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Remote infrared signage evaluation for transit stations and intersections

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Abstract--Opportunities for education and employment depend upon effective and independent travel. For mainstream society, this is accomplished to a large extent by printed signs. People who are print disabled, visually impaired, or totally blind are at a disadvantage because they do not have access to signage. Remote infrared signage, such as the Talking Signs® (TS) system, provides a solution to this need by labeling the environment for distant viewing. The system uses a transmitting "sign" and a hand-held receiver to tell people about their surroundings. In a seamless infrared signage environment, a visually impaired traveler could: walk safely across an intersection to an ATM or fare machine, from fare machine to bus stop, from bus stop to bus; from bus to building, from building to elevator, from elevator to office, from office to restroom, and so forth.

This paper focuses on two problems that are among the most challenging and dangerous faced by blind travelers: negotiating complex transit stations and controlled intersections. We report on human factors studies of TS in these critical tasks, examining such issues as how much training is needed to use the system, its impact on performance and safety, benefits for different population subgroups and user opinions of its value. Results indicate that blind people can quickly and easily learn to use remote infrared signage effectively, and that its use improves travel safety, efficiency, and independence.

Key words: *audible, blindness, infrared, low vision, navigation, orientation, rehabilitation, remote signs, signs, talking signs.*

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INTRODUCTION

Assistive Technologies for Orientation and Mobility

The printed sign is a major aid to orientation that is taken for granted by sighted travelers but unavailable to blind persons. Braille signs do not provide the same functionality; before they can be read, they must be searched for and found. The purpose of the present study was to evaluate remotely readable infrared signage for blind persons. We report here on the training requirements and efficacy of this technology in subway stations and controlled intersections.

The National Center for Health Statistics estimated that 4.3 million people in the US have difficulty reading the newspaper with their corrected vision--a functional definition of perceived limitations termed Severe Visual Impairment (1). Importantly, an additional 2.3 million people have a disability that involves the loss of intermediate or distant vision. From these statistics, we may conclude that a total of 6.6 million people may be unable to read printed street signs or signage inside buildings at normal viewing distances. Data from the Bureau of the Census put the figure for this same level of impairment at 9.7 million people (2). There is another important way of looking at the demographics of blindness. Estimates of tested acuity classify 1.1 million people as Legally Blind, defined as corrected acuity of 20/200 or less and a visual field of $<20°$ (3).

Many other disabilities prevent persons from reading print. In addition to people who may not be able to see the print, there are many stroke, head-injured, autistic, and dyslexic (or even just educationally impaired) persons who may not be able to assimilate printed language even though they can see the page. Many of them can accept this information through speech, that is, by having print read aloud to them.

In modern society, independent travel is a prerequisite to successful education and employment. For blind persons, independent travel involves not only finding a safe path through the environment, but also being able to find landmarks and orient themselves: challenging tasks that have been the object of many efforts to develop assistive technology to make some or all aspects of travel easier. The following is a summary of these developments.

Mobility Devices

Technology to assist blind travelers can conveniently be categorized as Orientation devices and Mobility devices. Historically, most efforts focused on the *mobility* part of the problem of helping the blind traveler to detect objects, hazards, and boundaries in, near, or alongside his path, to avoid collisions, and to steer a straight and safe course through the immediate environment. A family of mobility aids known as Electronic Travel Aids or ETAs has resulted. These vary from simple obstacle detectors to more complex environmental sensors. For example, the Mowat Sensor is a hand-held ultrasonic device that uses a vibratory code to warn of the presence and range of an object in its beam. At the other end of the spectrum is the head-worn Sonicguide that processes broad-band ultrasonic reflections so that the pitch of the received signal indicates range, the timbre indicates the nature of the target, and the inter-aural amplitude difference indicates direction. The Laser Cane uses laser beams to detect objects, and incorporates the ability to warn of drop-offs. Another mobility aid is the Sonic Pathfinder, the subject of another paper in this issue.

Orientation and Navigation Devices

Technology to address the broader orientation and navigation aspect of the Orientation and Mobility (O&M) problem has a shorter history, and devices in this category have only recently entered commercial production. The infrared Talking Signs® (TS) system here examined was developed as an environmental labeling system to allow blind travelers to locate and identify landmarks, signs, and facilities of interest in the environment. It uses speech messages stored in infrared transmitters as labels, and the user's hand-held receiver converts the transmissions back into speech. The infrared beam pattern provides control of range and coverage, and the directional nature of infrared light allows the user to accurately locate each sign.

Since this concept was put forward in 1979, a number of other technologies have been proposed for the orientation problem, though only infrared signage systems are currently available. The Sonic Orientation and Navigation Aid (SONA), a prototype environmental-labeling system with sound sources triggered by a garage-door-opener transmitter, was developed by the VA concurrently with TS (4). Variants of this concept using speech labels triggered by a user-carried device include the REACT system (5), The Open University device (6), and the Acrontech International system.

A number of systems using radio transmission of speech messages to receivers carried by the user have been proposed. Verbal Landmark® demonstrated a system in 1993 in which a portable receiver detects messages transmitted from an electromagnetic loop. The Fanmark "Locator," advertised in 1993, employed consumer receivers to pick up digitally recorded voice messages on an unused FM band. A proposed Chico system (7) would use transceivers triggered by a user-carried speech output transceiver. A proposed NYNEX system (8) would employ a grid of radio frequency transmitters located on tall structures and street corners, to which the user would orient and triangulate using a directional receiver and headphones.

Several projects have explored Global Positioning System (GPS) applications for assisting orientation. Loomis (9) has systematically studied this possibility combined with externalized sounds for locating environmental features. A derivative of this approach has been developed by Arkenstone, Inc. (10) whose prototype uses a notebook computer packaged with the GPS and synthetic speech in a backpack. A GPS enhancement was proposed for the Nynex system, with speech recognition to respond to user inquiries. The project of the Royal National Institute for the Blind, Mobility of Blind and Elderly People Interacting with Computers (MoBIC), used GPS technology and proposed a protocol, based upon ISO's Open Systems Interconnection architecture (1978), to interface different technologies that could be used for orientation and navigation (11).

An infrared system ("Pathfinder," modeled on the TS system) is currently being evaluated in a London subway station (12). The OPEN (Orientation by Personal Electronic Navigation) project set out to investigate the feasibility of a networked multilingual system of infrared transmitting signs (1994) incorporating real-time information for subway applications (13).

Intersection-Specific Technology

Accessible traffic signal systems are gaining prominence with at least 11 products readily available to cities. These devices variously provide information about the light cycle, the street name and direction of travel, street geometry, location of the pedestrian crossing actuator, and location of the opposite corner (14). Devices can be audible, using speaker or infrared transmission to communicate by way of spoken messages, tones, or other unique sounds. Other devices are tactile, with either raised lines to communicate properties of the intersection or vibrators to indicate the light cycle. Perhaps the greatest improvement in the traditional audible speaker system is circuitry that automatically adjusts the output volume depending upon the ambient sound level.

