Walking Between the Lines: Nonvisual Cues for Maintaining Headings During Street Crossings

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Abstract: Five cues were evaluated with respect to their usefulness in directing the headings of pedestrians who were blind during street crossings. The study was conducted at a simulated crosswalk, with the angle of the crosswalk varied relative to the approach and direction of the slope of the ramp. Three cues worked well over the distance equivalent to the width of a six-lane road.

Orientation and mobility (O&M) instruction emphasizes the use of traffic sounds as a cue for maintaining heading while crossing streets and for "recovering" from heading errors (Hill & Ponder, 1976). However, there are many locations where there may be little or no traffic traveling parallel to the crosswalk, such as wide crossings of arterial roadways, T-intersections, midblock crossings, or crosswalks at roundabouts and channelized turn lanes (Barlow, Bentzen, Sauerburger, & Franck, 2010). At some intersections, there may be a sufficient volume of traffic for directional guidance during peak traffic periods and insufficient traffic during off-peak periods. Even with a steady flow of parallel traffic, pedestrians who are blind have been found to complete many crossings outside the crosswalk (Bentzen, Barlow, & Bond, 2004).

Straying from the crosswalk is an everyday travel hazard for pedestrians who are blind and typically results from an initial heading error or "misalignment" (see Guth, Hill, & Rieser, 1989; Scott et al., 2011) and from veering from one's intended heading while walking (see Guth & LaDuke, 1994; Kallie, Schrater, & Legge, 2007; Rouse & Worchel, 1955). To address this problem, O&M instruc-

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tors have devised a variety of strategies for recovering from heading errors during street crossings (Hill & Ponder, 1976; La Grow & Weessies, 1994) but relatively few strategies for preventing these errors.

In light of these widely recognized challenges, a Curb Ramp and Intersection Wayfinding Workshop in 2004 (U.S. Institute of Transporation Engineers, 2004) to discuss "intersection design to optimize directional cuing for pedestrians who do not use visual cues in crossing streets." At the workshop, numerous ideas were discussed for providing information on alignment and heading to pedestrians who are blind, but little research was presented to confirm the efficacy of the various cues that were suggested. These cues included audible beacons associated with accessible pedestrian signals (APS), remote infrared audible signage (RIAS), and tactile guidestrips.

Various configurations of audible beaconing associated with APS (simultaneous sounds from both ends of the crosswalk, sounds alternating from one end of the crosswalk to the other, and sounds coming from the opposite end of the crosswalk only) have been evaluated with mixed results. For example, while several studies (Laroche, Giguere, & Poirier, 1999; Laroche, Leroux, Giguere, & Poirier, 2000; Tauchi, Sawai, Takato, Yoshiura, & Takeuchi, 1998) found that alternating signals result in greater accuracy in crossing than do simultaneous signals, a similar study (Wall, Ashmead, Bentzen, & Barlow, 2004) did not confirm this effect. Studies comparing beaconing from the opposite end of the crosswalk to simultaneous signals (Barlow, Scott, & Bentzen, 2009; Scott, Barlow, Bentzen, Bond, & Gubbe, 2008) suggested an advantage for "far side only" beaconing.

RIAS (exemplified by Talking Signs) makes use of handheld receivers that provide spoken messages when they are activated and pointed in the direction of infrared transmitters. In research at signalized intersections, crossings were completed within the crosswalk 56% of the time when RIAS was not used and 76% of the time when it was used (Crandall, Bentzen, Myers, & Brabyn, 2001; Crandall, Brabyn, Bentzen, & Myers, 1999). Because the participants were asked not to use their receivers as they crossed, this effect was probably due to the usefulness of RIAS for initial alignment. Marston (2002) also reported improvements with RIAS at a busy downtown intersection. Although Marston did not preclude participants' use of RIAS while crossing, the participants' comments suggested that RIAS was used primarily for alignment and for identifying the onset of the walk signal.

Tactile guidestrips of raised bars that are oriented in the intended direction of travel are widely used in some countries on pedestrian ways and indoor locations, but they are not commonly used to provide information at crosswalks, and they are seldom used for any purpose in the United States (Gómez, 1991; Shimizu, Murakami, Ohkura, Tanaka, & Tauchi, 1991). Guidestrips have been installed at some crosswalks in San Diego and Sacramento, California, for more than 20 years (Elias, 1974), but there has been no research on them.

