Nonvisual Cues for Aligning to Cross Streets

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Abstract: Accurately aligning to a crosswalk is an important component of safe street crossing for pedestrians who are blind. Six alignment cues were evaluated in a simulated crosswalk environment in which the angle of the crosswalk was not always in line with the slope of the ramp. The effectiveness of each cue is reported and implications are discussed.

For individuals who are blind, the tasks required to cross a street include detecting the street, locating the crosswalk or crossing location, aligning (determining the appropriate initial heading), determining an appropriate time to cross, and traveling on an appropriate heading until the crossing is completed (Guth, Rieser, & Ashmead, 2010; Tauchi, Sawai, Takato, Yoshiura, & Takeuchi, 1998). The study reported here is the first of a series that evaluates the effectiveness of various treatments as aids for alignment and for maintaining the correct heading while crossing streets without vision.

Orientation and mobility (O&M) specialists teach various strategies for aligning one's facing direction with the direction of a crosswalk before initiating a street crossing. It is assumed that an appropriate facing direction leads to an appropriate initial heading once the pedestrian begins to cross. If individuals who are blind are misaligned, they may misinterpret traffic sounds (for example, they may think that turning traffic is traveling straight through the intersection), dog guides may aim for an incorrect corner or island, and an individual's first step may be toward moving traffic. Some alignment strategies involve the use of physical cues, such as grasslines and returned curbs (curbs along the edges of curb ramps), that are perpendicular to the street

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that is about to be crossed (Hill & Ponder, 1976; Whipple, 2004). Others involve acoustic cues, such as the sounds of traffic moving parallel or perpendicular to the crosswalk (Barlow, Bentzen, Sauerburger, & Franck, 2010; Guth et al., 2010; Stollof, 2005b). At modern intersections, however, such cues may be unavailable. For example, at a curb ramp, grasslines at the sides of the ramp, if present, are rarely aligned with the crosswalk. Parallel and perpendicular patterns of the movement of traffic often do not occur at some crosswalks, such as crosswalks at roundabouts and channelized turn lanes, and may be unreliable at other crosswalks, such as those where the volume of traffic is low during parts of the day.

The installation of curb ramps at many intersections has further complicated the alignment task. In the United States, curb ramps often slope toward the center of the intersection, rather than in the direction of the crosswalk (see Figure 1), which sometimes results in pedestrians who are blind crossing toward the center of the intersection (Hauger, Rigby, Safewright, & McAuley, 1996).

Even when separate curb ramps serve the two crosswalks on a corner, the large radius of many corners results in curb ramps at which the slope is out of line with the crosswalk to be perpendicular to the edge of the street and the gutter. Curb ramp slopes are required to be perpendicular to the gutter to minimize the tipping hazard for wheelchair users. Although some curb ramps are aligned with the crosswalks they serve, it is not known whether the slope of the ramp actually provides a useful cue to alignment for pedestrians who are blind. In areas where sidewalks are narrow, parallel ramps are often used, in which the sidewalk itself slopes down to an area that is level with the street (see Figure 2). At a parallel ramp, the sidewalk often curves, and this curvature can affect the direction the pedestrian is facing upon arrival at the street.

Previous research evaluated alignment on the basis of traffic sounds, tactile arrows, and bar tiles. Chew (1986) and Guth, Hill, and Rieser (1989) assessed the skill with which experienced pedestrians who were blind aligned themselves parallel and perpendicular to traffic that ranged from a single car to heavy traffic. Their findings suggested that under geometrically ideal conditions, traffic sounds can be used to align to within about 10 degrees of the desired direction. At complex intersections without special alignment cues, blind pedestrians have been found to be misaligned prior to crossing between 24% and 50% of the time (Barlow, Bentzen, & Bond, 2005; Scott, Barlow, Bentzen, Bond, & Gubbe, 2008; Crandall, Brabyn, Bentzen, & Myers, 1999).

