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Beaconing Signalization Substantially Reduces Blind Pedestrians' Veer on Snow-Covered Pavement

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Abstract

Veering outside of crosswalks is a common problem experienced by individuals who are blind. One technology found to be effective for reducing this veer when other guidance cues are absent is audible beaconing. However, veering in general and veering from crosswalks in particular have been studied primarily on smooth, flat walking surfaces such as clear pavement. This experiment compared veering on clear pavement with veering on snow-covered pavement, with and without audible beaconing. Eleven blind participants traveling with long canes attempted to walk a straight path for 72 ft (21.9 m), a typical length of a six-lane crosswalk. Beaconing substantially reduced veering at 36 ft (11.0 m) and 72 ft from the starting point and enabled participants to remain within a simulated crosswalk. Walking on snow was not found to affect veering but did increase the number of steps taken. The findings suggest that in snowy and clear conditions alike, audible

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beaconing is an effective wayfinding tool for intersections equipped with accessible pedestrian signals.

Veering from crosswalks is an important practical problem that increases the street-crossing risk experienced by blind pedestrians. A growing body of evidence documents the effectiveness and value to blind pedestrians of equipping accessible pedestrian signals (APS) with audible beaconing as a means of reducing veering during street crossing. This section first summarizes and reviews the problem of veering and the use of audible beaconing to reduce veer. The section then develops the case for the present study, which assessed audible beaconing as a veer reduction strategy at a simulated 72 ft (22 m) crosswalk that was snow covered.

The veering of lost or blindfolded-sighted pedestrians and of blind pedestrians is a well-studied topic, initially investigated out of curiosity and reported in such papers as an 1893 *Scientific American* report, “Why Lost People Walk in Circles” (1). Recent interest has been motivated by basic questions about human motor control (2–4) and applied questions about the safety implications of veering for blind pedestrians, including the high risk that veering can create while crossing streets (5–7).

Veering has been measured over many walking distances, from a few feet to many miles, but this introduction is limited to distances relevant to crosswalks. In the most commonly used research protocol, blind or blindfolded-sighted participants, or both, stand in a quiet, open area such as a parking lot, use a physical cue to face (align in) a particular direction, and then attempt to walk straight in that direction until asked to stop. Many studies have shown that under these information-sparse conditions, participants would have veered far outside the boundaries of typical multilane crosswalks. These studies have also shown substantial variability within and between individuals. A synthesis of eight pre-1990 studies found that at 72 ft (22 m) from the starting location, the average blind or blindfolded-sighted research participant can be expected to be approximately 16.5 ft (5.0 m) to the left or right of the intended straight-line path (8). Later studies had comparable results (6, 7, 9, 10).

A second approach has been to measure blind pedestrians’ veer as they cross roadways at crosswalks equipped with APS. APS were originally developed to inform blind pedestrians of pedestrian signal-head status (11, 12), not to assist with finding the crosswalk, aligning in the direction of the crosswalk, or staying within the crosswalk (12, 13). Evidence that these wayfinding tasks remain problematic at many modern intersections (3, 14), including those with standard APS, has motivated a growing body of research about how to provide the wayfinding information needed for a crosswalk to be accessible to individuals with blindness and low vision (15–18). One goal of this accessibility-focused research is to contribute to FHWA efforts to support federal regulations that require that “aids, services, or benefits” for individuals with disabilities afford “equal opportunity to obtain the same result, to gain the same benefit, or to reach the same level of achievement as those provided to others” (19, 20).

Several studies have evaluated the efficacy of adding audible beaconing to APS, to reduce veering, thus reducing crossing risk at crosswalks. This strategy of providing an auditory

aiming point at the far end of a crosswalk was devised by Poulson (13) and is currently discussed in Section 4E.13 of the *Manual on Uniform Traffic Control Devices* (MUTCD) (21). The present study is a continuation of a line of research that began with studies that assessed the acoustic, timing, and location characteristics of various beacons (12, 14, 22, 23), after which a standard audible beacon, described later, was adopted for further study. These later studies all involved the measurement of veering with and without a beacon (9, 24, 25), along with other comparisons.

Individuals who are blind routinely cross streets, and they do so safely and efficiently. They use a variety of strategies and technologies to determine the crosswalk location, to align in the direction of the crosswalk, to determine when to initiate street crossing, and to remain in the crosswalk. At many crosswalks, the sounds of traffic and other naturally occurring cues are adequate for completing these tasks, provided that individuals have appropriate training and experience (14). At such locations, beaconing to reduce veer and other wayfinding technologies may not be needed. However, according to MUTCD guidance, audible beaconing should be considered when crosswalks are longer than 70 ft unless an APS-equipped median is present, at crosswalks that are skewed, and at intersections with irregular geometry (21). Audible beacons should also be considered on request of individuals with visual disabilities and when a study indicates that they would be beneficial.