The study presented here directly compared the usefulness of five cues for establishing and maintaining an appropriate heading during street crossings. These clues included the three cues described earlier, a

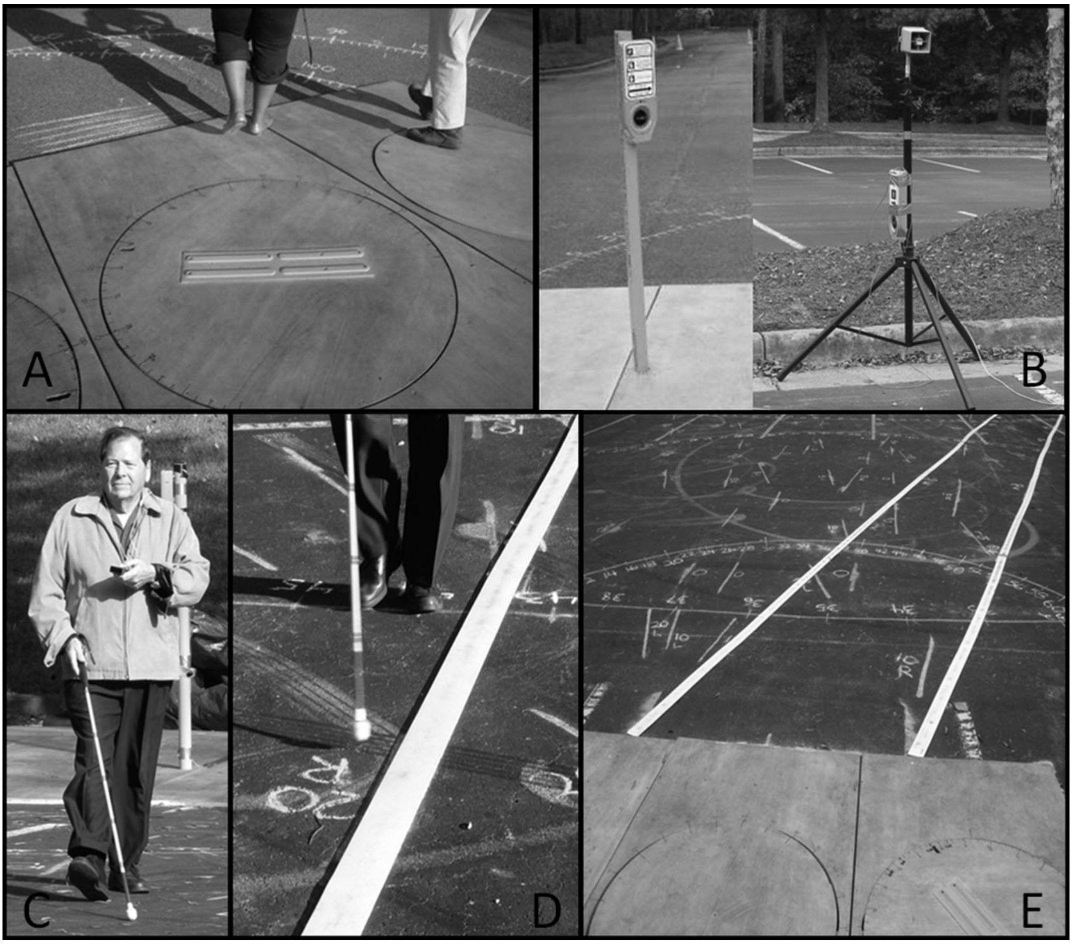

Figure 1. Alignment or heading cues (details in the text).

variation on the guidestrip, and an underfoot bar tile that was among the best alignment cues identified in our previous research (Scott et al., 2011). The long-term goal of this program of research is to identify nonvisual wayfinding cues that are applicable to a wide range of street-crossing situations, recognizing that only some types of crossings may need additional cues.

Methods

Cues and apparatus

The five cues that were evaluated are shown in Figure 1. Each was assessed over simulated crosswalk distances of 12, 36, and 72 feet (distances similar to the crossing distances of one, three, and six lanes, respectively). Because curb ramps are likely to be present at crosswalks and their slopes are often not aligned with the direction of the crosswalks (see Scott et al., 2011), the running slope of the ramp and the cues were sometimes aligned in the same direction and sometimes in conflicting directions. The cues that were tested were as follows.