Tactile arrows are incorporated into the pushbuttons of Accessible Pedestrian Signals (APS) to enable users to confirm which crosswalk is controlled by the pushbutton. Individuals at a workshop on the alignment of curb ramps suggested that tactile arrows may also aid pedestrians in aligning to cross a street (Stollof, 2005b). However, Poulsen (1982) found that the presence of an "arrow" (a 2.5-inch-long rod mounted atop an APS) did not improve the accuracy of alignment. Tauchi, Takeda, Nakamura, and Takato (2007) found that when participants aligned with tactile arrows as long as 8 inches, they were able to stay within a

Figure 1. Intersections with perpendicular curb ramps in which (A) the ramp slopes in the direction of travel on the crosswalk and (B) the ramp slopes toward the center of the intersection.

10-foot-wide by 30-foot-long path on only 75% of the trials; shorter arrows resulted in poorer accuracy.

Takeda, Watanabe, Takahashi, and Tauchi (2006) investigated the ability of participants who were blind to walk in a straight line for approximately 30 feet when they used a standardized Japanese guiding surface of bar tiles to establish their initial heading. The participants deviated from the intended heading the least when the bars were oriented perpendicular to the intended direction of travel.

In the study presented here, we assessed the precision of alignment under six cue conditions: ramp slope alone and

Figure 2. Intersection with parallel ramps used in the sidewalk.

ramp slope in combination with each of five other cues. The cues were ones that have been suggested in the literature as alignment cues, are used as alignment cues in other countries, or are advertised or sold as alignment cues. In the combination conditions, the ramp slope and the other cues were sometimes aligned in the same direction and sometimes in conflicting directions. Because of the variety of configurations of curb ramps in the United States and the difficulty of installing any configuration consistently (Kirschbaum et al., 2001), we assumed that any alignment cue would need to be installed either on curb ramps or on the flares (the sloping sides) of curb ramps, and would often be on a surface that did not slope in the direction indicated by the cue. If a cue provides good information on alignment even when it is misaligned to the slope, we speculate that it should work as well or better on a level surface, such as the landing of a parallel curb ramp.

Methods

Alignment cues and apparatus

The alignment cues evaluated in this study are shown in Figure 3 and described next.

Slope only

The slope-only condition (the running slope of the ramp) was included because it has been assumed to provide useful information for alignment, although this assumption has never been documented. For example, the draft of the Public Rights-of-Way Accessibility Guidelines, Advisory R303.1 (U.S. Access Board, 2005), advises aligning the slope of the ramp with the direction of pedestrian travel at crosswalks to provide wayfinding information for pedestrians who are visually impaired (that is, are blind or have low vision).