In the most comprehensive study of audible beaconing to date, Barlow et al. measured the veering of blind pedestrians at nine crosswalks at large, complex, signalized intersections in three U.S. cities (24). Three guidance conditions were compared: standard APS only; APS plus a prototype tactile guide strip (a raised strip of polymer tape, marketed as a temporary rumble strip, which was accessed with the participants' long canes); and APS plus audible beacon. Crosswalk lengths ranged from 56 to 115 ft (17.1 to 35.1 m), and all crosswalks were 10 ft (3.0 m) wide, with the exception of one 8-ft (2.4-m) crosswalk. At various points during each crossing, veering was measured by recording participants' distance from the center of the crosswalk. Across all three intersections, in the standard APS condition, participants were outside of the crosswalk on 59.7% of measurements. For these measurements outside of the crosswalk, participants were 6 ft (1.8 m) or more outside of the crosswalk 48.5% of the time. The beaconing APS condition used a standard APS, plus a 1-Hz beaconing tone emitted from a loudspeaker mounted at the pedestrian signal head at the opposite end of the crosswalk. Beaconing was triggered by a button press of 1 s or more, after which participants heard seven repetitions of a loud tone from the opposite-end loudspeaker. They served as a cue to help identify the direction of the crosswalk. The onset of the "Walk" interval was communicated by typical, relatively quiet walk indications heard from a nearby APS. The louder beacon from the opposite end of the crosswalk sounded again for the duration of the flashing "Don't Walk" interval. In this condition, no participant missed the destination corner, although some were outside the crosswalk at the completion of crossing. (On some crossings, the pedestrian signal head was outside the crosswalk, so participants were actually being led to a destination outside of the crosswalk.) Across all three intersections, participants in the beaconing APS condition were outside of the crosswalk on 26.1% of measurements. Of these measurements outside of the crosswalk, participants were 6 ft or more away from the crosswalk 16.5% of the time.

Studies of audible beaconing to date have all been conducted on clear pavement, and they have evaluated other directional guidance cues. The only cue found thus far to be as effective as audible beaconing for guidance is a prototype raised guide strip attached to the pavement (9, 24, 25). However, many questions remain about the design and durability of guide strips (24). Guide strips may ultimately be effective in many situations, but not when they are snow covered. Not only does snow mask tactile cues such as guide strips (26, 27), but it also creates numerous other challenges to blind pedestrians at crosswalks. The inherently variable conditions of roadway snow and ice (26, 28) modify the sounds of traffic, sometimes muting it and sometimes amplifying it (26, 29). Consequently, vehicles may not only be more difficult to detect, but the predictability and therefore the usefulness of their sounds for directional guidance (30, 31) may be diminished. Long canes can frequently become stuck in snow and ice (32), causing more frequent starts and stops. This increases the time and number of steps needed to navigate a crosswalk. A 2007 biomechanical model of veering by Kallie et al. suggests that the directional variability of individual steps is a principal contributor to nonvisual veering (2). If so, the additional steps taken during snow travel could result in greater veering.

The present study was designed to address two questions. First, does walking in snow increase blind pedestrians' veering? Second, is audible beaconing as effective on snow-covered pavement as it is on clear pavement? This is the first study to address these questions, and like the other first studies in this line of research [e.g., Scott et al. (9)], it was conducted at a simulated crosswalk in a large, quiet, paved parking lot. This arrangement enabled the collection of data under well-controlled snow conditions.

METHOD

Participants

The participants were recruited among long cane users who had participated in other pedestrian-focused research at Western Michigan University (WMU) during the 3 years preceding this study. Of the 11 adult participants, 7 were totally blind, and 3 had light perception only. Light perception is the ability to detect the presence of ambient light and was not useful for the experimental task. One participant had slight peripheral vision in one eye and reported that this vision was not useful for the wayfinding task. As a precaution, the participant wore a blindfold during the experiment. The median age of the eight male and three female participants was 40 years, and the mean age was 41.5 years (SD = 15.8 years).