Bar tile perpendicular

The bar tile perpendicular cue was a tile of two parallel raised bars arranged perpendicular to the intended direction of travel. This was one of the two cues that enabled the greatest accuracy in alignment in the first study in this series (Scott et al., 2011). It was the only cue that provided no additional guidance information after a participant began crossing.

Beaconing APS

The beaconing APS was an APS with prototype audible-beaconing features that were emitted from a loudspeaker mounted at the opposite end of the crosswalk approximately 9 feet off the ground. Beaconing was triggered by a button press of one second or more, after which the participants first heard seven repetitions of a loud 1-herz alignment (locator) tone from the distant loudspeaker. The choice of seven repetitions was based on observation of the time needed for the participants to detect and align toward the beacon in previous research (Barlow et al., 2009). The onset of the walk interval was announced by two repetitions of the phrase, "Walk sign is on." Following the walk indication, the loud locator tone from the opposite end of the crosswalk sounded again and played until the participant had completed the trial.

RIAS

For the RIAS condition, a speech message ("Walk sign") was continuously transmitted from a transmitter mounted at the far end of the crosswalk approximately 9 feet off the ground. The participants received the message when they pressed the button on a handheld receiver and scanned for a clear signal from the transmitter. They then used the direction in which the receiver was pointed to provide a cue to the direction of the crosswalk. While crossing, the participants occasionally pressed the button for the message. Although the RIAS message was continuously broadcast, it could be lost whenever the participant was not pointing the receiver toward the transmitter or when the participant had walked outside the cone of infrared transmission (see Marston, 2002). Because this crossing was not associated with any signal timing, the message never changed from Walk to Wait, as in typical RIAS applications.

Guidestrip

The guidestrip was composed of a raised strip of polymer tape, 4 inches wide and 0.25 inches high (marketed as temporary rumble strip), that was laid along the left edge of the crosswalk, beginning at the base of the ramp. The orientation of this strip relative to the slope of the curb ramp could be quickly changed.

Edgestrips

The same material that was used in the guidestrip condition was used for the edgestrip condition, but with strips laid parallel to one another and separated by 6 feet, beginning at the base of the ramp. This condition was included to test further whether information on accessible crosswalk boundaries might promote faster crossing than the guidestrip.

Two ramp structures were used in a minimally sloped, paved parking lot in a quiet area. This location was chosen because our primary interest was to identify cues that would be useful in environments where information from traffic sounds, the crown of the roadway, and movements of pedestrians was misleading or not present. Each of the two structures consisted of a 12 foot by 4 foot landing

Figure 2. Experimental ramp structures and site layout.

(representing the sidewalk at the top of a ramp) and a 12-foot-wide by 8-foot-long ramped surface, at a slope of 1:12, secured to the landing (1:12 is the maximum slope permitted by the regulations of the Americans with Disabilities Act). The two structures were installed approximately 80 feet apart with ramps facing one another but slightly offset (see Figure 2).

Measurement of alignment

While walking away from the ramp structure, the participants crossed 3 arcs. These arcs had radii of 12 feet, 36 feet, and 72 feet, measured from the base of the center ramp. The location at which the left side of a participant's left heel crossed each of these arcs was recorded.

Participants and procedure

The participants were 19 adults who were blind or had light perception only, all of whom were experienced cane users. Eleven had participated in the previous study (Scott et al., 2011). The study received ethics approval from the Boston College Institutional Review Board, and all the participants gave their informed consent prior to participating.

Before the first cue condition, the participants were oriented to and explored the ramp structures and walking area. Before they began each cue condition, they were instructed how the cue was intended to be used and were shown how the cue would be moved to different positions. They then explored the cue and made one or more practice crossings (at a different crosswalk angle than used for their first trial) until they were confident that they understood how to use the cue. The instructions regarding the expected use of each cue included the following: The participants were instructed to find the end of the guidestrip with their long canes while still standing on the curb ramp and then to follow it with the long cane using the constant-contact technique. For edgestrips, the participants were instructed to stay within the raised lines using the constant-contact long-cane technique and to make heading corrections whenever they encountered an edgestrip. For the beaconing APS, the participants were encouraged to start crossing during the walk indication, making corrections as needed as the beaconing began (after the walk indication). With RIAS, the participants were reminded that they were "in the street" and that they should not stop walking as they scanned for a message. This instruction was based on observations during pilot testing that the participants sometimes stopped as they attempted to relocate the message. Such stopping did not occur in the other conditions, and thus no similar instruction was provided for those conditions.