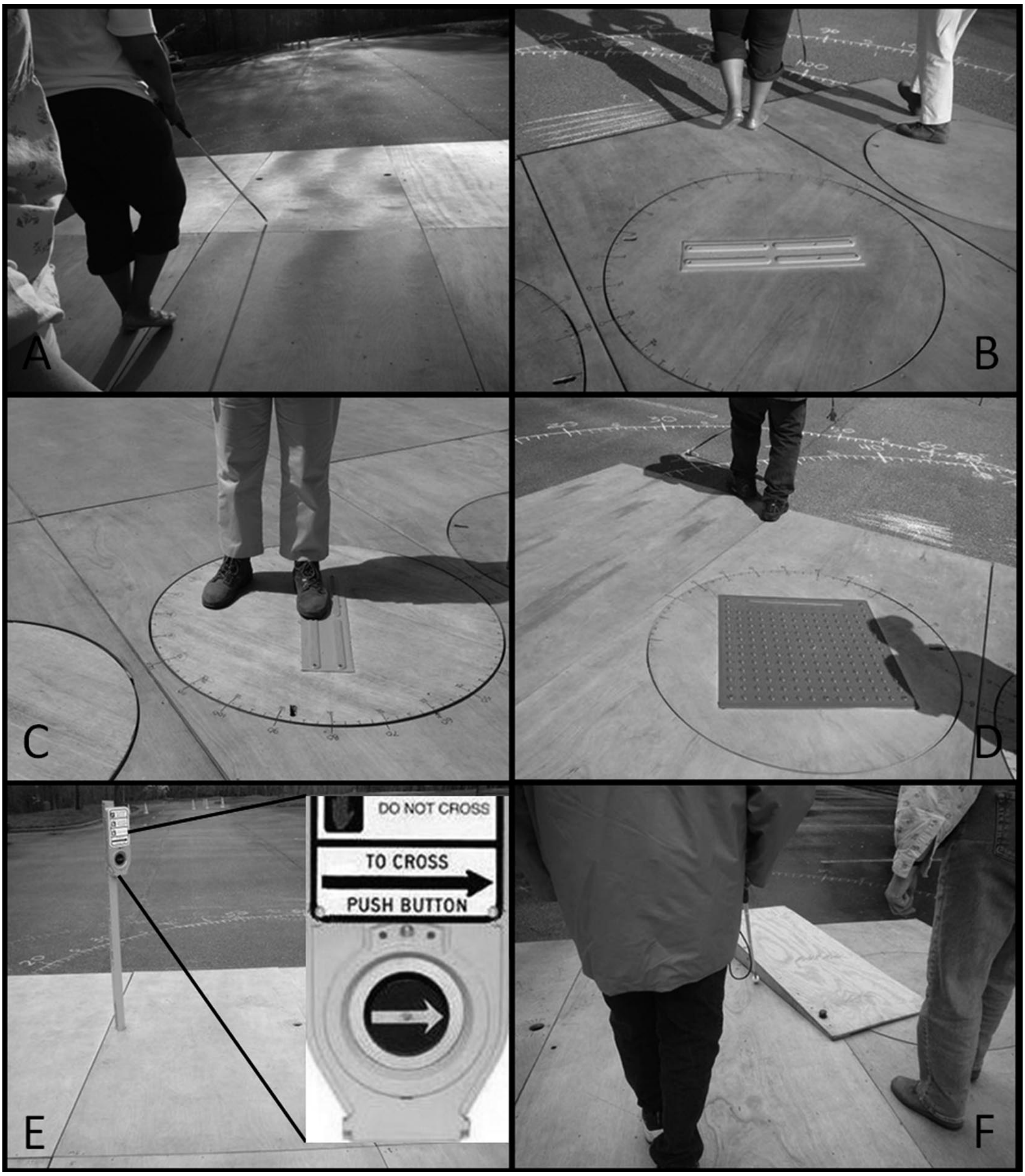

Figure 3. Alignment cues and apparatus (details in the text).

Bar tile perpendicular

The bar tile perpendicular cue constitutes two parallel raised bars that are arranged perpendicular to the intended direction of travel. It was included because Tauchi et al. (2007) found that bar tiles that are arranged in this way promote a more accurate initial heading than do bar tiles that are arranged parallel to the intended direction of travel.

Bar tile parallel

The bar tile parallel cue was the same configuration of tiles used in the perpendicular condition but with the raised bars arranged parallel to the intended direction of travel. It was included because it is commonly used internationally as a guidance surface.

Detectable warning with a bar tile

The detectable warning with a bar tile cue was a modification to the truncated dome detectable warnings that are required at curb ramps in the United States (U.S. Access Board, 2005) and in many other countries. In the United States, detectable warnings indicate the edge of the street and are not intended to indicate a direction of travel. However, installation standards in the United Kingdom, Australia, and New Zealand require that truncated dome surfaces be installed perpendicular to the direction of travel on a crosswalk (Department of Transport, 2002; Standards Australia/Standards New Zealand, 2002).

In an unpublished pilot study that also focused on alignment, Long, Barlow, and Bentzen (2007) assessed cues that included an unmodified detectable warning. The participants who were blind were unsuccessful in aligning with the detectable warning, so this cue was not included in our study.