All participants used a long cane as their primary mobility tool, reported having normal hearing, and had received formal orientation and mobility (O&M) instruction. All were experienced snow travelers [see Couturier and Ratelle (28) for a review of long cane travel in snow], with most having recently participated in a related study (32) that involved traveling in snow for much longer distances than the present study. All participants' gaits appeared normal, and they had no other disabilities.

All participants provided informed consent and the methods described herein were approved by WMU's Human Subjects Institutional Review Board.

Experimental Design and Variables

The experiment used a 2 (walking surface) $\times$ 2 (beaconing condition) $\times$ 3 (measurement distance) repeated-measures design. The two levels of the walking surface factor were clear pavement and snow-covered pavement, referred to as clear and snow. All participants underwent the snow condition first, in February, followed by the clear condition in April. The two levels of the beaconing factor were beaconing and no beaconing, and the three levels of the measurement distance factor were 12 ft (3.7 m), 36 ft (11.0 m), and 72 ft (21.9 m) from the starting location (Start). The experiment was conducted over 6 days, with 3 days of testing for each walking-surface condition.

The experiment was conducted on weekends on an unobstructed, quiet section of a remote campus parking lot, shown in Figure 1. The remainder of the parking lot held a few vehicles, with almost no vehicle movement except for the arrival and departure of research participants. Except for the experimental beacon, no sound sources that might have provided directional cues were noticed by the research team or the participants. The site was flat, except for its slight drainage camber.

In the figure, the black stars and arrows show Start and the ideal straight-line walking path, respectively. For clarity, in Figure 1*b*, a stick figure of the tripod and beaconing speaker is superimposed over these items in the photograph to show their location relative to Start, with a photograph of the speaker head shown in the upper right.

Walking Surfaces—Figure 1 shows the experimental site under both walking-surface conditions. The Google Earth photograph in Figure 1*a* accurately represents the site as it appeared during the clear condition. Figure 1*b* shows the site from the perspective of Start on the first day of testing in snow.

Air temperature, which affected snow characteristics, was recorded at the beginning of each block of 10 trials per participant per condition. For the snow condition, the mean temperature was 31.9°F (SD = 8.0°F) (−0.05°C, SD = 4.4°C); and for the clear condition, the mean temperature was 57.9°F (SD = 7.3°F) (14.4°C, SD = 4.0°C). On the first and warmest day of winter testing, the snow was soft and slushy; the second day began with a base of hard-packed snow under approximately 1 in. of freshly fallen compactible powder to which was added an approximately 4-in. layer of soft snow; and the third and coldest day began with a hard-packed base of snow and ice under an approximately 5-in. layer of crisp snow that was less compressible than on the previous days.

At the beginning of each day of the snow condition, after refreshing the snowfield to an approximate total depth of 5 in., as needed, a truck and an automobile were driven back and forth across the snow-field, perpendicular to the intended line of travel. This provided an approximation of snow conditions at a tire-rutted crosswalk. The goal was a walking surface that was approximately 50% tire tracks, with Figure 2 showing typical patterns of these tracks. After the tracks were made, any remaining clumps of snow greater than 6 in. across were broken apart with hand shovels.

Between the activities of one participant and another, especially during the warmer conditions of the first day of the snow condition, it was sometimes necessary to add new snow to portions of the snow field and then re-create the tire tracks. Also between their activities, it was sometimes necessary to add snow to the area immediately ahead of Start. This area, which can be seen in the lower middle of Figure 1*b*, tended to become worn or slippery, or both, owing to the footsteps of the previous participant and the O&M instructor who accompanied the participant as a safety monitor. During the colder test sessions later in Day 2 and on Day 3, the site was frequently inspected for areas of bare ice. When these were found, the ice was treated with a biodegradable ice melt and traction-creating product, and the partially melted ice was then covered with approximately 5 in. of snow.

Beaconing APS—The beaconing apparatus was functionally the same as that evaluated in three other simulation and crosswalk studies of beaconing APS (9, 24, 25), except that the tripod-mounted beacon was actuated by a hardwired on–off switch near the location of the beacon rather than by a pedestrian push button at Start. The system was battery powered, with the loudspeaker mounted 9 ft above the ground, 84 ft from Start (Figure 1*b*). The beacon sounded at 1 Hz with a fundamental frequency of 880 Hz with added harmonics, compliant with MUTCD requirements for audible tones used as walk indications (21). These tones are also commonly used as APS locator tones. The beacon’s sound level was a theoretical nominal of 82 dB(A) at 1 m.