The Present Studies

The purpose of this article is to report on the training requirements and evaluation findings for the TS system in two vital areas of travel: transit stations and intersections. These two aspects are arguably the most critical in the blind person's daily travel from home to work. Being able to use public transit is often a prerequisite for getting to work or school, and a large underground station presents a daunting challenge even to the sighted traveler unfamiliar with it. Crossing intersections is another critical factor in travel; this is where most accidents and fatalities occur, and dangerous situations occur with very high frequency. If infrared signage can enhance performance in these two situations, it is very likely to be able to assist other less critical tasks in daily travel where signage information is needed.

Developed at the Smith-Kettlewell Rehabilitation Engineering Research Center, the TS system has now undergone several years of intensive human factors testing (15-20). This research has also spawned a number of variants developed for specialized situations (transit systems, intersections, public terminals, and the like). In a suitably equipped environment, a visually impaired traveler could: walk safely across an intersection to an ATM or fare machine, from fare machine to bus stop, from bus stop to bus, from bus to building, from building to elevator, from elevator to office, from office to restroom, and back. Within the past 4 years, approximately 800 TS units have been installed in San Francisco.

In the TS system, transmitters placed at or near the locations of signs send out a spoken message on a beam of infrared light. The prerecorded human speech frequency modulates (FM) a 25 kilohertz carrier. The blind user carries a receiver (a small hand-held box containing photodetector, FM discriminator, amplifier, and internal speaker) that, when activated by a push button, translates the message back into spoken language. Users hear the digitally recorded message whenever the front of the receiver is pointed in the direction of the infrared transmitter. The beam starts out at a point in the infrared diode and spreads in a cone-like fashion, becoming wider as it moves away from the source (**Figure 1**). Adjustment of the transmitters and the LED arrays ("tuning" of the system) allow control of the maximum distance at which the TS message is received, the direction from which the message is transmitted, and the area the message covers.

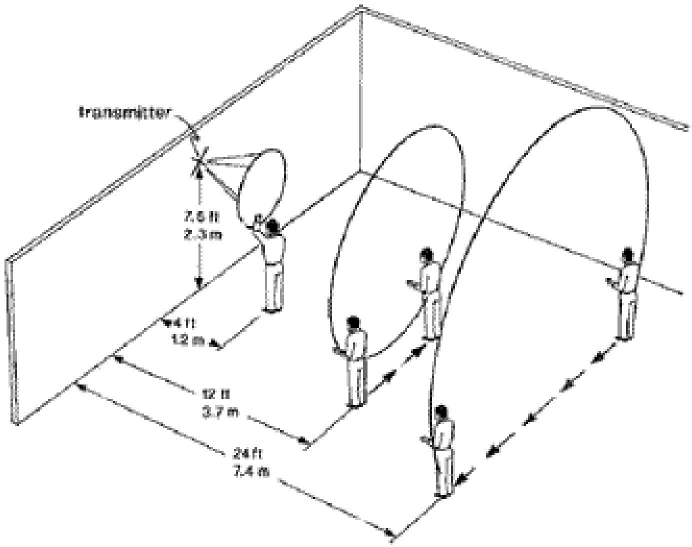

Figure 1. *A user standing in the cone-shaped transmission field of the LED array. Circles indicates how much of the user's body is illuminated by the message at each of three distances from the TS transmitter.*

METHODS

Underground Transit Study

The first study was designed to determine whether blind travelers could use TS to navigate through a subway station, and to examine the amount of training needed to achieve proficiency in the use of the technology (21).

Remote Signage Installation

Ninety-three transmitter signs were located throughout the three levels of the Powell Street transit station in San Francisco, which has BART (Bay Area Rapid Transit) trains on its lower level, Muni (San Francisco Municipal Railway) light rail trains (streetcars) on the second level, and station agent booths, faregates, stairs, escalators and elevators, shop entrances, restrooms, change machines, telephones, and corridors to other parts of the station on the upper level (**Figure 2**). On the train platforms, TS enabled users to locate various stair and escalator exits, elevators, the station agent, and public telephones, to determine which trains stop on each side of the platform, and to locate the main boarding areas for each train. All Signs were approximately 3 m high, either on a wall or suspended from the ceiling, usually in the vicinity of printed signs. Transmitters were adjusted for a range of 3.1 to 18 m, depending on the function and location of each sign. The stand-alone transmitters employed for this project incorporate individual recording circuits and LED arrays, and are connected to remote, modular power supplies at locations convenient to the 110 V mains.

