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Interactive tactile maps, visual disability, and accessibility of building interiors

Aries Arditi[1]
Emily Holmes[1]
Peter Reedijk[2]
Roger Whitehouse[3]

[1]Arlene R. Gordon Research Institute, Lighthouse International, New York, NY, [2]Studio Reedijk, Portland, OR, and [3]Whitehouse & Company, New York, NY, USA

Abstract *Objectives*: To test the feasibility of interactive tactile maps as a public intervention for the effects of severe vision loss on the loss of travel independence in building interiors. *Methods:* An experiment in which wayfinding performance of blind participants was compared after planning routes with either an interactive tactile map or mock 'bystander' directions. Additionally, a questionnaire assessing perceived usefulness of the system was administered. *Results*: There were significantly fewer errors, and significantly more errorless wayfinding trials in the interactive map condition than in the bystander directions condition. Participant ratings of usefulness and ease of use of the interactive map averaged 5.59 on a 1-7 Likert scale. *Conclusions*: Interactive tactile maps may provide an effective intervention for increasing access of blind persons in building interiors.

Key words Vision impairment; blindness; wayfinding; mobility; spatial orientation

Correspondence and reprint requests to:
Aries Arditi
Arlene R. Gordon Research Institute
Lighthouse International
111 East 59th Street
New York, NY 10022
USA
Tel: 212 821 9500
Fax: 212 751 9667.
e-mail: aries@play.lighthouse.org

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Introduction Provisions of the Americans with Disabilities Act (ADA) require architectural changes in new and renovated structures to make them accessible to disabled people. These have been in effect since early 1993. This broad civil rights law requires public entities, and private businesses and services who accommodate the public, to remove architectural and communications barriers to access if doing so is 'readily achievable'. The ADA Accessibility Guidelines[1] (ADAAG), published by what has come to be known as the Access Board, constitute the bulk of the interpretation for what is considered 'readily achievable', and provide guidance on how mandated changes are to be implemented for compliance with the law.

Virtually all of the requirements in the ADAAG that are intended to provide equal access for visual disabilities pertain only to signage. The ADAAG and its likely next revision[2] both mandate and recommend where signs should be *located* and what their *format* should be (e.g., braille, raised letter, high contrast, etc.). However, they do not address the realities of how visually impaired persons will *use* such signs to find their way in unfamiliar public spaces. A blind person in a hallway has a good chance of identifying a room if a mandated tactile sign is present at the mandated (and consistent) location next to the door, but this does little to help her or him actively find their way to a desired location that does not happen to be the one immediately in front of them. Thus, while the ADA mandates equal access, in the case of visual disability, there is currently no available technology that can provide effective access in building interiors that is recognized as 'readily achievable'.

Among the wayfinding aids that do exist or are under development are geographic database route planning systems for town maps[3] and systems for outdoor travel incorporating a satellite navigation component. These latter systems include the personal guidance system under development by Golledge et al.,[4] and the MoBIC travel aid which has a route planning and an on-the-route system.[5] None of these systems work for building interiors.

One technological aid for visually impaired travelers that does work inside buildings is the remote 'talking' signage systems[6] currently available from two companies. However, these, like the tactile signage described above, provide only 'identification' information for signed locations. While useful and promising aids, they do not work as wayfinding systems since one cannot plan a route with them. Another technology that has the potential to be developed into a wayfinding system is the interactive touch-tablet teaching aids designed for education of blind persons in concepts of graphics.[7] These devices work by providing auditory feedback when their surface, covered by a tactile graphic, is pressed. They are used in teaching shapes, geography, and map reading; however, none has as yet been specifically incorporated into an indoor wayfinding device, as we suggest here.

We envision a route-planning aid for visually impaired people based on touch-tablet technology, that is specifically designed for building interiors. We wish to know whether an interactive tactile map system that responds to users with verbal feedback can enhance access of blind persons to their environment compared to the common strategy of obtaining verbal assistance from a bystander. In the present experiment, this was assessed by comparing participants' ability to walk to landmarks in an unfamiliar building environment using these two conditions. It should be noted that when blind people ask for directions while traveling, they may occasionally be offered an arm (rather than given verbal directions) and walked to their desired location. The goal here, however, is to provide them with an aid that allows independent travel, and we used verbal directions as an ecologically valid comparison condition in this study.

