Far-Side Audible Beaconing of Accessible Pedestrian Signals: Is it Confusing?

Alan C. Scott, Ph.D., Billie Louise Bentzen, Ph.D., Janet M. Barlow, M.Ed., David Guth, Ph.D., & Jennifer Graham, M.A.

Alan C. Scott, Ph.D. (Corresponding author)
Assistant Professor of Psychology
Elon University
2337 Campus Box, Elon, NC 27244-2010
Phone: 336-278-5125
Fax: 336-278-6397
Email: ascott20@elon.edu

Billie Louise Bentzen, Ph.D.
Certified Orientation and Mobility Specialist (COMS)
Director of Research
Accessible Design for the Blind
25 Village Lane, Berlin, MA 01503
Phone: 978-838-2307
E-mail: bbentzen@accessforblind.org

Janet M. Barlow, COMS
President, Accessible Design for the Blind
3 Manila Street, Asheville, NC 28806
Phone: 770-317-0611
E-mail: jmbarlow@accessforblind.org

David Guth, COMS, Ph.D
Professor, Department of Blindness and Low Vision Studies
Western Michigan University
1903 W. Michigan Avenue--Mailstop 5218, Kalamazoo, MI 49008-5218
Phone: 269-387-3446
E-mail: david.guth@wmich.edu

Jennifer Graham, COMS
Graham Rehabilitation Services
2298 Hidden Knoll Court, SE, Caledonia, MI 49316
Phone: 616-340-3310
E-mail: jen.graham@sbcglobal.net

Originally Submitted: July 25, 2013
Resubmitted: November 11, 2013
Word Count: 6,909 words + 4 figures (250 words each) = 7,909 words
ABSTRACT

Research has demonstrated that Accessible Pedestrian Signals (APS) with pushbutton-integrated speakers increase pushbutton use and starting to cross during the walk interval by pedestrians who are blind. However, consistently positive effects on locating the crosswalk or establishing or maintaining an accurate heading for crossing have not been found. Attempts have recently been made to configure APS to provide better audible information for these wayfinding tasks. A configuration that has been shown to improve heading accuracy provides audible tones from a speaker at the destination corner prior to the walk interval (to assist with establishing heading) and during the flashing don’t walk interval (to assist with maintaining heading).

Major concerns are that beaconing information may be ambiguous or misleading, resulting in dangerous crossing behavior at intersections where buildings create echoes of audible signal information, and where beacons for multiple crosswalks might be active simultaneously. The research reported herein is an evaluation of the effects of a beaconing APS system on pedestrian crossing behavior at an acoustically complex intersection and with multiple beacons sometimes concurrently active. Eighteen participants who were totally blind attempted a total of 216 crossings under three conditions. The results revealed no evidence that participants were distracted or misled by concurrent beaconing information coming from a corner other than the target destination. Moreover, despite an acoustically complex environment, the beacon led to improved wayfinding performance in some conditions, and showed no evidence of having any deleterious effects.
INTRODUCTION

It has been repeatedly demonstrated with pedestrians who are blind that accessible pedestrian signals (APS) increase the probability of initiating street crossings during the correct pedestrian signal interval, reduce the delay in starting to cross after the onset of the walk indication, and reduce the likelihood that the pedestrian will be in the roadway at the end of the pedestrian phase (1,2,3). Such audible signals may provide benefits to many pedestrians with visual impairments (including, but not limited to legal or total blindness), as it has been demonstrated that those with various amounts of functional vision may struggle to locate and/or effectively use visual pedestrian signals in common pedestrian environments (4,5,6).

Based on American Community Survey data (a U.S. Census Bureau survey), and using affirmative responses to the question “Is this person blind or does he/she have serious difficulty seeing even when wearing glasses” (ital. added) as a proxy for visual disability, the Cornell University Employment and Disability Institute estimated in 2011 that there were approximate 6.2 million people 16 years of age or older living with a visual disability in the U.S. (7). Data from the National Health Interview Survey collected by the U.S. Census Bureau for the Centers for Disease Control and Prevention indicates that there are approximately 21.2 million Americans age 18 and older who report experiencing vision loss (8). Vision loss in the survey refers to individuals who reported they have trouble seeing even when wearing glasses or contact lenses (this includes those who reported being blind).