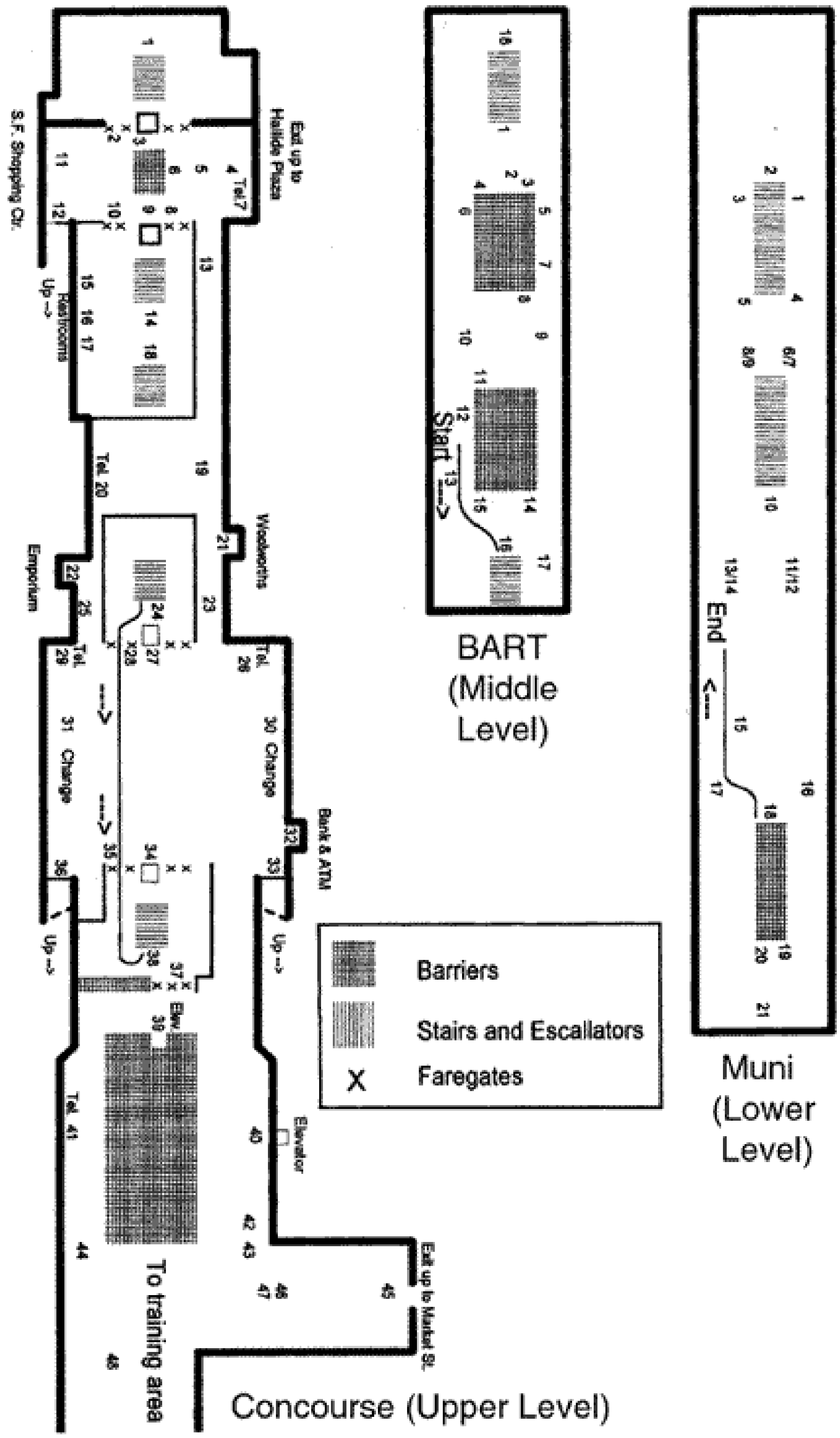

Figure 2. *Floor plan of tri-level transit station, site of the demonstration project. Numbers on map designate the location of each of the 93 Talking Signs transmitters. Following the arrows from the "Start" label on Muni platform (at sign #13) through the Concourse level to the "End" label on the BART platform (at signs #13/14) demonstrates an example "Hard" test route.*

Subjects and Training

Three groups of 12 blind subjects, aged 18-62 were balanced using intake survey data on vision impairment history, age, educational background, O&M training, usual travel aid (cane vs. dog guide), knowledge and use of the local transit system, health status, prior TS experience, and spatial problem-solving skills. Group I received 1 to 2 hr of training, until they achieved successful independent travel on 6 practice routes in a quiet end of the station. Practice routes were 15 to 61 m long and required the use of 2 to 4 TS messages. A typical task and instruction was: "Go to the turnstiles into BART. Tell me when you're there." Group II received 15 to 30 min of training, or until two out of the six practice routes were completed with verbal assistance only. Group III received only prior text instructions on how to use TS, a receiver, and a practice transmitter that provided a beeping signal when the receiver was pointed toward it.

Testing and Data Recording

Test routes were constructed to encompass three levels of complexity. For the easiest route (requiring use of two key signs), subjects were started from locations facing (and within range of) signs relevant to reaching the destination. Both signs were close together along the path of travel so that as soon as the subject passed one sign, another was within range of the receiver. For both the medium difficulty (three key signs) and hardest routes (five to seven key signs), subjects were started from locations where relevant signs might not be immediately available, and the signs were much further apart. **Figure 2** includes a sample difficult route, one taking transit patrons at Powell Station from the Muni inbound train (near TS #13, Muni level) to the BART Richmond-bound train.

Each subject was required to complete successfully two consecutive easy routes without intervention in order to progress to medium routes. To progress to hard, the subjects were required to independently complete any two routes within the medium level. If subjects gave up or failed to complete a route, their performance was classified as "Failed to Complete." The same set of routes was used for all participants, but not all subjects needed all routes to reach criteria for advancement. Subjects attempted as many routes as possible within a 1-hr test period. The following data were recorded:

- Routes attempted
- Routes successfully completed
- Routes not successfully completed

Problems along each route:

- Poor grip on receiver
- Failure to understand concept of pointing
- Failure to scan fully, at appropriate angle of elevation
- Failure to monitor progress toward sign
- Misinterpretation of message
- Perservation in ineffective problem-solving strategy
- Confused by reflected signal

Potential safety problems along the way:

- Collisions
- Failure to detect drop-offs
- Walking backwards
- Scanning while walking
- Scanning while walking along platform edge
- Use of receiver while negotiating stairs or escalator

An O&M specialist accompanied all subjects for safety.

Study Follow-up:

Following the testing, all Group I subjects agreed to use TS in Powell Station for 4 mo. Eight members of Group II, and six members of Group III received additional training after the initial testing and agreed to use the system twice monthly for 4 mo.

RESULTS

Successful Route Completion

A route was considered to be completed successfully if the subject required no assistance in order to reach a destination other than that provided by TS messages.

Table 1 illustrates that more Group I subjects (most highly trained) succeeded in traveling medium and hard routes. For example, 8 Group I, 5 Group II and only 4 Group III subjects successfully completed two hard routes. Thus, amount of training appears to be related to the level of route difficulty subjects were able to accomplish in a given period of time. A Chi square test, by training group, of the number of subjects who successfully completed two hard routes versus those who did not (2 df, Chi square=2.95) failed to reach statistical significance. However, statistical modeling of the data shows that had there been additional subjects in each group, resulting in similar proportions of successful trials for each group, it seems likely that the Chi square statistic would have achieved significance. At any rate, while more subjects who received the most training succeeded at traveling more difficult routes than subjects who received lesser amounts of training, even subjects with no individual training were able to benefit from the additional information provided by the TS system.

Table 1.

Number of participants who completed two or more routes at each level of route difficulty within the 1-hour test period.

	Easy		Medium		Hard	
Group	**A[1]**	**B[2]**	**A[1]**	**B[2]**	**A[1]**	**B[2]**
I	12	12	11	9	10[3]	8
II	12	12	10	7	6	5
III	12	11	9	7	8[3]	4
Total	36	35	30	23	24	17

[1]**A**=Attempted; all subjects attempted easy routes. Subjects who successfully completed two consecutive easy routes progressed to medium routes. Subjects who successfully completed any two medium routes progressed to hard routes if there was time remaining. [2]**B**=Succeeded; subjects succeeded in independently traveling at least two routes within the time available. [3]One subject each in groups I and III had time to attempt hard routes although they had not successfully traveled two medium routes.

Table 2 shows that participants reached their destination on 81 percent of the easy routes they attempted, 88 percent of of the medium, and 92 percent of the hard routes. This should not be construed to indicate that the technology works best for more difficult routes, but rather that subjects who attempted each higher level were those who were most likely to succeed. Overall, 86 percent (169/196) of attempted routes were successfully completed. On those successfully completed, subjects had to pick up, understand, and correctly use the information provided by TS transmitters on a total of 500 occasions (2.96 transmitters per route). On each occasion, if the information was not picked up, understood, and correctly used, the subject would not have completed a route successfully. Had TS transmitters been unavailable, subjects would have had to get some form of information or assistance, or to make their travel decisions on less definitive information 500 times.

Table 2.

Route completion based upon level of training for Easy, Medium, and Hard routes.