Method

MATERIALS AND APPARATUS The interactive tactile map system we developed consisted of a computer-controlled electronic touch tablet

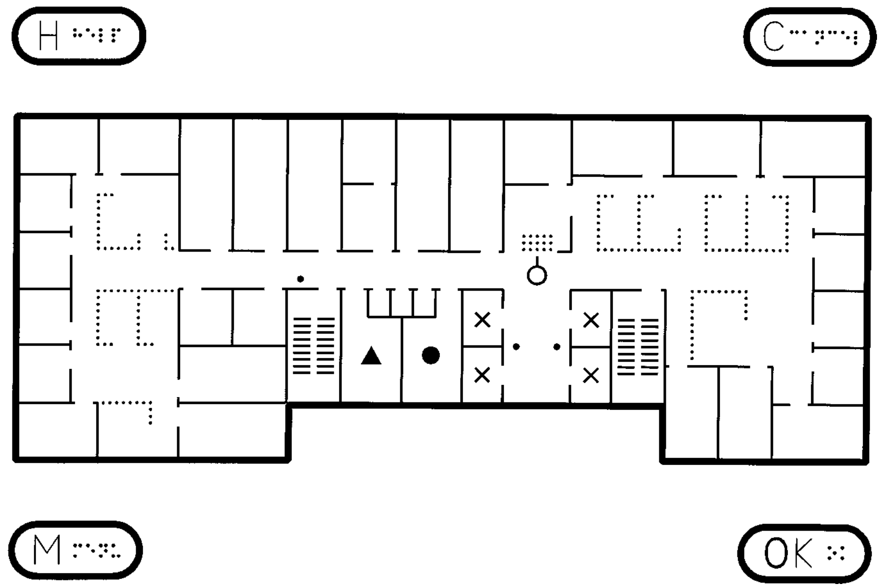

Fig. 1. Tactile map overlay used in the experiment, with raised portions shown in black. The 'you are here' symbol is shown as a circle with a vertical bar on this diagram, just above the elevators (indicated by ×'s). On the actual map, a steel ball was used for quick location of this important feature.

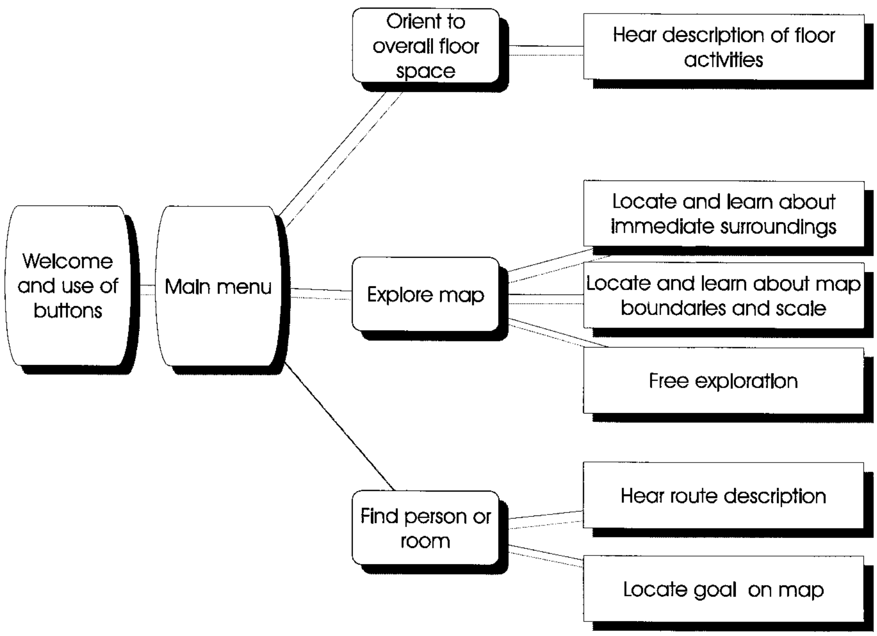

Fig. 2. Menu structure of interactive map used in the experiment.

with a tactile map overlay depicting the 10th floor of Lighthouse International's Manhattan Headquarters. Based on earlier work,[8] the tactile map overlay is an architectural (as opposed to path) style map, depicting walls and boundaries rather than just the routes of travel. The tactile overlay was created by printing on swell paper and subsequently 'toasting' it to raise the image using a Reprotronics Inc. Tactile Image Enhancer. It was mounted on a touch tablet (Concept Keyboard Infomatrix). This touch tablet allows free exploration of a relief surface on top of the membrane without transmitting any signal. When the user desires information, a firm press conveys information specific to the coordinates of the key press. Both the map and the touch pad are size A3 (42 cm × 29.7 cm). Custom software controlling the system ran on a Macintosh laptop computer equipped with Yamaha YM10 speakers for artificial speech output. A visual representation of the tactile map overlay is shown in Figure 1.