While research has demonstrated the value of APS with respect to the measures described above, it has been challenging to develop technologies or treatments that have consistently positive effects on wayfinding during street crossing: specifically, establishing a heading (aligning to cross) and maintaining a heading in line with the crosswalk while crossing (9). Researchers in Japan and Canada found that APS with audible walk indications that alternated between one end of a crossing and the other resulted in greater accuracy on measures of wayfinding than audible walk indications that came simultaneously from both ends of the crosswalk (10,11), but efforts to replicate this finding in the US have not been successful (9). Poulsen (12) demonstrated in Denmark that audible walk indications that came from the far-side of the street only (i.e., the side of the street toward which the pedestrian was crossing), resulted in superior wayfinding. This result was replicated in laboratory research comparing walk indications coming simultaneously from both ends of a crosswalk, alternating between each end, and coming from the far-side only (9). However, a number of concerns have limited the consideration of practical implementation of such a system; as far as the researchers know, far-side audible walk indications have not been implemented in any country. Some of the concerns which have been raised (9,13) include:

- When used at the same time for 2 parallel crossings, far-side beacons might cause blind pedestrians to veer toward the center of the intersection
- The beacons are too noisy to be tolerated in a neighborhood
- The far-side audible walk signal for one crosswalk might be mistaken for the signal for another crosswalk
- The far-side audible signal would not work if people on both ends of a crosswalk pushed the button to cross during the same cycle
- The systems were technologically difficult and expensive, and require considerable care and attention during installation with respect to acoustic properties as influenced by loudspeaker location and orientation as well as other factors
In 2008 and 2009, research was published on a prototype APS with novel beaconing features that attempted to overcome some of these concerns (1,14). With the prototype APS, beaconing features were triggered by a button press of one second or more. This duration has been shown to greatly limit the number of false activations (15), thereby reducing unnecessary noise and limiting occurrences of activations from both ends of the crosswalk during a single cycle. When the pushbutton was depressed for over one second, an audible alignment cue was immediately presented in the form of a once-per-second tone (the same tone as the pushbutton locator tone), played for seven repetitions from a far-end loudspeaker mounted on the pedestrian signal head. The tone was played at a volume loud enough to be audible to the waiting pedestrian, and the same tone at the same volume was again emitted from the far-end speaker for the duration of the flashing DON’T WALK to provide a cue for maintaining heading.

The functioning of the prototype APS devices was refined over the course of several rounds of research (1,14,16,17), and in the most recent system configuration (16,17) walk indications were only presented from the near-side APS, further reducing unnecessary noise and limiting the likelihood that any far-side signal would be mistaken as a walk signal for another crosswalk. This prototype beaconing APS supported excellent heading performance in simulated crossings (16) and improved wayfinding performance as compared to standard APS at complex intersections in three cities (17). Despite the improvement in wayfinding attributable to the prototype audible beaconing, questions remain about the installation and application of audible beaconing in various intersection configurations, including where there may be echo from close-by buildings, where the angular distance between beacons for two different crossings is less than 90 degrees (and thus a beacon intended for one crosswalk may be confused with the beacon for another crosswalk), or when audible beacons are actuated for two different crossings in the same pedestrian phase.

Based largely on these sorts of concerns, the Manual on Uniform Traffic Control Devices currently includes cautionary language on the use of audible beaconing (18; section 4E.13, paragraphs 5-6). Providing audible beaconing in the manner described above has not been evaluated in situations where there are nearby buildings, where the angular distance between beacons for two different crossings is less than 90 degrees, or where beacons for two different crossings are actuated simultaneously. The research reported here is thus an effort to study the effects of beaconing APS on the wayfinding performance of pedestrians who are blind while making street crossings under conditions that highlight these concerns.