Group	**Subs[1]**	**Routes[2]**	**Succeed[3]**		**Fail[4]**	
			Easy Route			
I	12	29	24	83%	5	17%
II	12	33	28	85%	5	15%
III	12	33	25	76%	8	24%
Total	**36**	**95**	**77**	**81%**	**18**	**19%**
Low Vis	10	24	20	83%	4	17%

Medium Route

I	11	22	19	86%	3	14%
II	10	20	18	90%	2	10%
III	9	18	16	89%	2	11%
Total	**30**	**60**	**53**	**88%**	**7**	**13%**
Low Vis	9	17	15	88%	2	12%
			Hard Route			
I	10	18	17	94%	1	6%
II	6	11	11	100%	0	0%
III	8	12	11	92%	1	8%
Total	**24**	**41**	**39**	**92%**	**2**	**5%**
Low Vis	6	12	12	100%	0	0%

[1]Subjects: the total number of subjects who attempted routes at this level; [2]Routes: the total number of routes attempted by those subjects who traveled routes at this level; [3]Succeed: number and percentage of subjects who reached the destination successfully, without need for assistance or restart; [4]Fail: number and percentage of subjects unable to reach destination successfully (either gave up or required assistance or restart); [5]Low Vis=Low vision subjects.

Reasons for Difficulty or Failure to Complete Routes

There were eight identifiable reasons that participants had difficulty completing routes independently (**Table 3**). Poor use of the TS receiver, namely failing to scan fully with the receiver held level, and failing to monitor progress toward transmitters at all, account for approximately half (49 of 99) of the difficulties tallied. For these items there is a clear effect of training, with a majority of members of Group III showing difficulties in one or both of these areas. Participants who scanned ineffectively typically either failed to scan at all or did not scan a full 180° about the body. Participants who failed to monitor their progress typically found signs and turned toward them, but then attempted to locate relevant landmarks without further systematic use of their receivers. Three other problems appear to be associated with lack of training: understanding the concept of pointing, misinterpreting messages, and a poor way of holding the receiver.

Table 3.

Reasons for difficulty in successfully completing routes.

Group	Scan[1]	Monit[2]	Point[3]	Mess[4]	Grip[5]	Explor[6]	Reflect[7]	Spatial[8]
I	2 (2)	3 (5)	1 (1)	---	---	3 (5)	4 (4)	1 (1)
II	4 (6)	3 (5)	---	1 (1)	---	5 (10)	3 (5)	3 (5)
III	7 (19)	5 (12)	4 (4)	3 (3)	2 (2)	4 (7)	1 (1)	1 (1)
Total	12 (27)	11 (22)	5 (5)	4 (4)	2 (2)	12 (22)	8 (10)	5 (7)

The first number in each cell represents the number of participants observed to have this difficulty. The second number, in parentheses, represents the total number of times that difficulty was tallied. [1]Scan=ineffective scanning; [2]Monit=failure to monitor; [3]Point=no concept of pointing; [4]Mess=misinterpretation of message; [5]Grip=poor grip; [6]Explor=ineffective exploration; [7]Reflect=problem with reflections; [8]Spatial=apparentl poor spatial reasoning.

Individual Differences

Of six *dog guide users,* four completed all routes--a higher percentage than for the entire subject pool--indicating no incompatibility between TS and use of a dog guide. Results from the six persons with *hearing loss* and the 10 participants who reported at least enough *sight* to tell what direction light is coming from conformed closely to the pattern observed for all participants.

Posttesting

Eleven participants (10 in Group I and 1 in Group II) returned for posttesting following 4 mo unsupervised travel using the TS system in Powell Station. Beginning by traveling medium routes, the participants progressed to hard routes after successfully completing two. Of the 11, 8 completed at least 2 medium and 2 hard routes. Three who had had some difficulty completing routes at pretest also had difficulty at posttest. During travel, use or nonuse of each relevant transmitter was noted and subsequently discussed with that participant to determine why particular messages were or were not used. Participants looked for and found 284 of 297 messages at decision points on routes traveled at posttest, even though they were familiar with the routes. Thus the remote signage system was desired by users for negotiating familiar routes as well as for traveling in unfamiliar areas. Further insights into the continuing usefulness of the remote signage system even in familiar areas was obtained in the Focus Group.

Focus Group

In order to supplement the objective data with subjective information and gain more insight into improving instructional procedures and in enhancing the design and implementation of the technology, a focus group composed of 2 groups of 5 participants (8 from Group I and 2 from Group II) was convened 4 mo after the initiation of the study. These participants had actually used their receivers in Powell Station from once to 47 times during the 4 mo. To guide the discussions, 12 questions were developed to elicit information on the effect of TS on travel, ways to use the receiver, and recommendations on training. Responses are summarized below.

Talking Signs Versus No Talking Signs

Participants were enthusiastically unanimous in finding that travel in a station with TS was easier and more enjoyable than travel without it. Many benefits were mentioned, such as:

- "I don't have to stop and ask for help."
- "I don't have to rely on people who point; TS are verbal."
- "When I don't have TS I need reassurance."
- "With TS, I have a better sense of orientation."
- "With TS, I can discover all the facilities such as alternative exits, phones, restrooms, and ATM's in the station. Otherwise they're out of reach."
- "I don't have to remember so much."
- "I can make the correct [wayfinding] choice each time; I don't have to analyze and infer and hope I get it right."
- "I'm less tired. I don't have to suffer to get around."

Three participants who previously avoided Powell Station because of its size and complexity now prefer using it as a transfer station instead of other options they used to prefer.

Most Important Thing to Emphasize in Training

Participants stressed that TS must be understood as providing additional information for decision-making, not for safety. Users must rely on traditional mobility techniques and aids, as well as on good spatial reasoning when using TS.

Searching with the Receiver while Walking

During training, participants were told not to search back and forth with the receiver while they were walking. We were concerned that the effort involved in searching with the receiver might take needed attention away from mobility skills, especially for persons who were not skilled in use of the technology nor familiar with the environment in which they were traveling.

- All participants recommended that users be taught to stop and search.
- All agreed that the greatest safety was provided by stopping to search.
- All agreed that at times, particularly when they were in somewhat familiar environments, they might now search back and forth while walking.
- Participants using dog guides or having low vision are more likely to search while walking.

Recommended Amount of Training

Participants were in agreement that individual instruction was very helpful but that amount of training needed would vary with the general travel proficiency and spatial ability of users. No participant thought that there should be any minimum amount of training required before an individual could obtain and use a TS receiver independently. All participants felt that they became more proficient in use of TS as they continued to use the technology in normal travel situations.

Recommended Way to Provide Training

All participants were in agreement with the following recommendations:

- Training in use of TS should be included in instruction in orientation and mobility.
- It should not be required that training in use of TS be given only by orientation and mobility specialists.
- Training provided by persons who are not orientation and mobility specialists should be given only to users who are already proficient in independent travel and safety.
- Training can be provided by persons who are visually impaired or blind.

One participant summed up his feelings about using the TS system in Powell Station in this way: "In this station I am truly equal!"

Intersection Study

The purpose of this study was to determine the effects of TS on street crossing performance at complex signalized intersections. Twenty persons having very little or no vision were asked to cross four complex signalized intersections in the Civic Center area of San Francisco under two conditions: with and without information provided by TS. All crossings were made under normal daytime traffic conditions (22).