On each trial, the participants were guided to the level landing of one of the ramp structures by an O&M specialist and positioned facing the center of the ramp. They then walked forward onto the ramp using their canes, used the cue to establish a heading, and continued across the parking lot until they had passed the 72-foot arc. After passing the last arc, the participants were asked to stop walking and were guided to the next ramp structure for the next trial.

The participants completed five trials per alignment cue: one trial in which the cue was aligned with the running slope of the ramp (0 degrees) and one trial each with the cue (the simulated crosswalk) positioned 10 degrees and 20 degrees to the right and to the left of the running slope. They alternated cues and starting locations until they completed all five trials for each condition. Each participant thus completed four of the cue conditions in this manner. The other cue condition was completed without such an alternating procedure, with all five trials beginning at the same landing. To deal with the procedural demands of handling the guidestrip-edgestrips material, the guidestrip and edgestrips conditions were paired. For example, the participants completed an edgestrips trial from one ramp structure and then began a guidestrip trial from the other ramp structure.

Using a combination of counterbalancing and randomization, we made an effort to control for the effects of the following factors: the order of presentation of the five cues, the order of the five trials for each cue (the five angles of the crosswalk relative to the ramp slope), which cue condition was conducted without alternation with another cue condition, and the ramp structure used for each condition. At the completion of the experimental trials, the participants rated each cue and provided their opinions about which cue conditions they preferred and why.

Results

Overview

Two dependent measures were of particular interest: how far the participants were from the center of the simulated crosswalk upon traveling 12, 36, and 72 feet and the amount of time needed to complete the 72-foot simulated crossing. Using the locations at which a participant crossed the three arcs, we computed linear deviations from the center of the crosswalk at each distance. The crosswalks were 6 feet wide, and thus linear

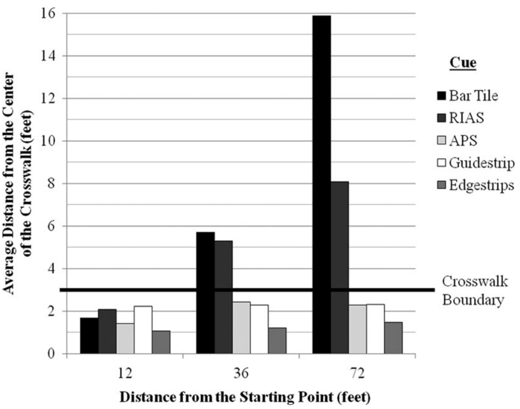

Figure 3. Average linear deviation from the center of the crosswalk by cue condition and crossing length.

deviations of less than 3 feet reflect a participant being within the crosswalk.

For each cue, the participants completed five trials. Their average performance was computed for each cue by averaging across these five trials. Following this procedure, we performed an outlier analysis using a 2.5 standard-deviation cut and median replacement, resulting in the replacement of 8 of 380 data points (approximately 2% of all the data). Outlier replacement is performed in an effort to improve the likelihood that sample statistics (such as the means reported throughout this article) accurately estimate the related population parameters. In no case was the significance of a statistical test or the interpretation of the results affected by this procedure.

Linear deviation from the center of the crosswalk

Figure 3 displays how far the participants were on average from the center of the crosswalk in the various cue conditions and for all three lengths of crosswalk. The reference line indicates the boundary between being within or outside the crosswalk. A two-way repeated-measures analysis of variance (ANOVA)—cue (5) x distance (3)—revealed a significant interaction, $F(8, 144) = 52.91$, $p < .001$, and significant main effects for both types of cue: $F(4, 72) = 51.23$, $p < .001$, and distance from the start, $F(2, 36) = 161.66$, $p < .001$. The significant interaction reflects the fact that the participants' performance in the beaconing APS, guidestrip, and edgestrips conditions was excellent and similar at all measured distances, while the bar tile and RIAS resulted in increasing errors the farther the participants walked (analyses of these simple main effects for each cue are presented next).

