greater user acceptance and better performance, at least within some environments. The Haptic Pointer Interface has the virtue of being used in conjunction with location identifiers, like RIAS, which require a handheld receiver. By integrating the HPI with the RIAS receiver, people can transition seamlessly from using the HPI to locate virtual waypoints and off-route landmarks to using the receiver to locate and hear the message from RIAS transmitters located in the environment. Of course, a disadvantage of such an interface is that it ties up the use of one hand. The virtual sound display is attractive in that it does not, but it does require in-ear input. Furthermore, the virtual sound display resulted in better performance and user acceptance, as reflected in the shorter travel times and higher subjective ratings.

The research we have discussed so far has focused on route guidance. Other important functions of a navigation system are allowing a blind traveler to learn about points of interest in the environment (restaurants, businesses, etcetera.) and facilitating the formation of cognitive representations of the spatial layout of the environment. Existing commercially available systems using speech output provide detailed information about points of interest. We believe that spatial displays, especially virtual sound, are more intuitive and potentially more efficient ways of providing this information. Because the directional cues for spatial hearing are omnidirectional, switching between virtual sounds is essentially instantaneous, and the traveler is able to perceive each location in rapid succession. In contrast, haptic pointing, body pointing, and synthesized speech all take more time for conveying information about environmental locations. Thus, virtual sound might be more suited when a blind traveler wishes to get a quick preview of the route to be followed or a quick overview of points of interest and their spatial layout.

In connection with the formation of cognitive representations of spatial layout, we have conducted only one experiment (Loomis, Golledge, & Klatzky, 2001) comparing different displays. It revealed that both virtual sound and synthesized speech were equally inefficient in allowing participants to build up representations of the layout of three landmarks during a short training session. However, it is likely that a blind traveler who traverses the same path day to day might be able to learn the locations of a few new points of interest every day, eventually leading to a quite detailed spatial representation of the environment. Basic research we have done indicates that spatial representations of a small number of locations acquired through language (e.g.,"two o'clock, 20 feet") are functionally similar to those acquired using auditory space perception, except that learning proceeds more slowly with language (Avraamides, Loomis, Klatzky, & Golledge, 2004; Klatzky, Lippa, Loomis, & Golledge, 2002, 2003; Loomis, Lippa, Klatzky, & Golledge, 2002). Thus, although synthesized speech might be less efficient than spatial displays for environmental learning, the ultimate cognitive representations acquired over many learning opportunities are likely to be quite similar.

A downside of virtual sound displays is the physical occlusion and perceptual masking of ambient sounds, including the high frequencies for echolocation, that are used by blind people for sensing critical features in the environment, like obstacles at head level. Although air tube earphones largely eliminate the problem of occlusion, the perceptual masking of environmental sounds may be greater than that associated with other out-of-ear auditory displays, like a speaker worn on the torso.

RESEARCH ON REMOTE INFRARED AUDIBLE SIGNAGE ((RIAS)

The inability to travel independently and to interact with the wider world is one of the most significant handicaps facing the vision-impaired (Golldege, 1993, p. 71). With the exception of walking, public transportation is often the only form of mobility available to persons who are blind or visually impaired. Especially difficult are many tasks associated with transit use and making transfers from either one vehicle to another or one mode of transportation to another. Lacking the ability to read printed schedules, process signs, identify buses and other transit vehicles, locate a transit stop, and quickly understand the function and layout of large areas (such as terminals), many visually impaired people have very limited activity and travel options (Golledge & Marston, 1999; Marston & Golledge, 2003). RIAS has been installed at, and had experiments conducted in many transit locations, including a large subway station (Crandall, Bentzen, Myers, & Brabyn, 2001). bus stops (Bentzen, Crandall, & Myers, 1999; Crandall et al., 2001; Golledge & Marston, 1999), moving bus vehicles (Golledge & Marston, 1999; Marston & Golledge, 1998), bus terminals (Golledge & Marston, 1999), and street intersections (Crandall et al., 2001; Marston, 2002). These and other experiments have demonstrated that RIAS is easy to learn and to use; RIAS also decreases search and travel times, provides for large reductions in navigational errors, and promotes a marked decrease in dependency on others. We next discuss results of an experiment (Marston, 2002) that combined most of these tasks, conducted at a large multimodel urban train terminal, adjacent to cab stands, bus shelters, and a light-rail station.