When the user first touches the system, it introduces itself and makes the user locate its essential features: the 'you are here' symbol and the buttons for Main menu, Cancel, Help, and OK. The user then enters a menu system (see Fig. 2) from which a range of options may be chosen. These include a general description of the floor space and activities, introducing scale and orientation both in terms of compass directions and locally accepted conventions (e.g. the 60th Street side of the building). There are interactive options which guide the user in where to move their finger to reach desired goals on the map, or allow free exploration of map features by providing speech output identification of tactile features in response to pressing on them. If desired, the user may obtain an accurate route description to a specified goal in terms that are useful to a blind person, including information about walls to trail when necessary and physical and auditory landmarks they will encounter along the way. Users may make a 'test-walk' on the tactile map with their fingers, using these descriptions, prior to making the actual journey to their desired location.

The touch pad with tactile map overlay, computer, and speakers were installed at the reception area of the floor, just off the elevator. All participants were greeted by the experimenter in the lobby of the building and escorted to the 10th floor, so as to prevent uncontrolled or incidental learning of the test space.

A series of verbal route description scripts intended to be typical of those that might actually be given to a blind traveler by an able-sighted bystander, were obtained for use in the bystander directions condition (see below). We collected these scripts by asking 18 office occupants of the 10th floor for the directions they would give a blind person who asked them how to get to each goal location used in the study. These descriptions were obtained at the reception location where the participants were later tested. The bystander directions were taped and subsequently transcribed. One goal per describer was used to achieve a variety of natural styles of description. Only route descriptions that were factually correct were used. Typical examples of the bystander directions used are:

Workstation 21: 'Okay, you're going to go to your right, okay, and you're going to walk about 10 feet until you get to your first opening on your left. Okay, it's not a doorway but it's kind of a hallway; you'll go down a little ways to the left and there at the end of that cubicle; Workstation 21 is going to be located on the right.'

Room 20: 'You're going to make a right, and walk until you cannot walk any further. Make a left and walk until you cannot walk any further; Make another left and it's going to be the third office on your right, if you can make out the doors, or maybe about 12–15 steps to Room 20, which will be on your right.'

These descriptions are very likely significantly better than those that would be obtained from occupants of an ordinary business building since the occupants of the 10th floor, which is the research floor, are accustomed to interacting with, and in most cases, conducting research involving people with visual impairments.

It is widely accepted by blind people that directions from strangers are likely to be inaccurate or lack useful information. Able-sighted bystanders are often unable to give effective geographic directions even to other able-sighted strangers. They are especially poor at remembering or making a point of using nonvisual landmarks, making it difficult to formulate route plans that are relevant to blind people. In fact, we had to collect a total of 27 route descriptions in order to obtain 18 that contained factually correct wayfinding information! This is despite each participant being extremely familiar (i.e., their offices were on this floor) with the routes they were describing. We believe that the increased accuracy of the information presented by a well-planned interactive tactile map 'machine' alone would be a significant advantage for blind people relative to the inaccurate directions they are likely to obtain from bystanders.

Another advantage of pre-planned route descriptions is that they can be tailored for the particular needs of blind travelers, including auditory and tactile cues and special travel techniques such as trailing walls. The interactive tactile map made heavy use of such customization. To illustrate, descriptions from the interactive map system for the same examples given above for the bystander directions are:

Workstation 21: 'From where you are now, turn right. Trail the left wall past the bulletin board, a very short distance. Turn left at the first opening, which is where the carpet starts. Trail the right wall which is covered in fabric around the corner to the right, to the entrance to workstation 21.'

Room 20: 'From where you are now, turn right. Trail the left wall past the bulletin board, a very short distance. Turn left at the first opening, which is where the carpet starts. Continue to the end of the corridor. Turn right. The door to room 20 is the first on the left past the glass wall.

Note that the same route description is used for the portion of the paths that is common to the two routes. This was intended to facilitate learning of the space.