Because Tauchi et al. (2007) found that establishing a heading from raised bars perpendicular to the intended direction of travel resulted in relatively accurate travel, we hypothesized that substituting a single raised bar, perpendicular to the direction of travel, for the bottom two rows of truncated domes on a detectable warning pattern might enable relatively accurate alignment. If this proved to be the case, a single cue (detectable warning with bar) might be used to provide both edge-of-street information and a cue for alignment. The raised bar on this prototype surface was 18 inches long, so users of most wheelchairs could avoid traversing the bar by placing it between their wheels.

Arrow

The arrow cue consisted of a tactile arrow on a pedestrian pushbutton mounted 42 inches above the surface of the ramp. For half the participants, the pushbutton was on the left, and for the other half, the pushbutton was on the right. This condition was included because a tactile arrow aligned with the direction of travel on the associated crosswalk is required on the pushbuttons of APS in the United States (U.S. Department of Transportation, 2009). The arrow is intended primarily to indicate which crossing is actuated by pressing the button. However, if the tactile arrow enables accurate alignment, the use of the arrow for alignment could be encouraged.

Returned curb

Where a curb ramp is completely contained within a nonwalking surface (for example, a planting strip), the sides of the curb ramp can include steep vertical boundaries (that is, a returned curb). The returned curb cue consisted of a simulated curb mounted on one side of a ramp. A returned curb has been assumed to provide alignment information to pedestrians who are blind. For example, Stollof (2005a, p. 27) suggested: "The returned curbs give good cues to crosswalk direction." This assumption was not tested before.

Each cue was attached to a ramp structure. Figure 4 shows the profile of the

Figure 4. Experimental platform with landing and ramps.

structure that was constructed of plywood and positioned on a level area in a quiet, paved parking lot. The 16-foot by 24-foot structure had a landing (representing the sidewalk at the top of a ramp) with four 4-foot-wide by 8-foot-long ramps, at a slope of 1:12, secured to the landing on each side, with the ramps also secured to each other. The directional cues that we evaluated were mounted on the two inside ramps on each side of the landing, with the outside ramps used to provide a safety zone so that the participants did not step off the side of the raised structure.

As is shown in Figure 3, some of the ramps were outfitted with inlaid rotating circles to which various underfoot tactile directional cues were attached. The circles were locked in place on each trial so the orientation of the cue could be positioned in one of the following seven positions: 0 degrees (in line with the ramp slope) and 15, 30, and 45 degrees to the right and left of the ramp slope (Figure 3D shows a cue oriented at 45 degrees left). Other cues were mounted atop the ramps and could likewise be rotated to each of the seven positions (see Figures 3E and 3F).

Measurement of alignment

The measurement of alignment has traditionally involved measuring the facing direction of the body. For example, Guth et al. (1989) used a shoulder-mounted compass in studies of the use of traffic sounds for alignment. There are several practical problems with this approach, the greatest of which is the calibration of the compass such that its orientation relative to the body is known. This and other practical problems involved in the use of a compass were detailed by Guth (1986). There is also the conceptual problem of assuming that the facing direction of one's trunk reflects one's future heading. In other words, one's facing direction is interpreted as predicting one's initial walking direction.

In our study, we took a more direct approach by measuring a participant's heading over the first 10 feet of walking. Once the participants decided they were aligned, they walked forward and, while doing so, crossed over arcs at two distances from the alignment cue. The first arc was near the starting location and can be seen along the outside edge of the circles shown in Figures 3B–3D. Similar arcs were drawn for the conditions that did not use an inlaid circle (Figures 3A, 3E, and 3F), but these arcs cannot be seen in the photographs. In the same manner, arcs with radii of 10 feet were drawn on the asphalt using chalk (see Figures 3B and 3D). The location at which the left side of the participant's left heel crossed these arcs was recorded. The two recorded locations for a given test surface and trial allowed us to calculate the participant's initial heading.

Participants and procedure

All 20 participants were blind (that is their vision was no more than light perception) and were experienced long cane users, although some customarily used dog guides. The study was approved by the Boston College Institutional Review Board, and all the participants gave their informed consent prior to participating.