The San Francisco Caltrain station and its immediate surroundings were equipped with 51 RIAS transmitters in different locations. Each gave precise identity and directional cues to a person using a hand-held receiver. Thirty persons who were legally blind and were skilled urban travelers made five simulated transfers between the terminal and three other nearby modes of transportation. RIAS transmitters were installed at every entrance and exit at the terminal; at the boarding doors of all 12 train tracks; at within-building sites such as concession stands, the ticket window, bathrooms, and at nearby street intersections; and transit mode transfer points. Fig. 7.2 shows the main entrance area of the terminal, with concession stands, the ticket window, and the exit to 4th Street. The experiment site was a large and complex area that was well equipped with auditory cues, making it an ideal location to test how these cues could affect a variety of travel behaviors.

While navigating the various routes to find the next transfer point location, participants also had to locate various amenities and features along the way, such as a ticket window, a concession stand, or a restroom. In all, each participant had to find 20 locations, including places for crossing streets. Recorded data included times to complete the tasks, errors made, and the number of requests they made for assistance.

In this test, times needed by blind users to make the five searches and reach the transfer points with RIAS were about half of those consumed while using normal, unguided navigation skills. With RIAS, there was a large reduction in error, and many more participants completed each of the 20 tasks in the allotted time (4 minutes per location task). During the experiment, people could ask passersby for verbal assistance of any type (as is done in everyday life). This was done quite often when performing tasks using their normal travel strategies. However, when using RIAS, no participant asked any passersby for help. Thus among its advantages, RIAS affords far more independent travel.

The percentage performance decrement of the blind subjects relative to a sighted control was measured by $100 \times [(TT_{participant} - TT_{sighted}) / TT_{sighted}]$. This is a Relative Access Measure (RAM); (Church & Marston, 2003; Marston & Church, 2005) and allows an easy way to standardize the data and show the extra time penalty of travel, quantifying the effects of vision loss on travel behavior within the context of different tasks and locations. Only those participants that had no useful vision ($N = 20$) are reported