Remote Signage Installation

A TS module has been developed for attachment to the visual pedestrian signal, or "ped head" of signalized intersections. Twenty-nine experimental units were installed at intersections in San Francisco's Civic Center area. The unit's messaging strategy (encompassing wording, location, direction, and beamwidth) has evolved over the past 6 yrs from early prototypes and field tests, followed by a focus group of blind pedestrians who had used the prototype system, leaders of agencies serving blind people, teachers of blind persons, O&M Specialists, and rehabilitation engineers. The messaging parameters established by this Focus Group were organized into a survey and presented to 46 blind travelers, O&M specialists, and technical specialists. Members of the national survey group were offered various permutations of messages from which to select preferences. Data from the 29 respondents were analyzed in order to establish the most favored message structure and content.

In the resulting design (**Figures 3** and **4**), as users come within 46 m of an intersection, their receivers provide them with orientation information, such as: "Traveling East on the zero hundred block of Larkin Street towards Grove Street." As users near the curb, a pedestrian crosswalk indicator message tells them the condition of the pedestrian signal. It repeats, for example, "Wait...Grove Street" or "Walk Sign....Grove Street" through the corresponding signal phase. The focus group and survey recommended the term "Walk Sign" instead of "Walk" to avoid the perception of a possibly dangerous instruction or command to begin walking; it only indicates the signage information available to the sighted pedestrian. The cadence of the two-word message is also easily distinguished from the single-word warning.

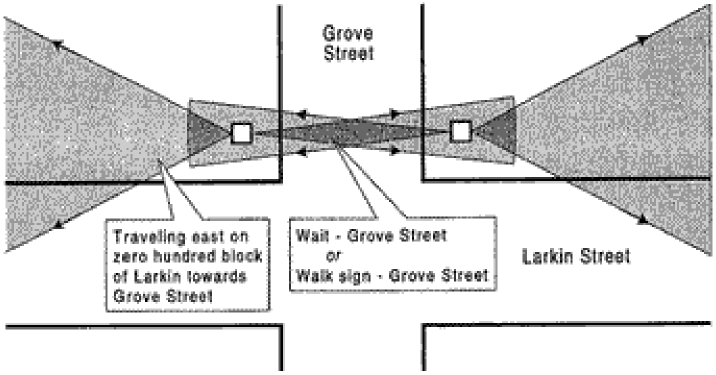

Figure 3. *Birds' eye view of an intersection with TS units installed. Each unit contains two transmitters: A wide-beam infrared transmitter gives ``directional'' information to pedestrians as they approach the intersection. A narrow-beam ``crosswalk indicator'' message tells pedestrians the status of the ``Walk/Wait'' signal.*

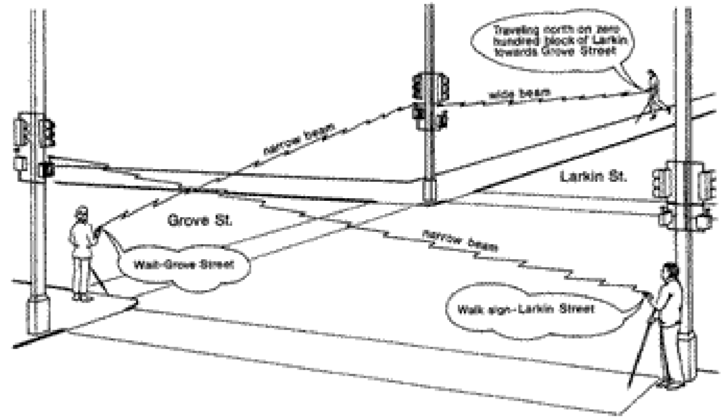

Figure 4. *Configuration of a typical TS intersection installation showing messages available to users at different phases of the street crossing task.*

In addition to the messages described above, participants had access to an Auxiliary Message (stored in a palm-sized unit carried on a waist strap) with specific information about the particular intersection. This was functionally equivalent to a second channel originating from the opposite corner (pedestrian crosswalk indicator) and was activated by a switch on the receiver. If this were to be implemented commercially, the information would be transmitted from the ped head either as a second channel or on the same channel as the conventional messages.

The experiment took place at one crosswalk at each of four intersections in San Francisco's Civic Center area. Three were plus-shaped (four-way), and one was T-shaped (three-way), and all had fixed, timed traffic lights (**Figure 5**). For example, one plus-shaped intersection (at Grove and Larkin Streets), was 89 feet wide. The curb ramp was not well aligned with the crosswalk, which was straight ahead (10° deviation). The auxiliary message was: "This is a plus-shaped intersection. It is controlled by a fixed timed traffic light in which the walk phase begins with the onset of traffic on Grove. Larkin has two-way traffic on this side of Grove, but one-way traffic coming toward you on the opposite side of Grove. The San Francisco Public Library is across Larkin, and has entrances on both Larkin and Grove."

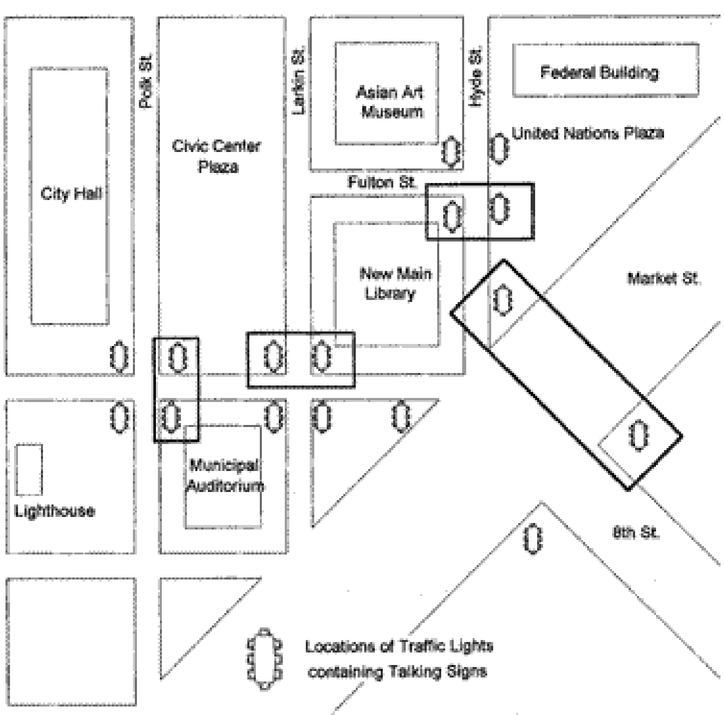

Figure 5. *Twenty-nine TS units were installed atop pedestrian crossing signals in the Civic Center area of San Francisco. Test intersections are marked by rectangles.*

Subjects

Participants consisted of 15 males and 5 females, aged 21 to 62, who were independent travelers. All were visually impaired and unable to see pedestrian signals or painted crosswalk lines, or to visually identify the curb line. Most participants considered themselves to be good to excellent travelers. Two considered themselves to be fair to poor travelers but did travel some familiar outdoor routes independently. Two used dog guides as their preferred travel aid, and 18 a long cane. Four had mild-to-moderate hearing loss; one of these used a dog guide. Although some participants had previously traveled in the area of the experiment, care was taken to provide them with minimal opportunity to become aware just which intersections they were crossing. They were guided from one intersection to the next by circuitous routes.