Before the first experimental condition, the participants were oriented to the ramp structure, and before each cue condition they were shown the cue (including exploring the underfoot cues with their hands) and how the orientation of the cues would be changed from trial to trial. The exception was the slope-only condition, before which the participants were instructed that they would be approaching the slope from an angle and should try to align themselves so they were walking straight down the slope of the ramp. Before each cue condition, the method for using the cue was first explained in general terms (for example, “align your feet in the same direction as the underfoot bars”), and then a variety of strategies for using the cue were suggested, with the participants adopting whatever method they preferred, including methods not mentioned. For example, in the condition shown in Figure 3C, the participants were told that they could put one foot to the side of one of the bars, put a foot between the bars, put one or both feet atop the bars, straddle the bars, or use any other strategy that they thought would be effective. For each cue condition, the participants practiced for as many trials as they wished until they felt confident in their use of the cue.

For each trial, the participants were guided to the level landing by an O&M specialist and positioned facing one of the ramps at randomly varied distances. They then walked forward onto the ramp using their long canes, located the alignment cue, used the cue to establish a heading, and then walked down the ramp and continued beyond the 10-foot arc. Several feet after passing the arc, the participants were asked to stop walking and were guided back to the landing for the next trial.

The participants completed eight trials per alignment cue, including two trials in which the cue was aligned with the ramp’s running slope (0 degrees), and one trial each with the cue positioned 15, 30, and 45 degrees to the right and to the left of the running slope. As we described earlier, for the slope-only condition, the participants approached the slope from different angles.

The trials were blocked such that the participants completed all eight trials with a given cue before moving on to the next cue. The order of the six cue conditions, as well as the order of the alignment orientations, was completely randomized for each participant. At the completion of the experimental trials, the participants were debriefed to obtain subjective information about which cue conditions they preferred and why.

Results

For each trial, the orientation of the alignment cue indicated the desired heading. Angular errors were computed as the absolute difference between the desired heading and the actual heading. Thus, the average angular error represents how far out of alignment the participants tended to be from perfect alignment. Smaller values represent better alignment than do larger values.

Table 1
Average angular errors by alignment cue condition.

Alignment cue	Average angular error (in degrees)
Slope only	10.2
Arrow	10.9
Returned curb	8.5
Bar tile, parallel	7.7
Bar tile, perpendicular	6.4†
Detectable warning with perpendicular bar	6.3*

*$p < .01$, †$p < .0125$ (when compared to the slope-only condition using the step-down Holm–Bonferroni procedure for alpha correction).

Table 2
Average angular errors by cue-slope misalignment angle.

Cue-slope misalignment angle (in degrees)	Average angular error (in degrees)
0 (aligned with slope)	7.6
15	7.7
30	9.4
45	9.7

The effect of the alignment cue on the average angular error

A one-way repeated-measures analysis of variance (ANOVA) revealed a significant effect of the alignment cue on the average angular alignment error: $F(5, 80) = 3.68$, $p < .01$, $\eta_p^2 = .187$ (see Table 1 for the means). The step-down Holm-Bonferroni procedure was used to evaluate single-degree-of-freedom planned comparisons between the slope-only condition and each other condition. Both the detectable warning with a perpendicular bar and the perpendicular bar tile resulted in significantly smaller errors in the initial alignment compared to the slope-only condition: detectable warning, $F(1, 17) = 11.66$, $p < .01$; bar tile, $F(1, 17) = 7.90$, $p < .0125$. No other comparisons were significant. Consistent with previous research, these results suggest an advantage for underfoot cues that can be oriented perpendicular to the desired direction of alignment.

Effect of the cue-slope misalignment

With the exception of the slope-only condition, the task for the participants was to base their heading on the alignment cue, not the ramp's running slope. We hypothesized that the greater the discrepancy between the two, the more heading error would occur. A one-way repeated-measures ANOVA revealed a significant effect of the cue-slope misalignment on the average angular error—$F(3, 57) = 2.96$, $p < .05$, $\eta_p^2 = .135$—the result of a linear trend of larger errors with greater angles of misalignment between the running slope of the ramp and the cue: $F(1, 19) = 4.81$, $p < .05$ (for the means, see Table 2).