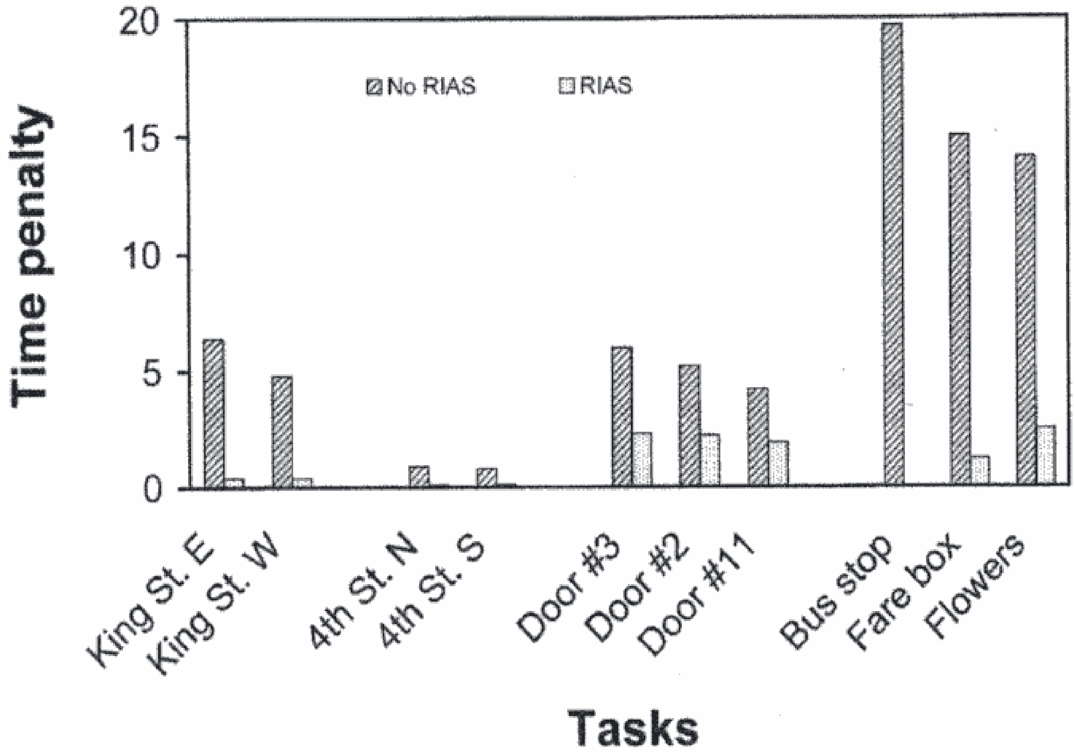

Fig. 7.7.
Results of an experiment using RIAS at an urban train terminal. Time penalty coefficient for 20 blind participants to complete tasks with and without RIAS compared to a sighted person. Locations and tasks shown are crossing two streets in both directions, finding three train platform doors, and finding a bus shelter, fare box and flower stand. From "Towards an Accessible City: Empirical Measurement and Modeling of Access to Urban Opportunities for Those With Vision Impairments, Using Remote Infrared Audible Signage, by J. R. Marston, 2002, doctoral dissertation, University of California, Santa Barbara. Copyright© 2002 by J. R. Marston. Adapted with permission

here. These data compare a group who used their regular skills (no RIAS) and those who used RIAS.

Figure. 7.7 compares the time it took the blind participants to complete various tasks, compared to a sighted person who was familiar with the layout. A percentage decrement of zero means that the blind person was able to complete the task in the same time as the sighted person. High values show that performance was greatly impaired without vision. Participants crossed two different streets two times each. The first two sets of bars on the figure show King street, which had high-speed traffic and many cars turning in front of the traveler. Without RIAS, it took much more time to cross that street, whereas with RIAS, the task was almost as quick as a sighted traveler. Fourth street was much easier to cross in both conditions, but, again, the times were faster when using RIAS. The slow times for the No-RIAS condition were caused by having to wait and listen while trying to understand the traffic and turning patterns. With RIAS, participants knew immediately when the "Walk" sign was activated and they just followed the directional beam to the opposite corner, safely staying in the crosswalk. In the other tasks shown, participants were far from the transmitters when they started their search and travel, and so they had to explore the environment and search for signs as they walked. Participants had to find three different train platform doors at various times in the experiment; these three attempts to find the doors were difficult without RIAS and the graph shows how much faster it was when using RIAS. The right side of the graph shows three locations that are not sited consistently. The bus shelter, which had no tactile or braille markings; the fare box at the light rail station, which was located off to the side of the path of travel; and the flower stand in the terminal were all shown to be very hard to find without sight. Travel times to find these difficult locations were much faster with the additional cues provided by RIAS.

The train station results highlight the valuable benefit of using additional and accessible cues that can aid a blind user to navigate through unknown or complex environments. Other results from field tests and interviews (Marston, 2002; Marston & Golledge, 2003) revealed that persons with vision problems said they would travel more often and to more places with RIAS, rated the difficulty of various transit tasks as much lower when using RIAS, and indicated that they would be more likely to make transit transfers if RIAS cues were available. Still other results showed that the additional RIAS cues allowed them to form superior mental representations of the area and to cross streets with straighter paths and in, ways promoting greater safety.

CONCLUDING REMARKS

Compared to sighted individuals, visually impaired people are at a disadvantage when it comes to wayfinding, both in sensing the near environment and in navigation. Sensing the near environment for obstacles and hazards is effortful and error prone, even with the long cane and echolocation. For navigation through larger scale spaces, visually impaired people lack much of the information needed for planning detours around obstacles and hazards and have little information about distant landmarks, heading, and self-velocity, information that is essential when traveling through unfamiliar environments. Over the years, many

Electronic Travel Aids (ETAs) have been developed to assist both with navigation and with sensing the near environment. Although it might be argued that providing visually impaired people with wayfinding technology may undermine their maintenance of other learned techniques, the potential gain in capability and safety is likely to outweigh this cost.

In recent years, most ETA research and development has focused on the navigation function. Two ETAs that are indeed proving helpful with navigation are GPS-based navigation systems and RIAS. Our chapter reviews recent research demonstrating the effectiveness of RIAS for pedestrians negotiating an urban environment and research evaluating the relative effectiveness of different display interfaces for GPS-based navigation systems. The latter research shows high user satisfaction and excellent route following performance with several types of spatial displays that provide direct perceptual information about important environmental locations.

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