PARTICIPANTS Ten blind persons whose visual capabilities were at most 'light perception' participated. None had been on the 10th floor before. Most were recruited using records identifying them as having received services in Lighthouse satellite facilities in Queens, Staten Island, Westchester, or Suffolk Counties rather than the Manhattan facility. Some had limited familiarity with the building, such as being in the lobby or another floor of different layout, or having been in the building prior to an extensive renovation that took place from July 1992-July 1995. Further participant characteristics are shown in Table 1.

PROCEDURE Each participant was tested in both the interactive map condition and the 'bystander directions' condition. Half the participants were tested on the interactive map condition first, the other half on the 'bystander directions' condition first. In both conditions, participants

TABLE 1. Characteristics of study participants. LP, light perception only; NLP, no light perception.

age (years)	sex	sensory status	age of vision loss	cause of vision loss	any experience with maps			can read		has used		highest education	mobility aid
					tactile	talking tactile	visual	braille grade	raised letters	computers	synthesized speech		
46	F	NLP	42	retinopathy of prematurity			✔	I	✔	✔	✔	high school	guide dog
48	F	LP, deaf one ear	11	retinitis pigmentosa				I		✔	✔	BA	cane
35	F	LP	5	optic neuropathy	✔			II	✔	✔	✔	2 years college	cane
36	F	NLP	0	retinopathy of prematurity				II		✔	✔	high school	guide dog
22	M	NLP	0	retinopathy of prematurity				II		✔	✔	high school	cane
38	F	LP, uses amplification both ears	13	retinal detachment		✔		II	✔	✔	✔	high school	cane
44	M	LP	23	retinitis pigmentosa			✔	I	✔			1 year college	cane
43	M	NLP	8	retinopathy of prematurity				II	✔	✔	✔	BA	cane
55	M	LP one eye NLP other	8	hydrocephalis	✔			II	✔	✔	✔	high school	cane
38	M	NLP	0	glaucoma				II	✔		✔	some high school	cane

were told that their task was to walk to specified goals on the floor, either by planning a route with the interactive map or by following the 'bystander's directions'. Participants started at the same location and orientation and were instructed to find the goal using their customary navigation techniques (guide dog or cane). For each participant, the 18 goals were randomly divided into two sets of nine for the two conditions. In both conditions, an error was scored if the participant was incorrect in identifying a specified goal, if he/she made an error at a decision point (e.g. a wrong turn) and proceeded at least 2 feet in this wrong direction (at which time they were guided back to the point at which the incorrect decision was made), or he/she paused and was unable to continue. Under all circumstances, they could opt for a 'hint'; this hint, given verbally in both conditions, was a repeat of the route plan script that had been given in the route planning phase of the trial (by either the experimenter or the interactive map system). The number of hints requested was recorded. Finally, interaction with the map and wayfinding performance testing were videotaped for later analysis. The entire experiment, including rest breaks, took between three and four hours to conduct per participant.

Interactive map condition In this condition, the interactive map software was run and participants were allowed to interact freely with the system without intervention or assistance, except when the participant was querying the system for a name or room number. In this one case, because the text input facility was not yet implemented, the experimenter typed the desired name or room number into the system for the participant. When the participants felt sufficiently confident with their route planning, they walked to the goal location.

Bystander directions condition In this condition, the experimenter read out the set of valid directions to the target goal, as described above. The participant then walked to the specified location.

In both conditions the only restriction imposed on participants' strategies was that they were not allowed to ask other bystanders for help. All staff on the 10th floor were warned in advance of the experiment and told not to offer assistance, but to otherwise go about their daily activities in a natural way, including talking and walking about on the floor.

Questionnaire After both conditions were completed, a 12-item questionnaire was administered that solicited participant ratings on several aspects of the system and the experiment, including usability, interface quality, and ease of travel. Where possible, ratings were solicited for both the interactive map and the bystander directions condition, for comparison.

Results

ERRORS IN WAYFINDING The mean number of *wayfinding errors* per participant was 5.60 (s.d. = 1.59) in the interactive map condition, compared with 10.05 (s.d.= 1.63) in the bystander directions condition. This difference is significant (Wilcoxon matched pairs signed ranks test $T = 8$, $n = 10$, $p < 0.05$). Thus, even in this first generation test system, and with users having never used the system before, the interactive touch map system reduced wayfinding errors by half.