Procedure

Based on the information gained from the underground transit study, it was determined that this relatively uncomplicated outdoor task required only a very limited amount of training in the use of the receiver. Thus, participants received approximately 10 min of training in using TS at a crosswalk that was not subsequently used in the experiment. Participants practiced obtaining information from both the primary and auxiliary messages as they crossed at the practice crosswalk at least twice. During training and the experimental trials, subjects were accompanied by an O&M instructor at all times to ensure safety.

Subjects were guided to a starting location 7.5 to 15 m from the street to be crossed. For both TS and unaided conditions at the two plus-shaped intersections, the only instruction was "Cross the street that's in front of you." For the T intersection, the instruction was "Find a mid-block crossing and cross the street on your right." For the fourth intersection, participants were asked to "Go to the boarding platform that is in the street in front of you." Participants were divided into two groups, balanced as nearly as possible for reported travel ability, additional disability, and the use of cane or a dog, and the order of the trials was counterbalanced within and between these groups to minimize practice effects.

In the TS conditions, participants were asked to listen for identifying information as they approached the intersection. When they reached the intersection and decided that they were well positioned at the crosswalk, they switched to the secondary channel and listened to the Auxiliary message, finally they switched back to the primary channel and kept the on button depressed until they received a message saying "Walk sign, (name) Street." They then listened for traffic to be sure the way was clear, and initiated their crossing. Participants were asked not to use their TS receivers while they were in the street.

In all conditions, participants were asked to make the crossing as if no experimenters were present who would assure their safety. However, they were free to ask for assistance at any time. After each crossing, they were asked what information they used to determine their heading, what information they used to determine when it was safe to cross, what the shape of the intersection was, and what the traffic control system was at that intersection. They were given no feedback regarding their crossing. They were then guided, by a circuitous route, to the next crosswalk.

During each street crossing the following types of data were collected by an experimenter.

Safety

1. During what part of the signal cycle did the participant start the crossing? Under what traffic condition/s did the participant start the crossing?

Precision

2. Where did the participant begin the crossing, relative to the cross walk and curb ramp?
3. In what direction was the participant aligned when he/she began the crossing, relative to the crosswalk and the parallel street?
4. Where did the participant end the crossing, relative to the cross walk and the desired corner?

Independence

5. Did the participant request assistance to find the crosswalk?

6. Did the participant request that the experimenter tell him/her when it was safe to begin crossing, or did the experimenter provide this information after the participant had failed to initiate a crossing during three successive walk intervals?
7. Did the participant request assistance crossing the street, or did the experimenter intervene to prevent possible injury?

After each crossing participants were asked

8. What information did you use to align yourself before you crossed the street?
9. How did you know when it was safe to cross the street?
10. What shape do you think the intersection was?
11. What kind of traffic control do you think the intersection had?
12. What other information did you find useful or necessary in planning this crossing?

After completing all crossings, subjective data were obtained from participants regarding their evaluation of the usefulness of different features of the system.

No data were collected on conflicts with turning vehicles, as number of conflicts was not expected to be related to use of TS information.

Overall Performance

Percentages of successful crossings with and without TS were computed (**Figure 6**). The definition of success varied by measure. For example, in the measure of safety, participants either did or did not begin crossing within the walk interval. If they asked the experimenter to tell them when it was safe to cross, this was statistically treated as missing data for this measure of safety because there was no way to determine when participants would have started crossing in the absence of assistance. In another example, in the measure of Precision (Did the participant end up within the crosswalk at the opposite corner?) participants either did or did not end up within the limits of the marked crosswalk at the opposite corner when they completed their crossing. If they required assistance for the crossing, this was also statistically treated as missing data for this measure. For measures of independence, success meant not requesting assistance or information or requiring experimenter intervention for safety. ("Lack of success" was those trials which were treated as missing data in measures of precision.) For the question regarding the shape of the intersection, participants were expected only to identify intersections as plus- or T-shaped. For the question regarding the type of traffic control, participants were expected only to know that each intersection was controlled by a traffic signal.

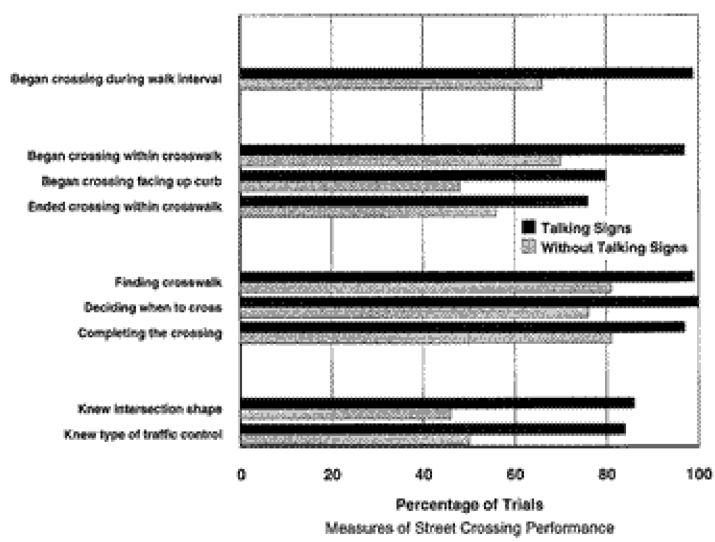

Figure 6. *Percent of successful crossings. Nine measures in four categories, with and without TS.*

Performance by subject, for each of the nine measures of street crossing success, with and without the use of the TS system (TS/non-TS) was tabulated (**Figure 7**). For each subject, for each measure, if more crossings were successful with TS than without, subjects were scored +1; if more crossings were successful without TS than with, subjects were scored -1; if success was the same with or without TS, subjects were scored 0. For each subject, those scores were then summed. Nineteen of 20 participants were more successful on more measures TS than non-TS. One subject had a nearly flawless performance on every measure. This tabulation was the basis for a binomial (step) test that compared each subject with her or himself on each of the nine measures at each of the four intersections, in both the TS and non-TS conditions. A statistic was computed to determine the probability that differences between performances TS and non-TS were significant. The probability of having 19 out of 20 subjects be more successful with TS than non-TS due to chance alone approaches zero.