Additional analyses looking for differences among the APS, guidestrip, and edgestrips conditions were not conducted for two reasons. First, the outcome of most practical significance was whether the participants managed to remain within the crosswalk, not their precise position within the crosswalk. The participants' average performance in these three conditions placed them within the crosswalk for all three crosswalk lengths. Second, the nature of the installations of the guidestrip and edgestrips was likely to produce slight differences in the linear deviation measure. The guidestrip was not installed at the center of the crosswalk, but at an outer boundary of the crosswalk; thus, the participants who used the guidestrip as intended were about 2 feet from the center of the crosswalk. Those who used the edgestrips as intended were more likely to travel, on average, in the center of the crosswalk. This difference is evident in Figure 3 for all three crosswalk lengths. Thus, comparisons of the linear deviations in these two conditions would be artificially affected by this aspect of the installation, even if both cues were affecting the participants' performance as intended.

For a 12-foot crossing, no individual had an average deviation across the five trials that was greater than 3 feet in the bar tile, APS, guidestrip, or edgestrips conditions. Two participants had an average performance in the RIAS condition that exceeded the crosswalk boundary (average of 3.2 feet). Thus, it is apparent that for a 12-foot crossing, the participants were largely able to stay within the crosswalk regardless of the type of cue.

Bar tile

The simple main effect of distance for the bar tile cue is significant, $F(2, 36) = 104.46$, $p < .001$, revealing a linear trend with increasingly poorer accuracy as the length of the crosswalk increased (see Figure 3). By 72 feet, not one participant had an average linear deviation of less than 3 feet, and the participants were, on average, nearly 13 feet outside the crosswalk (average linear deviation of 15.9 feet). It is apparent that although the bar tile was effective in assisting the participants to establish an appropriate initial heading (see Scott et al., 2011), it did little to support the participants who remained within the crosswalk over a typical multilane crossing. One potential advantage of audible cues is that they may provide midcrossing information that can help individuals who are blind maintain a correct heading or perform appropriate course corrections.

RIAS

In this condition, the participants received intermittent information via the handheld receiver during their crossings. The simple main effect of distance for RIAS was significant, $F(2, 36) = 34.46$, $p < .001$, revealing a linear trend with increasingly poorer accuracy as the length of the crosswalk increased (see Figure 3). By 72 feet, the average performance of 17 of the 19 participants was outside the crosswalk, with the participants on average about 5 feet outside the crosswalk (average linear deviation of 8.1 feet). There is some evidence of course corrections with RIAS; the angular deviation decreased between the 12-foot and 72-foot distances on 60% of the trials (57 of 95 crossings; chance factors would predict such decreases on 50% of trials).

Beaconing APS

The participants' average performance on the beaconing APS trials resulted in linear deviations that were within the crosswalk at all three lengths of crosswalk. Despite their relatively equivalent performance on 12-foot crossings regardless of the cue, for the 36-foot crossings the participants in the APS condition performed the task more successfully than they did with the bar tile, $F(1, 18) = 33.56$, $p < .001$, or RIAS $F(1, 18) = 33.23$, $p < .001$. These differences became greater as the length of the crosswalk increased to 72 feet.

Although the average linear deviations were within the crosswalk for all three lengths of crossings, there was a significant simple main effect as the length of the crossing increased: $F(2, 36) = 8.73$, $p < .001$. The participants' performance worsened some as the length of the crossing increased from 12 to 36 feet, $F(1, 18) = 31.78$, $p < .001$, and then remained stable between 36 feet and 72 feet, $F(1, 18)$ $p < 1.0$. The participants' overall average performance still reflected crossings completed within the crosswalk, but about a third of the participants at 36 feet and a quarter of the participants at 72 feet had average linear deviations that placed them outside the crosswalk. However, these participants were, on average, only about 1 foot outside the crosswalk, much less than with the RIAS or bar tile cues. With regards to midcross course corrections, the angular deviation dropped between the 12-foot and 72-foot recordings on 85% of the trials (81 of 95 crossings).

Guidestrip and edgestrips

At 36 feet, the participants were more successful with the guidestrip than with the bar tile, $F(1, 18) = 54.78$, $p < .001$, or RIAS, $F(1, 18) = 62.72$, $p < .001$, and the effect was magnified at 72 feet. The average linear deviation from the center of the crosswalk remained the same for all three lengths of crosswalks in the guidestrip condition, $F(2, 36)$ $p < 1.00$. Moreover, each of the 19 participants had an average linear deviation of 3 feet or less at all the distances.