WAYFINDING WITH ZERO ERRORS We also summed the number of *individual trials* on which no wayfinding errors were made, i.e. those in which the participant reached the goal fully independently and correctly. Per person, with nine goal trials in each condition, 5.9 (s.d. = 0.63) such 'perfect' trials were made on average in the interactive map condition, whereas 4.1 (s.d. = 0.69) were made in the bystander directions condition. This difference is also significant (Wilcoxon matched pairs signed ranks test, $T = 2$, $n = 9$, $p < 0.01$). Thus, the interactive map, used virtually independently and with the training provided through its own interface, produced almost 1/3 more 'perfect' wayfinding experiences than did a condition mimicking directions obtained from a stranger (even though our 'bystander directions' were rated superior to actual directions usually obtained in real life from strangers; see below). This suggests that a blind person wishing to find a location in a building is significantly more likely to do so with aid from the interactive map system than from even the oral directions from an able-sighted stranger who is a resident of the building and an expert on vision impairment.

HINTS REQUESTED There were 24 requests for hints in the bystander directions condition compared with 16 in the interactive map condition, again suggesting that participants were better oriented with the map system than with bystander directions. However, this difference was not statistically significant using the Wilcoxon matched pairs signed ranks test.

TABLE 2. Questionnaire results. Means (standard deviations) of ratings on a scale ranging from 1 to 7. **, statistically significant difference between interactive map and bystander directions.

Aspect Probed	Rated Attribute (scale is 1=extremely, 2=very, 3=fairly difficult; 4=neither easy nor difficult; 5= fairly, 6=very, 7=extremely easy)	Interactive map	Bystander directions
Overall usability of wayfinding method	using the system as a whole for wayfinding	5.2 (1.26)	4.5 (1.51)
	learning to use the system	4.8	N/A
	using the system to plan a route	5.4 (0.97)	N/A
	building a meaningful mental picture** t=3.17, p=0.0048, df = 9.	5.6 (0.70)	3.4 (2.0)
Quality of Interface	quality of interactive map's synthesized speech	5.2 (1.2)	5.1 (3.1)
	readability of the tactile map	5.4 (1.69)	N/A
	ease of working with options and menus	5.5 (1.43)	N/A
Ease of travel	finding your way (navigating) to goal** t= 2.70, p = 0.024, df = 9.	5.8 (0.92)	4.7 (1.49)
	remembering the planned route	5.9 (0.92)	4.9 (1.45)
General	quality of verbal directions given in "bystander" condition	N/A	5.1 (3.1)
	likely usefulness of interactive map system for travel when alone in an unfamiliar building	6.6 (0.52)	N/A
	likely usefulness of interactive map system for travel when strangers are present in an unfamiliar building	6.1 (0.88)	N/A

LEARNING EFFECTS We tested whether participants' wayfinding accuracy improved with additional trials. Neither a Friedman two-way analysis of variance nor a standard ANOVA showed any significant effect of trial over the nine trials in either condition. This is consistent with the idea that the interactive map produced accurate wayfinding immediately. This is highly desirable for a building wayfinding system where first-time users would need the system most.

PARTICIPANT RATINGS Ratings for the interactive map, detailed in Table 2, were high, averaging 5.59 out of a possible 7, indicating that the interactive map was rated very easy to use. Of special note is the fact that it was rated very useful for travel both alone and with strangers present in an unfamiliar building. This illustrates the importance of *independent* travel to blind people. Also, for each item in which the interactive map was compared with the bystander directions condition, the interactive map was rated more positively.

Finally, in order to be sure that our bystander directions were a fair comparison with those that might be obtained from a real bystander, we asked participants to rate the quality of verbal directions they typically experienced in everyday travel. The average (and standard deviation) rating was 3.2 (1.99); this was significantly different from the rating of the quality of verbal directions of 5.1 (3.1) in the bystander directions condition ($t = 2.70$, $p = 0.024$, $df = 9$). This result indicates that our test of the interactive tactile map system against these bystander directions was a tough test.

STRATEGIES USED BY PARTICIPANTS The sequential strategies used in planning a route using the interactive map were also analyzed from the videotape. Participants utilized a rich variety of ways to acquire wayfinding knowledge. On 59% of map trials, participants explored the tactile map overlay, either freely or in conjunction with either the 'hear route description' or 'locate goal on map' option (see Fig. 2). As one of the (blind) participants remarked: 'Feeling the map as well as hearing the route meant I could really see where I was going to go.' On 41% of map trials, only verbal route directions were used. In these trials, participants invariably followed the directions tactually on the map while hearing them. All participants used the 'orient to overall floor space' option at least once, and many commented that this feature was extremely useful in understanding the area.