This general pattern of results suggests that although slope alone is not a particularly useful alignment cue (as shown in Table 1), a running slope that is discrepant with an alignment cue by 30 degrees or more may have a deleterious effect on the usefulness of that cue. Furthermore, the data suggest that when the cue-slope misalignment was 30 or 45 degrees, the slope exerted a directional "pull" on the participants' paths of travel. On average, the participants veered in the direction of the ramp's running slope (for instance, in 45-degree left conditions, the average error was to the right of the direction indicated by the cue).

Subjective responses versus objective findings

After completing all the experimental trials, the participants were asked to indicate their preferred cue and the cue they found the least useful. It is interesting that the tactile arrow received the most first-place votes (7 out of 20), even though their alignment errors were the largest in that condition. Overall, there was no clear consensus with regard to the participants' preferences, with each of the five cues receiving 3–7 first-place votes. There was a far greater consensus regarding the least useful cue; 11 of 20 participants indicated that the detectable warning with a bar was the least useful and an additional 4 selected the slope-only condition. Once again, the data on the participants' subjective preferences were counter to the objective behavioral measures, since the detectable warning with a bar resulted in the most accurate alignment performance. Eight of the 11 participants who thought that the detectable warning was the least useful commented that the surface was "too busy," that it was difficult to distinguish between the bumps and the bar, and that it was difficult to detect the bar.

Discussion

To relate the alignment errors found in the study to an actual street crossing, consider the crossing of a four-lane road where a crosswalk is approximately 50 feet long. Assuming that pedestrians began walking in the center of a 6-foot-wide crosswalk and maintained their initial heading for the full distance and that there was neither veering from nor correction to the initial heading, with 4, 6, 8, and 10.5 degrees of initial misalignment, they would deviate 3.5 feet, 5.25 feet, 7 feet, and 9.25 feet, respectively, from the center line of the crosswalk. Given these assumptions, the pedestrians would not finish crossing within the crosswalk with even 4 degrees of initial misalignment. If the assumed crosswalk was 10 feet wide, the pedestrians would complete the crossing within the crosswalk only under the condition of 4 degrees of initial misalignment. The average angles of initial misalignment measured in the study ranged from 6.3 to 10.9 degrees. Accommodating a 10.5-degree initial misalignment would require a crosswalk that is at least 18.5 feet wide. Because many crosswalks are longer than 50 feet and veering from one's initial heading can reasonably be assumed (Cratty, 1967; Guth & LaDuke, 1994; Rouse & Worchel, 1955), even 4 degrees of misalignment could be a severe problem in the absence of information with which to adjust one's heading, such as the sound of parallel traffic (Guth et al., 1989). In contrast, substantially greater misalignment may be tolerable at shorter crosswalks, such as the typical 12-foot crosswalk at a single-lane roundabout. Using the same assumptions for a 50-foot crosswalk, it would require 14.5 degrees of initial misalignment for a pedestrian at a 12-foot crosswalk to leave the crosswalk before completing the crossing.

Not only was the running slope of the ramp found to be an inaccurate alignment cue, but it was found to interfere with the usefulness of the other cues when it was misaligned with those cues by 30 and 45 degrees. The good news is that there was little effect of this misalignment at 15 degrees, which suggests that minor discrepancies of alignment cues with a ramp's running slope may not be of much consequence. This pattern of findings supports attempting to align the slope of the curb ramp as closely as possible with the direction of travel on the crosswalk to maximize the usefulness of other sources of alignment information. It would be a benefit for wheelchair users as well, since turning near the curb to align with the crosswalk or ramp adds time and difficulty to their crossings (Kirschbaum et al., 2001).