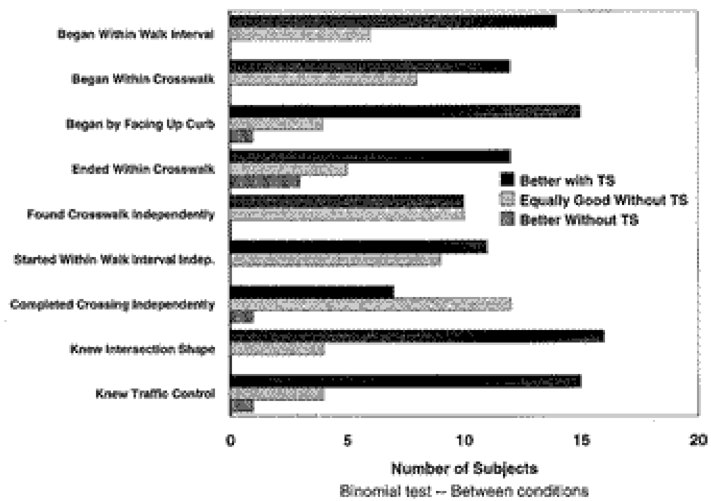

Figure 7. *Binomial tests for nine measures of street crossing performance with and without the use of the TS system. Participants were significantly more successful ($p<0.05$) on eight of the nine measures when using TS than when not using TS. The only measure in which there was not a significant difference in performance attributable to the use of TS was the need for assistance to complete a crossing.*

There were 80 crossings with, and 80 without, TS. On all but one measure, a higher percentage of trials was statistically successful ($p<0.05$) when TS than non-TS (**Figure 8**). The only measure on which there was not a significant difference was the need for assistance in completing a crossing ($p<0.07$). Of interest in this regard, however, is that although participants were told and encouraged to ask for assistance on any crossing, with or without TS, if they would not normally make such a crossing without assistance: following a number of crossings without TS information, participants said they would not have attempted the crossing if experimenters had not been accompanying them. This remark was not made following any trials on which TS information was used.

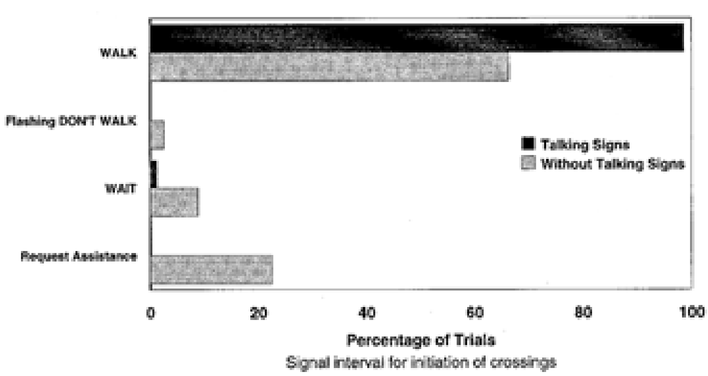

Figure 8. *Percentage of trials on which participants initiated their crossings on each interval of the signal cycle, with and without TS.*

Safety

With TS, participants started crossing during the walk interval on all but one trial, while non-TS participants independently started crossing during the walk interval on only 53 of 80 trials and started during the flashing don't walk or wait intervals on 9 trials. NonTS participants requested that the experimenter tell them when it was safe to cross on 22.5 percent of crossings versus zero when using TS. On three of the five trials in which participants started during WAIT, and one trial on which the participant started during the clearance interval, the participants were unaware that they were crossing at a signalized intersection. All these trials occurred in the non-TS condition.

Participants reported using eight different clues to determine when it was safe to cross (**Figure 9**). A total of 133 clues were reported in the TS condition, 59 of which were in addition to those provided by TS messages. In the non-TS condition, 79 clues were reported.

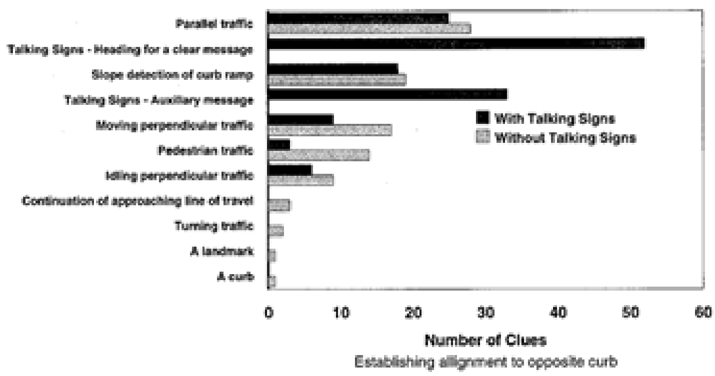

Figure 9. *Clues used to establish alignment toward the destination curb.*

Precision

Participants were much more successful at starting within the crosswalk in the TS trials (**Figure 1**). They would not get the message about the status of the pedestrian signal unless they were within the crosswalk and facing the destination curb. On 14 trials in the non-TS condition, participants were unable to locate the curb ramp or other starting location information and requested experimenter assistance.

With TS, subjects were much more likely (80 percent versus 48 percent) begin on a heading so their projected path of travel would be within the crosswalk. Participants reported using 11 different clues to align themselves in the direction of the destination curb. A total of 146 clues were reported in the TS condition, including 61 not provided by the system. Subjects reported using the system by facing the direction of the clearest signal and/or using information in the Auxiliary message such as "The crosswalk is angled away from Fulton." In the non-TS condition, 94 clues were reported, such as using information from the travel patterns of other pedestrians and from perpendicular traffic on more crossings than in the TS condition.

Seventy-six percent of crossings using TS ended within the crosswalk versus 56 percent without. There were two crossings which ended at the diagonally opposite corner in the TS condition versus four without TS. On 8 (of 20) crossings of Hyde Street at Fulton Street (T intersection) without TS, participants veered into Fulton Street (the stem of the T) far enough to encounter the line of parked cars along Fulton Street. Some were quite disoriented. TS users had both the direction of the sign message and the descriptive information about the direction of the crosswalk, and completely avoided this incident.

Individual Differences

Four participants reported mild-to-moderate hearing loss. They showed essentially the same pattern of results as the total group of participants. They may have been slightly more careful and successful travelers. Performance was equal to or better than that of non-hearing-impaired participants on safety, precision, independence, and knowledge. The two subjects who did not normally travel or cross streets in unfamiliar areas, and did not consider themselves to be good travelers, benefited even more than the rest of the group from TS (**Figure 10**).

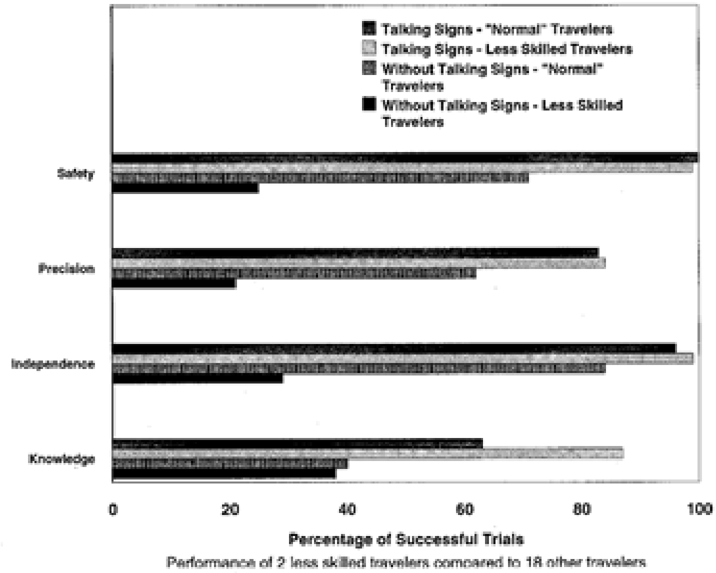

Figure 10. *Performance with and without TS of 2 participants who do not normally cross at unfamiliar intersections, compared with performance of the other 18 participants.*

Subjective Assessment

After completion of the experimental procedure, the 20 participants were asked a number of questions on the usefulness of the technology for intersections and the need for training in its use. Answers were given on a 5-point scale in which 1=strongly disagree, and 5=strongly agree (**Table 4**).