Procedure and Measures

At each session, a participant underwent 10 blocked trials with the beacon and 10 without, with the blocks counterbalanced across participants. On arrival for the first (snow) session, a participant reviewed the informed consent document (this had previously been sent electronically), asked questions, and gave informed consent. Participants wore athletic shoes or winter boots, and they wore the same footwear in both sessions.

Participants were then guided along the perimeter of the snowfield and then within its interior, using their preferred guidance technique. This continued until participants reported feeling comfortable walking in the snow with their long canes, which was usually after about 5 min of walking. Participants were also shown the end of the snow-field, opposite Start, where the snow gave way to clear or shoveled pavement. This general familiarization procedure was repeated at the beginning of the second session, when the pavement was clear. Before each of the two conditions per session (beaconing, no beaconing), the condition was demonstrated, and participants underwent two practice trials. Participants were offered additional practice, and several took one or two more practice trials for the first condition in which they participated. For the beaconing condition, participants were shown the beaconing apparatus during their practice trials.

All trials began with a participant’s back against the long edge of a 32-in. tall table that was fixed in place at Start (Figure 3), with his or her feet straddling a dot on the ground. Participants’ initial task was to align perpendicular to the table’s edge. They placed their upper legs or the back of their bodies against the table and also used their hands to feel the table edge. Using one’s body to face perpendicular to a physical cue is the most effective

known method of establishing a nonvisual walking trajectory (2, 9). Participants indicated when they believed themselves to be well aligned and began walking with their long canes after receiving confirmation that the research team was ready to begin. A participant's task was to attempt to walk straight ahead for 72 ft, the distance across a typical six-lane roadway. Participants walked until they crossed the final measurement line 72 ft from Start, and they were then asked to stop. In the beaconing condition, an experimenter at the beacon switched it on 4 s after a participant began walking, with the beacon remaining on until the participant crossed the final measurement line. The period of 4 s was selected because it is the minimum permissible "Walk" interval in the United States (21) and therefore is the earliest a beacon could be presented without overlapping with the audible walk signal of an APS. In prior studies at real-world crosswalks [e.g., Barlow et al. (24)], a 4-s "Walk" interval was commonly in use.

A participant's distance and direction (right or left) from the intended path was measured to the nearest inch at 12 ft, 36 ft, and 72 ft from Start, as illustrated in Figure 3. These distances represent typical widths of one, three, and six traffic lanes, respectively. Figure 3 also shows the boundaries of the hypothetical 26-ft (1.8-m) reference crosswalk used for this and previous studies. All trials were in the same direction, as shown in Figures 1 and 3. Participants were asked to walk at their normal walking speeds but were not otherwise given time constraints. No feedback about the direction or extent of veering was given until the end of the experiment, after all trials were completed. Participants were accompanied by an O&M instructor who could intervene in the event of a slip or fall. The instructor walked just behind and to the side of the participant. There were no falls, and the few observed slips involved slipping down from an uncompacted area of snow into a tire rut. Participants quickly recovered their balance, and no interventions were necessary. Participants were followed, at a distance of approximately 12 ft (3.7 m), by an experimenter who placed markers where the participant's midline crossed each measurement line. The location of these markers relative to the intended path was measured between trials. Another experimenter stood outside the measurement area and counted the steps taken on each trial. Participants knew that this experimenter randomly varied her location, to prevent potentially useful feedback. Also to prevent performance feedback, an instructor guided participants back to Start along circuitous routes between trials. After the second set of trials, when all trials had been completed, participants answered debriefing questions. The experimenters then provided general feedback to the participant about his or her performance and briefly described the findings of related studies of veering.

Measures of veering are inherently directional and require the use of unsigned error for some statistics and signed error for others (2, 33). Applied to the present study, absolute error is the mean of the absolute (unsigned) values of an individual's veering at a given measurement distance in a given condition. It reflects the amount of deviation from the intended path irrespective of whether the deviation was to the right or the left. Because unsigned errors do not permit a valid calculation of within-participant variability, variable error, the standard deviation of a participant's signed errors in a condition, is used to reflect trial-to-trial variability. The mean of signed errors, constant error, is used to assess whether there are left-right directional biases in veering.

Analyses

On completion of descriptive statistical procedures, a three-way repeated-measures analysis of variance was used to address the primary research questions (34). The Greenhouse-Geisser degree of freedom correction was used in case of the violation of the sphericity assumption. Checks for the presence of overall directional biases (constant error) in each condition were accomplished with a one- sample *t*-test. A significance level of .05 was used for all statistical tests (two-tailed). Bonferroni correction was used for post hoc pairwise comparisons. The statistical power was at least .92 for all analysis of variance and *t*-tests when a very large effect size ($f = .65$ or $d = 1.3$) was assumed, in accordance with the effect sizes obtained in similar previous studies (6, 24). All statistical analyses were conducted with SPSS version 22 except the power analyses, which used G*Power version 3.1.9.2 (35, 36).