**METHOD**

**Participants**

A total of 23 adults participated, all of whom were totally blind or who had light perception only. All participants were experienced long-cane users who traveled independently about the city on a regular basis, many daily. All stated that they crossed at signalized intersections more than once a week and that they were unfamiliar with the experimental intersection. Participants had no worse than mild hearing loss and did not have peripheral neuropathy. In order to meet counterbalancing requirements, the data from 18 participants were used in the final analyses (2 participants were pilot subjects, and 3 participants failed to complete all trials, did not follow instructions, or did not meet inclusion criteria), with a total of 10 males and 8 females ranging in age from 28 to 68. All participants provided informed consent and the methods described herein were approved by the Institutional Review Board of Western Michigan University.
Intersection
The experiment was conducted at the signalized intersection of NE Sandy Blvd., NE 43rd Ave., and NE Hancock St. in Portland, OR (see Figure 1, part A). Crossing length of the three crossings used for the experimental data collection varied from 35 to 70 ft. (10.7 to 21.4 m) and crosswalk widths varied between 11 and 12 ft. (3.4 or 3.7 m). A fourth crosswalk was used for familiarization with the procedure and APS features. This is a relatively small 5-legged urban intersection with buildings of two stories or more on all four major corners. Vehicular traffic is relatively steady on NE Sandy Blvd, and intermittent on NE 43rd Ave. and Hancock St. As can be seen in Figure 1, crosswalks varied in terms of their alignment with parallel or perpendicular traffic. Parallel traffic is typically a major heading or alignment cue used by pedestrians who are blind. Perpendicular traffic also can be used as an auditory heading cue. Other pedestrians were present at the intersection on some crossings, and their presence may have provided some information to participants; however, most individuals who are blind do not rely on the movements of other pedestrians since they can be unpredictable.

Equipment / Conditions
During every experimental crossing, participants had access to standard APS features. All crossings were further equipped with the capability for beaconing; however, the beaconing features could be turned on or off so the same units could be used as standard or beaconing APS.

Standard APS
The standard APS were installed on poles near the crosswalks but with some variability with respect to their exact locations relative to intersection features. Device features included a pushbutton locator tone, a vibrotactile arrow aligned with the direction of travel on the associated crosswalk, automatic volume adjustment, and pushbutton-integrated vibrotactile and audible (rapid tick) walk indications. Each device was on its own pole, at least 10 feet distant from any other APS device. All features and messages conformed to requirements in the Manual on Uniform Traffic Control Devices (MUTCD), Sections 4E.09–4E.13 (18).

Beaconing APS
The prototype beaconing APS emitted beaconing features from a loudspeaker mounted on the pedestrian signal head at the opposite end of the crosswalk. The positions of the loudspeakers relative to the crosswalks and other intersection features are shown in Figure 1 (part A), and as a result of making use of existing infrastructure, some were centered within the width of the crosswalk and some were not. A button press of one second or more activated the beaconing features, resulting in seven repetitions of a 1/second tone from the far-end loudspeaker – intended to serve as an alignment cue. This alignment cue, or “beacon”, was the same tone and repetition rate as the pushbutton locator tone, but was emitted at increased volume (approximately 100 dB) from the speaker mounted at the far end of the crosswalk. Standard, relatively quiet walk indications emitted from the nearby APS signaled the onset of the walk interval. The loud beacon from the opposite end of the crosswalk sounded again for the duration of the flashing don’t walk (FDW) interval. Thus the loud once-per-second tone always provided directional information, while the WALK was a relatively quiet rapid ticking tone coming from the pushbutton.
FIGURE 1 Overhead satellite images of the experimental intersection. Part A) Crosswalks used for experimental trials are marked with stars. Arrow callout boxes depict the approximate locations and orientations of the beacons. Parts B-D) Illustrations of the beacons which were activated concurrently with the target beacon during potential beacon confusion trials. Block arrows indicate the participant’s intended direction of travel, while dashed arrows point to the beacon which provided potentially conflicting information. Correct target beacons are not depicted in order to reduce visual clutter.
**Potential Beaconing Confusion**

In this condition, participants had access to all the device features described in the standard and beaconing APS conditions. However, in addition to being provided with beaconing information from the far-end loudspeaker for the intended crossing, a second beacon associated with another crossing at the intersection was activated by a member of the research team. This condition was not described to participants. Figure 1 (parts B-D) illustrates for each of the six unique experimental crossings which additional beacon was concurrently active and thus provided potentially confusing alignment and heading information. The beacons were not synchronized with each other and it was possible to hear both beacons prior to (i.e., alignment cue) and during (i.e., heading cue) crossing. For all crossings in this condition, the angle between the correct destination beacon and the potential confusion beacon was less than 90 degrees (angles ranged from approximately 14 to 80 degrees with a mean angle of 42 degrees).