Table 4.

Subjective rating (n=20) of usefulness of the Talking Signs system at intersections; 5-point scale, with 1=strongly disagree, 5=strongly agree.

Statement	1-2	3	4-5	Mean
I understood the meaning of the terms used in the description (2nd channel) message.	0	6	14	4.15
The description message helped me to know when and how to cross the intersection.	0	2	18	4.4
I could have performed the crossings just as well without the description messages.	4	6	10	3.65
I felt more confident crossing intersections when using Talking Signs than without Talking Signs.	1	3	16	4.35
The wait/walk sign message did not interfere with my hearing or attending to other important cues about the intersection.	3	1	16	4.35
A person copuld use Talking Signs for this task (crossing unfamiliar intersections) without any training at all.	13	2	5	2.35
A person who uses Talking Signs to navigate in a building would be able to use Talking Signs at intersections without additional special training.	12	2	6	2.7

Focus Group

A focus group of nine of the subjects was held to obtain additional subjective data. The group first addressed the use of Auxiliary Messages to provide additional descriptive information about each intersection. The group generated a list of 16 kinds of information they would like to be able to receive on the Auxiliary Message. The items were then rated in importance on a scale of 1-5 (5 being very important) by each member. Results appear in **Table 5.**

Table 5.

Focus Group results: Types of information desired in descriptive messages, ranked in importance on a 5-point scale, with 1=strongly disagree, 5=strongly agree.

Type of Information to be Included in Auxiliary Messages	Mean Rating
Shape of intersection	4.7
Location of push button	4.2
Angle of crosswalk	4.0
Direction of traffic flow if one-way	4.0
Relationship of crosswalk to any traffic islands	4.0
Number of lanes to be crossed	3.9
Presence of constant right-turning traffic	3.9
Location of median	3.3
Vehicular actuation or other variations in signal timing	3.3
Length of walk interval (in seconds)	3.2
Location of curb ramp in relation to crosswalk	3.1
Presence of a median	3.0
Street names	2.9
Landmarks	2.8
Relative length of walk interval	2.8
Shape of islands	2.8

Participants were asked to rate the importance, on a scale of 1 to 5, of the different types of information provided by TS as used in the experiment. They considered the orientation information (Example: "Traveling East on the 800 block, toward Larkin Street.") the most important (mean=4.7), followed by the "Wait .... Walk Sign .... " (mean=4.3) and the descriptive (mean=4.2).

Finally, participants were asked to consider the relative advantages of the TS system and audible traffic signals such as the cuckoo and chirp signals they had experienced elsewhere.

Advantages of the Talking Signs System at Intersections:

- The signal is highly directional and unambiguous
- The information is refusable (i.e. the user can ignore or not even listen to the information)
- The information is not heard by the general public
- The same information is provided as is available to pedestrians who are fully sighted
- The information is very specific
- There can be a lot of information

Advantages of Audible Traffic Signals at Intersections:

- No receiver is needed
- There is nothing to carry in the hand
- The signals can be heard far away
- The user continues to hear the signal while crossing (as long as the Walk interval continues)
- All pedestrians are alerted to the onset of the Walk interval

DISCUSSION

The studies reported here provided useful evaluative information on the utility of remote infrared signage in helping to solve the orientation problems of blind persons in such complex urban environments as transit systems and controlled intersections. From the results of the underground transit study, it is clear that blind persons are readily able to learn to use the TS system for traveling routes in a transit station without assistance. The system proved to be just as beneficial to travelers using dog guides as to those using long canes. It was also as useful to persons having hearing loss as to those having some useful vision. It is clear that at least some training is needed to ensure efficient operation. Individual training appears to be particularly important for users having poor spatial skills--the group that had the greatest difficulty using the TS system efficiently and to their best advantage. Nonetheless nearly all were successful in traveling one or more easy routes, and some were successful in traveling medium and hard routes. Persons with developmental delays or dyslexia have been found to decrease their need for assistance in negotiating the same transit station with the use of the information provided by the TS system (23,24).

Focus group participants expressed overwhelming pleasure in the opportunity to travel in a complex, relatively unfamiliar environment without the frequent need to ask for information or assistance. This transit station that had previously been avoided by some participants became a preferred one. The fact that many subjects continued using the TS system after they had become familiar with the layout of the transit station points to its usefulness in familiar as well as unfamiliar areas, just as visual landmarks continue to be useful for reinforcement in familiar areas.

It is instructive to consider the potential savings in time, energy and inconvenience provided by infrared remote signage in a complex environment. Subjects successfully reached their destinations on 169 of 196 routes, passing decision points at which information was needed 500 times. Without some form of remote signage, travelers would have had to find some other form of information or assistance 500 times.

The intersection study confirms the experience of many blind pedestrians as well as O&M specialists that there is insufficient nonvisual information at some intersections to enable many pedestrians who are blind to cross safely. The four San Francisco intersections selected for a comparison of street crossing safety, precision, independence, and knowledge were fairly conventional in their design. Nonetheless, in the absence of remote signage, participants requested assistance in knowing when the Walk interval began on 22.5 percent of crossings, and when no assistance was requested, participants started crossing during the flashing Don't Walk or Wait intervals on 17 percent of the trials. On 19 percent of trials assistance was requested in locating the crosswalk, and on 19 percent of trials it was requested for completing the crossing.

In contrast, with the additional information on orientation to the crosswalk, state of the signal, and auxiliary intersection descriptions provided by the TS, subjects were safer, more independent, and more precise in their use of the intersections. No participant requested assistance knowing when the Walk interval began in this condition, and only one crossing was started out of the Walk interval. Participants requested assistance locating the cross walk on only one trial

(3 percent) and on completing the crossing on only one trial (3 percent). Aside from the certainty of knowing when the Walk sign is on, orientation is improved by provision of unambiguous and definitive information about location and heading, so the anxiety associated with disorientation is also decreased. The more intangible benefit of greater knowledge of the intersection layout and controls also appeared to increase confidence. Nonetheless, for all measures, there were one or more TS trials on which subjects were not successful. No technology may be able to assure that all persons who are blind are always 100 percent successful in street crossings. The improved performance with TS as well as the results of the focus group indicate that the necessary information is provided by the TS system and that blind pedestrians are likely to be able to use it to enhance safety, precision, and knowledge at street crossings.

CONCLUSION

Everyone's effective mobility depends upon proper orientation; for mainstream society this is accomplished to a large extent by printed signs. Infrared signage such as the TS provides analogous information for blind individuals. The studies reported here indicate the clear value of this type of information in helping blind travelers to negotiate complex environments such as transit stations and crossing intersections with greater safety, precision and independence. The fact that infrared signage improves performance in these tasks, which are among the more complex and dangerous faced by the blind traveler, is a good indication of its broad applicability to the many other situations where signage information is helpful or necessary for independent travel.

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