RESULTS

Absolute Error

The three-way interaction among walking surface condition, beaconing condition, and measurement distance was not significant: $F(1.12, 11.22) = .88, p = .431$. The two-way interaction between beaconing condition and measurement distance was significant: $F(1.07, 10.72) = 61.16, p < .001$ (Figure 4), while the two-way interactions between the walking surface condition and beaconing condition, $F(1, 10) = 1.34, p = .274$, and the walking surface condition and measurement distance, $F(1.02, 10.16) = .218, p = .806$, were not significant. Given the significant interaction between beaconing condition and distance, simple effects, rather than the main effects, were examined in the analyses of these two variables (36). At 12 ft, the absolute error with beaconing ($M = 7.9$ ft, $SD = 3.8$ ft) was not significantly different from that without beaconing ($M = 8.4$ ft, $SD = 2.9$ ft), $t = .49, p = .633$. In contrast, at 36 ft, the absolute error with beaconing ($M = 21.0$ ft, $SD = 15.8$ ft) was significantly smaller than without beaconing ($M = 41.3$ ft, $SD = 11.4$ ft), $t = 4.96, p = .001$. This difference was present at 72 ft as well. At 72 ft, with beaconing, the mean absolute error was 28.2 ft with a standard deviation of 22.9 ft, and without beaconing, the mean was 140.7 ft with a standard deviation of 52.6 ft, $t = 8.01, p < .001$. The main effect of walking surface condition (snow versus clear) was not significant. In snow, the mean absolute error was 42.1 ft with a standard deviation of 19.9 ft, and on clear pavement the mean was 40.4 ft with a standard deviation of 19.9 ft, $F(1, 10) = .03, p = .857$.

Variable Error

The results of the analyses of variable error mirrored those for absolute error. The three-way interaction among walking surface condition, beaconing condition, and measurement distance was not significant, $F(1.02, 10.25) = 2.93, p = .076$. The only significant two-way interaction was the interaction between beaconing condition and distance, $F(1.04, 10.44) = 93.96, p < .001$; therefore, simple effects were examined in the analyses of these two variables. At 12 ft, the variable error with beaconing ($M = 6.9$ ft, $SD = 1.9$ ft) was not significantly different from that without beaconing ($M = 7.8$ ft, $SD = 2.1$ ft), $t = 1.30, p = .222$. In contrast, at 36 ft, the variable error with beaconing ($M = 17.4$ ft, $SD = 7.7$ ft) was smaller than that without beaconing ($M = 34.0$ ft, $SD = 10.7$ ft), $t = 6.47, p < .001$. At 72 ft,

with beaconing, the mean variable error was 23.6 ft with a standard deviation of 13.3 ft, and without beaconing, the mean was 109.4 ft with a standard deviation of 36.0 ft, $t = 9.41$, $p < .001$. The main effect of walking surface condition was not significant. In snow, the mean variable error was 37.4 ft with a standard deviation of 18.3 ft, and on clear pavement, the mean was 28.9 ft with a standard deviation of 9.9 ft, $F(1, 10) = 1.88$, $p = .201$.

Constant Error and Step Counts

No significant constant error was found in any of the conditions, including the snow condition ($t = -.29$, $p = .781$); clear pavement condition ($t = 2.00$, $p = .073$); beaconing condition ($t = 1.69$, $p = .122$); and no beaconing condition ($t = -.91$, $p = .382$). In addition, no significant constant error was found at any measurement distance: 12-ft distance ($t = -2.23$, $p = .050$); 36-ft distance ($t = .386$, $p = .708$); and 72-ft distance ($t = 1.66$, $p = .128$).

For the mean step counts per trial, the two-way interaction between walking surface condition and beaconing condition was not significant, $F(1, 10) = 1.28$, $p = .284$; therefore, the main effects of these two variables were examined. Participants took significantly more steps in the snow condition ($M = 42.4$, $SD = 13.2$) than in the clear pavement condition ($M = 35.2$, $SD = 6.0$), $F(1, 10) = 7.045$, $p = .024$.