**Procedure**

Each participant crossed each of the three experimental crosswalks twice from each direction (i.e., 12 total trials); one crosswalk served the standard APS condition, one served the beaconing APS condition, and one served the potential beaconing confusion condition. The north crosswalk across 43rd Ave. was used for familiarization with the cues and procedure. Participants also completed crossings of NE Hancock St., but because of the relatively short length of the crossing (20 ft. (6.1 m)), particularly in comparison to the other crossings, the data from these trials was not included in the final analyses reported here (the inclusion or exclusion of the data from the final analyses did not significantly alter the conclusions).

Which crosswalk served which treatment condition was counterbalanced across participants in a between-subjects manner. The trials of each condition were presented in a block, beginning with an introduction and practice at the familiarization crosswalk. The order in which each participant completed the three conditions (standard APS, beaconing APS, and potential beaconing confusion) was varied by means of counterbalancing. Participants typically completed two practice crossings for the standard APS and beaconing APS conditions with additional practice trials if the procedure was not being understood. While participants were familiarized with the device features and their intended function, they were not trained with respect to how to most effectively use the features or audible information. Furthermore, participants did not practice the potential beaconing confusion condition, nor were they told about it. This is analogous to the way in which users of beaconing APS might unexpectedly hear a beacon resulting from the extended button press of another pedestrian.

As in previous research on beaconing APS by these authors (1,14,17), participants began each trial on the sidewalk a random distance (40–80 ft. (12.2–24.4 m)) from the crosswalk. They located the crosswalk and aligned to cross using any cues available, including vehicular and pedestrian traffic, and crossed when they judged it appropriate. Participants were accompanied by a Certified Orientation and Mobility (O&M) Specialist (one of the authors) who provided assistance, if requested, and monitored participant safety, intervening only if a participant was proceeding into direct conflict with moving vehicular traffic.

An experimenter (also a Certified O&M Specialist) recorded information about participants’ accuracy and independence in locating the crosswalk, their alignment before crossing, their location relative to the crosswalk at several points during the crossing, and when in relation to the pedestrian signal they began and completed their crossing.
RESULTS
The final analyses were a series of repeated-measures Analyses of Variance (RM ANOVAs) with Greenhouse-Geisser corrections performed where the assumption of sphericity was not met. Post-hoc comparisons were conducted using dependent t-tests and the Holm-Bonferroni step-down procedure to protect against inflation of family-wise error ($\alpha = 0.05$). For many nominal variables (e.g., aligned with the crosswalk, aligned somewhat away from the intersection, or aligned somewhat toward the intersection), percentages were computed which reflect the percentage of trials in a given condition in which the participant performed accurately (e.g., aligned with the crosswalk). Participants’ percentages were then used in inferential analyses. For each variable of interest, only data obtained during independent participant performance was included in the analyses. For example, if an intervention by the O&M specialist was necessary during a crossing, no data was used regarding the participant’s position or heading for the remainder of the crossing.

Alignment and Heading During Street Crossings
The beaconing APS are specifically designed to provide information that can assist blind pedestrians with aligning their body toward the end of the crosswalk prior to crossing, and with staying within the crosswalk while crossing.

Alignment
Just before the walk interval began, a researcher recorded the participant’s alignment in a qualitative manner: participants were aligned “within the crosswalk,” “toward the intersection,” or “away from the intersection.” Participants aligned independently on nearly every trial in all treatment conditions (average rates of independence ranged from 98.6% to 100%, [F(2,34)<1.0]). The main effect of condition on the ability of participants to align accurately (within the crosswalk) was also not significant, [F(2,34)=1.235, p>.05], with participants aligning accurately on average on 52.8% of standard APS trials, 54.6% of beaconing APS trials, and 68.1% of potential beaconing confusion trials.

The potentially confusing beacon was always in a position such that if participants were to align towards it, they would be aligning towards the intersection (see Figure 1, parts B-D; this would almost always be true in natural environments). Thus a second one-way RM ANOVA was conducted to look at the average percentage of trials in which participants aligned towards the intersection. The analysis did not reveal a significant influence of condition on likelihood to align towards the intersection [F(2,34)<1.0]. Moreover, the overall average rate of aligning towards the intersection was actually lowest in the potential beaconing confusion condition (19.9% as compared to 23.6% in the standard APS and 25.5% in the beaconing APS conditions).