The participants performed the task more successfully with the edgestrips than with the bar tile, $F(1, 18) = 66.09$, $p < .001$, or RIAS, $F(1, 18) = 71.47$, $p < .001$, at 36 feet, and again, the effect was even larger by 72 feet. The average linear deviation from the center of the crosswalk remained statistically equivalent for all three lengths of crosswalks in the edgestrips condition, $F(2, 36)$ $p < 1.00$]. The main difference between the performance with the edgestrips and guidestrip was that when a participant did travel outside the crosswalk, the magnitude of errors was far larger in the edgestrips condition. Two participants had average linear deviations greater than 3 feet after traveling 36 feet, with a combined average of 8.7 feet (that is, 5.7 feet outside the crosswalk). By 72 feet, the combined average linear deviation of these two participants was 21.8 feet (that is, 18.8 feet outside the crosswalk). The data for one of these two participants were included in the outlier replacement described earlier, and the substituted value was used in the analyses already reported.

Time to complete a crossing

While we have provided strong evidence that the edgestrips, guidestrip, and prototype APS serve as good sources of heading information, another consideration is how the various cues affect the time needed to complete a long crossing. A one-way repeated-measures ANOVA revealed differences in the average time needed to complete the 72-foot crossing with the different cues: $F(4, 72) = 6.08$, $p < .001$. The participants were the fastest in the bar tile condition ($M = 19.6$ seconds, average walking speed of 3.7 feet per second), a condition that resulted in very poor wayfinding performance; the next-fastest with beaconing APS ($M = 20.5$ seconds, average walking speed of 3.5 feet per second); and the slowest with edgestrips ($M = 22.9$ seconds, average walking speed of 3.1 feet per second). Their performance was intermediate with the guidestrip or RIAS ($M = 22.3$ and 22.8 seconds, respectively).

Subjective responses

The participants' subjective ratings of how useful they found the various cues to be for the purposes of initial alignment and for maintaining heading matched the objective measures. A one-way repeated-measures ANOVA of the ratings for the five cues as alignment cues was significant: $F(4, 72) = 5.60$, $p < .001$. On a scale of 1 to 5 (not at all useful to very useful), the participants' average scores were the highest for the guidestrip and APS (4.7 and 4.6, respectively); edgestrips had an average score of 4.2, and the bar tile and RIAS scores were the lowest (3.8 and 3.5, respectively). When the participants were asked to rate each cue for how useful it was for traveling straight across the crosswalk, the same general pattern emerged (guidestrip: 4.9, APS: 4.7, edgestrips: 4.4, RIAS: 3.5, and bar tile: 3.1). The overall analysis of the ratings was significant: $F(4, 72) = 15.75$, $p < .001$.

Some participants also offered preferences and rationales for their preferences. APS was the overwhelming preference, with 12 of 17 participants indicating that it was their favorite cue; the remaining 5 selected either edgestrips or the guidestrip. Of 13 participants who reported a least favorite cue, 8 indicated RIAS, 4 indicated the bar tile, and 1 indicated APS. The principal concerns were that the RIAS requires too much effort and attention, as well as the use of one's free hand, and that the bar tile could be easily missed and does not assist with maintaining a heading.

Discussion

Pedestrians who are blind may benefit from cues that are designed to help them stay in a crosswalk, especially while crossing at locations where little or no traffic is traveling parallel to the crosswalk, such as at wide crossings of some arterial roadways, T-intersections, midblock crossings, or crosswalks at roundabouts and channelized turn lanes. Three of the five cues we tested resulted in maintaining an accurate heading over distances as great as a six-lane crossing: a beaconing APS with far-side features, a tactile guidestrip, and tactile edgestrips. These three were also rated more highly by the participants than were the other two for usefulness in providing information on both their alignment and their heading. The two additional cues, bar tile perpendicular to the intended direction of travel and RIAS, provided good accuracy only for the distance of a single lane.

It is useful to consider why some of the cues resulted in inaccurate headings, and given the simulated environment used in this experiment, it is useful to consider some factors that could make certain cues more or less successful or practically useful at actual crossings.