In principle, alignment based on the perception of a running slope requires discriminating differences between the downward angle and the lateral forces on the body when walking or standing facing various directions relative to the running slope of the ramp. When oriented in line with the running slope, the downward angle of the foot (that is, the drop or heel-to-toe-angle) is at its maximum, and there is no lateral force on the body. As the foot or body is rotated relative to the ramp slope, the downward angle decreases and the amount of lateral force increases (for example, the foot rolls to the side). Although many parts of the body would likely be involved in detecting these differences, it may be an extremely difficult perceptual task. Consider, for example, that relative to standing in line with the 1:12 slope, a 15-degree rotation changes the downward heel-to-toe angle by only 0.16 degrees.

Although several participants subjectively preferred the tactile arrows as an alignment cue, this cue resulted in the least accurate performance. One possible explanation of this finding is that adjusting the alignment of the body with the pointing direction of the hand or arm is a difficult challenge of perceptual-motor coordination (Guth et al., 2010). That is, it may be that the participants were pointing accurately, but they were unable to face or walk in the direction they were pointing. Also, a number of participants independently decided to use a strategy of placing their upper arms, held in a relatively vertical position, against the arrow, a strategy that may have felt comfortable or natural to them, but had little possibility of providing accurate directional information. Although it is possible that a strategy exists that would result in good alignment from the arrow, such a strategy was not intuitively obvious to the participants, an important consideration in selecting an alignment cue.

The participants were also relatively poor at using the returned curb and using the bar tile when it was aligned parallel to the desired direction of travel. In these conditions, we observed that they often adopted strategies that involved aligning one foot with the cue. The other foot was commonly observed to point away from the cue, apparently reflecting the normal 5–10-degree V-like out-toeing ("angle of gait") of the feet that occurs when standing or walking (Rigas, 1984). When the participants began walking, they tended to bisect the angle of gait; that is, they walked in the direction of the center of the "V." When the aligned foot was the right foot, veering was often observed to be to the left of the direction indicated by the cue, and vice versa. Unfortunately, we did not collect the data necessary to make a strong claim in this regard.

However, their alignment was the most accurate when the participants aligned with a bar perpendicular to their feet, either the bar tiles or the detectable warnings with a bar. Individuals used different strategies, some putting their toes or heels on the bar, others centering the bar on the balls of their feet, and at least one person lining up the back of the heels against the bar. This finding is consistent with the findings of Takeda et al. (2006) that perpendicular bars resulted in more accurate alignment than did parallel bars. Although the participants in our study were the most accurate when using the detectable warning with a bar, they subjectively judged it to be the least useful cue. They had difficulty finding the bar on the detectable warning surface, often exploring the surface with their feet and canes for several minutes, or even bending down to touch the surface with their hands to confirm the location of the bar. This practice would clearly be unacceptable in an actual street-crossing environment.

Conclusion

For the cues evaluated in our study, the participants' performance was the best in the two conditions involving underfoot bars mounted perpendicular to the desired walking direction, intermediate for underfoot bars and a simulated curb oriented parallel to the desired direction of travel, and the worst for tactile arrows and the running slope of a curb ramp. Better performance might have been observed had the participants received more instruction and practice and been required to use a strategy from which it was possible to obtain good directional information. When the running slope of a curb ramp was misaligned with another alignment cue by 30 or 45 degrees, it tended to exert a directional pull on the participant's heading, which exacerbated the alignment error. Even the best alignment cues resulted in an average error of approximately 6 degrees, which at many—but not all—crosswalks would be sufficient to result in walking outside the crosswalk unless additional guidance cues were available during the crossing. At many intersections, additional cues may be available from traffic and other features of the intersections; however, there are also many intersections where such cues are either not available or are intermittent.

Although establishing an initial heading is important, pedestrians who are blind must also maintain a proper heading to remain within the crosswalk. Accurate initial alignment may not be sufficient to enable them to maintain an accurate heading, particularly for long crossings or those where there is little or no vehicular traffic parallel to the crosswalk. In the second study in this series (Scott et al., 2011), we evaluated the usefulness of cues for maintaining a proper heading over simulated street crossings of one-, three-, and six-lane streets (approximately 12, 36, and 72 feet).

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