DISCUSSION OF RESULTS

As shown in Figure 4, participants veered very little in the beaconing condition, staying within the simulated crosswalk, on average, for the full 72 ft. Without beaconing, they were in the crosswalk at 12 ft, which suggests that at single-lane crosswalks, veering is probably not a substantial problem for pedestrians who are initially well aligned. However, on average, participants without beaconing were outside the reference crosswalk at both the 36-ft and 72-ft distances. The most important practical finding is that audible beaconing was found to be as effective when one is walking in snow as when walking on clear pavement. In response to debriefing questions asked at the end of the second session, all but one of the participants reported walking toward the beacon as intuitive; for example, "I just listened and walked straight [toward the beacon]." This is not surprising, given that walking toward sound sources is a fundamental component of everyday nonvisual wayfinding as well as of O&M instruction (37).

The amount and variability of veering in the present study are very similar to the findings of previous experiments in which veering with and without audible beaconing has been measured on clear pavement. In both simulation and on-the-street studies, when an audible beacon is present, blind pedestrians quickly adjust their walking trajectory toward the beacon and then maintain that trajectory (9, 24). The dearth of reliable wayfinding cues at long or complex crosswalks has been discussed extensively in the literature, with a focus on ways to provide blind pedestrians with the same wayfinding information that is available to sighted pedestrians. This experiment contributes to the discussion by showing that audible beaconing may be an effective source of directional guidance at snow-covered crosswalks and clear crosswalks alike.

The finding that snow did not increase veering is interesting, given the findings of other researchers about the relationship of stepping and veering. According to the biomechanical model and data of Kallie et al., the “stepping noise” associated with taking more steps over a given distance should be associated with greater veering (2). In this present experiment, the paths walked were approximately the same length in the snow and clear conditions, but participants took an average of 20% more steps in the snow. The hypothesized greater veering in snow did not occur. In addition to taking more steps, participants appeared to be making other proactive and reactive adjustments to their posture and gait to maintain balance (38, 39). Further research is needed to determine the impact of such adjustments on veering. The extra steps and other differences when walking on snow also appeared to correspond to a slower walking speed, although this was not directly measured. This would have obvious practical implications for the timing of pedestrian signals.

A limitation of the study related to the snow condition is that during familiarization and practice trials, participants learned the characteristics of the snow and also that there were no obstacles in the test space. Consequently, they adopted long cane techniques that minimized or eliminated the cane sticking that would typically have been observed in less familiar environments (32). For example, some participants held their cane tips above the snow as they walked. Following Kim et al.’s definition of cane sticking as an interruption of the cane tip’s forward momentum (32), there was a mean of only one sticking event per trial in the snow condition. These few events do not permit any conclusions related to the potential effects of cane sticking on veering. This finding also illustrates that the extra steps taken in snow were not the result of cane sticking, as originally hypothesized.

A second limitation is the possibility of an order effect owing to conducting all snow trials first. Such an order effect would be suggested by consistent differences in veering across the two walking surface conditions, and none was found. The similarity of performance in the clear pavement condition of the present experiment and performance in other studies of veering on clear pavement also argues against an order effect.

The design of accessible intersections requires attention to all of the wayfinding tasks involved in street crossing, not just directional guidance for staying in the crosswalk. There is a growing body of research about what works to enhance intersection accessibility, and this research, including the work presented here, can be a useful source of design guidance. In addition, blind pedestrians as well as the O&M instructors who serve them can provide support to engineers and designers as they consider various treatments to improve nonvisual wayfinding.

Veering is an important practical problem for blind pedestrians at many crosswalks. Veering was found to be substantially reduced at a simulated snow-covered crosswalk by audible beaconing, but additional research is needed to determine whether this finding extends to actual snow-covered crosswalks. Further research is also needed to determine the circumstances under which audible beaconing should be used in preference to guide strips (24) or other approaches to veer reduction. Finally, it is critical to properly locate and configure APS, with or without beaconing, at intersections. Technologies such as APS and

beaconing APS that are not located or configured in keeping with MUTCD 4.E guidance may create additional hazards for blind pedestrians, instead of mitigating them.

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FIGURE 1.
Experimental site under walking-surface conditions: (a) clear and (b) snow. (Source: Google.)

FIGURE 2.
Typical tire-rutted snow conditions.

FIGURE 3.
Measurement scheme.

FIGURE 4.

Mean absolute error with and without audible beaconing, collapsed across walking-surface condition [dashed line represents boundary of 6-ft (1.8-m) hypothetical reference crosswalk; error bars indicate 95% confidence intervals].