The bar tile cue provides information on alignment and the initial heading, but provides no information on the heading after crossing has begun. It is thus not surprising that the cue was shown to be an ineffective heading cue for crossing the distance of three or more lanes of travel. However, the results indicate that the bar tile may be a sufficient heading cue for crossing the distance of one lane of travel and may therefore be a good option where there is a single lane to be crossed, such as at some roundabouts and channelized turn lanes. No installation guidance has yet been proposed for this cue, however, and it may be unlikely that installing bar tiles on a curb ramp, together with the required detectable warning, will be acceptable. Another option may be to install bar tiles on the landing or flare of a curb ramp.

The prototype beaconing APS resulted in excellent accuracy and was highly rated by the participants. It also resulted in the fastest crossings of the treatments that provided good heading results. However, the experiment was conducted in a controlled environment with little noise interference from other sources. Beaconing APS may be harder to hear in real-world conditions where traffic and other ambient noise may interfere with pedestrians' ability to hear or localize the audible beacon, although preliminary data from one intersection are promising (Barlow et al., 2009). Use of a beaconing APS would be limited to signalized crossings.

Like the APS beacon, RIAS may be harder to hear in real-world conditions with higher ambient sound. However, at crossings that were shorter than in our research and where there was a strong parallel flow of traffic at three of four crosswalks, Crandall et al. (1999, 2001) demonstrated improved heading with RIAS in comparison to traffic cues alone.

Both the guidestrip and edgestrips resulted in participants staying within the crosswalk on most crossings, and both were highly rated by the participants. The participants used the constant-contact cane technique with the guidestrip; thus, if they veered away from it, they were likely to be aware of the fact almost immediately. In the edgestrips condition, the participants were to travel on what they believed to be the correct heading and make use of any contact with one of the edgestrips to make a correction and stay within the crosswalk. With such an approach, if pedestrians who are blind crossed an edgestrip without realizing it, they would be likely to continue traveling on the wrong heading while assuming that they were still within the crosswalk. Two participants crossed an edgestrip, resulting in large errors. Although the participants were instructed not to follow the edgestrips once they encountered an edgestrip, it was common for them to follow it for the rest of the crossing.

Guidestrips or edgestrips also may be affected by real-world conditions, such as cars idling on the tactile materials making them hard to find or follow, resurfacing that covers the strips, and snow and ice conditions that make it difficult to maintain the materials. In addition, because gutter widths and conditions vary, it may sometimes be difficult for users to find the strips. There does not seem to be any wayfinding advantage to edgestrips compared to guidestrips, and therefore the installation and maintenance of two strips at crossings, rather than a single strip, does not seem to be warranted. A guidestrip may be the preferred cue at nonsignalized crossings.

Of the three conditions that resulted in excellent heading performance, the average participant completed the 72-foot crossing with the beaconing APS in 20.5 seconds, the guidestrip in 22.3 seconds, and the edgestrips in 22.9 seconds. The difference of 2.4 seconds between the APS and edgestrips may seem small, but it is important to recognize that at signalized intersections it is sufficient to affect whether a pedestrian is able to complete a crossing within the time allotted for pedestrians. The *Manual on Uniform Traffic Control Devices* (MUTCD, U.S. Department of Transportation, 2009) uses a walking speed of 3.5 feet per second for the timing of pedestrian clearance intervals. The average walking speed with the beaconing APS was 3.5 feet per second and 3.1 feet per second with the edgestrips, somewhat slower than the MUTCD walking speed.

Having demonstrated that people who are blind are able to use several cues to improve their ability to stay within simulated crosswalks significantly and meaningfully, this program of research is being continued in several U.S. cities at actual complex intersections where vehicular travel is either not parallel to crosswalks or is not reliably present. It will also assess whether the cues provide any "added value" at crosswalks with strong traffic flows parallel to a crosswalk.

References

Barlow, J. M., Bentzen, B. L., Sauerburger, D., & Franck, L. (2010). Teaching travel at complex intersections. In W. Wiener, R. Welsh, & B. Blasch (Eds.), *Foundations of orientation and mobility* (3rd ed., Vol. 2, chap. 12). New York: AFB Press.

Barlow, J. M., Scott, A. C., & Bentzen, B. L. (2009). Audible beaconing with accessible pedestrian signals. *AER Journal: Research and Practice in Visual Impairment and Blindness, 2*, 149–158.

Bentzen, B. L., Barlow, J. M., & Bond, T. (2004). Challenges of unfamiliar signalized intersections for pedestrians who are blind: Research on safety. *Transportation Research Record: Journal of the Transportation Research Board, 1878,* 51–57.