Discussion Our results indicate the feasibility of an interactive tactile map wayfinding system to support the independent travel of blind persons in unfamiliar buildings, at least buildings of moderate size and complexity. Those of greater size and complexity might be navigated by 'daisy-chaining' route directions to interactive map systems in intermediate locations to the desired goal (e.g., on each floor). This is obviously an issue that will require further study.

The fact that even this first rough design of an interactive tactile map wayfinding system produced significantly fewer errors than *accurate* bystander directions, with no pre-training or experience with the system, suggests that it holds considerable promise as a wayfinding aid for visually impaired people. The interactive tactile map system made a more useful wayfinding aid than did the act of querying bystanders for several reasons. Users can set their own pace and allocate sufficient time exploring and interacting with the map to develop an appropriate route plan. They may test the directions with the fingers prior to walking, and also easily acquire repeats of route directions. Also, route directions can, as in the present study, be customized for blind travel, including tactile and auditory cues to location and paths of travel used by blind persons (e.g., trailing walls). Finally, as stressed above, the accuracy and appropriateness of wayfinding directions provided is an enormous advantage that the interactive map system has over ordinary bystander directions, which, in everyday situations, are not pre-screened for accuracy. This, in combination with the desire for independent travel, is likely to be the reason why usefulness of the interactive tactile map system was rated so highly by the study participants.

The totally blind population is likely the most challenging group to provide wayfinding access to, for several reasons. First, they generally rely on touch (e.g., via a long cane) in combination with environmental sounds to perceive their surroundings, and for this reason have a relatively limited space that they can immediately apprehend for navigation. This makes unfamiliar spaces particularly difficult to plan movements in. (Guide dogs aid the blind traveler in navigating a chosen path by avoiding obstacles and hazards, but a dog cannot plan a route.) Second, totally blind people cannot read signs, unless they are in braille or raised letters and the reader is able to read that particular format. Even such tactile signs, however, cannot be read remotely, requiring serial exploration of the rooms on a hallway, for example, to find the correct one.

Slightly less challenging, but important because of its greater prevalence than blindness,[9] is providing access for the low vision population. For low vision, it is the loss of ability to read signs, maps, and relatively distant visual details, and problems functioning in high or low lighting that reduce the ability to travel, especially in unfamiliar places. The majority of travelers with low vision are still able to detect landmarks of sufficient visual angular size and contrast, i.e. can see large but poorly resolved objects. Their primary difficulty is in reading directional and informational signs and maps, which limits their ability to plan complex routes. Those with a less prevalent class of 'tunnel' low vision (e.g., advanced stages of retinitis pigmentosa, advanced glaucoma) have normal visual resolution but have particular difficulty identifying large objects whose borders lie beyond their intact visual field. Such individuals may have great difficulty locating the signs themselves, but may be able to read them easily.

Tactile and/or large format interactive visual maps may be useful as wayfinding aids for this population as well. Indeed the interactivity of this kind of system provides the opportunity to tailor user feedback depending on the particular nature and severity of the disability. Hence, a blind user may receive route directions that emphasize tactile and auditory features of the environment, whereas a user with low vision could receive information about large, high-contrast environmental features which would allow them to navigate successfully. Such a system could query the user as to the severity of their vision loss and receive feedback according to their special (or ordinary) needs.

Expanding this concept even further, the system could be designed for universal use. A universal design would serve the broadest possible spectrum of users, including fully sighted persons, those with blindness or low vision, deaf persons, wheelchair users (who may require special routes of travel), and, potentially, speakers of different languages.

For both blind and low vision travelers, planning and executing a route to something that is not immediately visible or tangible is a great challenge that able-sighted people rarely experience. This is because society tends to design things for typical, sighted users rather than for universal use. Architectural provisions of the Americans with Disabilities Act of 1990 (ADA), however, mandate the design of buildings and spaces intended for public access with the disabled community in mind, and the present results suggest that design of a wayfinding aid that can remove barriers to access for visually disabled persons is within our reach.

It is our hope that eventual development of this kind of wayfinding technology can demonstrate to society and to rule-making bodies such as the Architectural and Transportation Barriers Compliance Board that, analogous to wheelchair ramps, effective wayfinding systems are both 'readily achievable' ways to remove barriers to access by visually disabled persons and effective environmental modifications that can help remediate the effects of vision loss.

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