Crandall, W., Bentzen, B. L., Myers, L., & Brabyn, J. (2001). New orientation and accessibility option for persons with visual impairment: Transportation applications for remote infrared audible signage. *Clinical and Experimental Optometry, 84*, 120–131.

Crandall, W., Brabyn, J., Bentzen, B., & Myers, L. (1999). Remote infrared signage evaluation for transit stations and intersections. *Journal of Rehabilitation Research and Development, 36*, 341–355.

Elias, H. (1974). A tactile guidestrip for blind pedestrians. *New Outlook for the Blind*, *68*, 322–323.

Gómez, J. P. (1991). Urban elements which limit the mobility of the visually impaired and suggestions for their elimination. *Proceedings of the 6th International Mobility Conference*. Madrid, Spain: The Scottish National Organization of the Blind (ONCE).

Guth, D. A., Hill, E. W., & Rieser, J. J. (1989). Tests of blind pedestrians' use of traffic sounds for street-crossing alignment. *Journal of Visual Impairment & Blindness, 83*, 461–468.

Guth, D. A., & LaDuke, R. O. (1994). The veering tendency of blind pedestrians: An analysis of the problem and literature review. *Journal of Visual Impairment & Blindness, 88*, 391–400.

Hill, E. W., & Ponder, P. (1976). *Orientation and mobility techniques: A guide for the practitioner*. New York: American Foundation for the Blind.

Institute of Transportation Engineers. (2004). *ITE hosts Curb Ramp and Wayfinding Workshop*. Retrieved from http://www.ite.org/accessible/curbramp

Kallie, C. S., Schrater, P. R., & Legge, G. E. (2007). Variability in stepping direction explains the veering behavior of blind walkers. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 183–200.

La Grow, S., & Weessies, M. (1994). *Orientation and mobility: Techniques for independence*. Palmerston North, New Zealand: Dunmore Press.

Laroche, C., Giguere, C., & Poirier, P. (1999). *Evaluation of audible traffic signals for visually impaired pedestrians.* Ottawa, Canada: University of Ottawa.

Laroche, C., Leroux, T., Giguere, C., & Poirier, P. (2000, August). *Field evaluation of audible traffic signals for blind pedestrians*. Paper presented at the 44th annual meeting of the Human Factors and Ergonomics Society, San Diego, CA.

Marston, J. R. (2002). *Towards an accessible city: Empirical measurement and modeling of access to urban opportunities for those* *with visual impairments, using remote infrared audible signage*. Unpublished doctoral dissertation, University of California, Santa Barbara. Retrieved from http://www.uctc.net/research/diss072.pdf

Rouse, D., & Worchel, D. (1955). Veering tendency in the blind. *New Outlook for the Blind, 49*, 115–119.

Scott, A. C., Barlow, J. M., Bentzen, B. L., Bond, T. L. Y., & Gubbe, D. (2008). Accessible pedestrian signals at complex intersections: Effects on blind pedestrians. *Transportation Research Record: Journal of the Transportation Research Board, 2073,* 94–103.

Scott, A. C., Barlow, J. M., Guth, D. A., Bentzen, B. L., Cunningham, C. M., & Long, R. (2011). Nonvisual cues for aligning to cross streets. *Journal of Visual Impairment & Blindness, 105,* 648–661.

Shimizu, O., Murakami, T., Ohkura, M., Tanaka, I., & Tauchi, M. (1991). Braille tiles as a guiding system in Japan for blind travelers. *Proceedings of the 6th International Mobility Conference*. Madrid, Spain: The Spanish National Organization of the Blind (ONCE).

Tauchi, M., Sawai, H., Takato, J., Yoshiura, T., & Takeuchi, K. (1998, July). *Development and evaluation of a novel type of audible traffic signal for the blind pedestrian.* Paper presented at the 9th International Mobility Conference, Atlanta, GA.

U.S. Department of Transportation, Federal Highway Administration. (2009). *Manual on uniform traffic control devices for streets and highways*. Retrieved from http://mutcd.fhwa.dot.gov/pdfs/2009/mutcd2009edition.pdf

Wall, R. S., Ashmead, D. H., Bentzen, B. L., & Barlow, J. (2004). Directional guidance from audible pedestrian signals for street crossing. *Ergonomics, 47*, 1318–1338.

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