Remaining Within the Crosswalk
As participants crossed, at four distances from the beginning of the crossing it was noted whether or not they were in the crosswalk and approximately how far they were towards or away from the intersection with respect to the centerline of the crosswalk. The effects of the three conditions and the four distances from the crossing start on participants’ positions relative to the crosswalk were evaluated with a two-way RM ANOVA. Participants were most likely to travel within the crosswalk in the potential beaconing confusion condition (see Figure 2), a fact supported by a significant main effect of condition [F(2,34)=8.214, p=.001] and significant post hoc comparisons with both the standard APS and beaconing APS conditions [t(17)=3.265, p<.01;
Neither the interaction between treatment condition and distance from the crossing start/end \( [F(3.6,60.8)<1.0] \) or the main effect of distance from the crossing start/end \( [F(1.6,27.2)<1.0] \) was significant. This indicates that within any given treatment condition, the rate at which participants tended to be within the crosswalk did not vary much throughout the entire course of the crossing. Average rates or being within the crosswalk were statistically equivalent in the standard APS and beaconing APS conditions \([t(17)=0.875]\).

FIGURE 2 The effect of three conditions on average percentage of trials in which a participant was within the crosswalk at various points throughout the crossing.

The above analysis does not differentiate being outside of the crosswalk and towards the intersection from being outside of the crosswalk and away from the intersection. Once again, the potentially confusing beacon was always in a position such that if participants traveled towards it, they would be traveling towards the intersection. Thus a second two-way RM ANOVA was conducted to look at the average percentage of trials in which participants were traveling in a position which was towards the intersection relative to the centerline of the crosswalk (and thus could have been either in or outside the crosswalk, but were towards the intersection).

Neither the interaction between treatment condition and distance from crossing start/end \( [F(3.1,52.3)=1.982, p>.05] \) or the main effect of condition \( [F(2,34)=1.571, p>.05] \) was significant (see Figure 3). There was however a significant main effect of distance from the crossing start/end \( [F(1.8,30.2)=10.458, p<.001] \). While the differences in rates were not significantly influenced by the different conditions, note that at all distances from the crossing start/end, average rates of traveling towards the intersection were actually slightly higher when only the correct target beacon was activated as opposed to when a second beacon was concurrently present.
FIGURE 3 The effect of three conditions and position relative to the crossing start/end on the average percentage of trials in which a participant was in a position towards the intersection with respect to the centerline of the crosswalk.

**Positions Relative to the Crosswalk**

In addition to recording participants’ positions relative to the crosswalk in a qualitative manner, categorical estimates of their distances from the crosswalk were also recorded (i.e., 0–5 ft., 5–10 ft., >10 ft. (0–1.5 m, 1.5–3 m, >3 m)). Using the midpoints of these categorical ranges (and 12.5 ft. (3.8 m) for the >10 ft. category), as well as information about where participants were located when within the crosswalk, an approximately continuous variable of distance from the center of the crosswalk was coded. This procedure allowed for a two-way RM ANOVA to consider the effects of condition and distance from the crossing start/end on participants’ position relative to the center of the crosswalk, but it did create an artificial cap on the obtained average distances. Note that the crosswalks were all 11 or 12 ft. (3.4 or 3.7 m) wide, and thus for the measure being described here, a value of 6 ft. from the center of the crosswalk would indicate that the participant was walking on the crosswalk boundary for a 12 ft. wide crosswalk.

In a pattern of results similar to those for rates of remaining within the crosswalk, neither the interaction between conditions and distance from the crossing start/end \( F(2.8,48.1)=1.896, p>.05 \) or the main effect of distance from the crossing start/end \( F(1.6,26.7)<1.0 \) was significant (see Figure 4). There was however a significant main effect of treatment condition \( F(2,34)=8.219, p=.001 \). Participants had lower average linear deviations from the center of the crosswalk in the potential beaconing confusion condition than in either the standard APS or beaconing APS conditions \( t(17)=3.451, p<.01; t(17)=2.929, p<.01; \) respectively. Average deviations were statistically equivalent in the standard APS and beaconing APS conditions \( t(17)=1.417, p>.05 \).
Interventions Due to Significant Safety Concerns During Crossings

One of the greatest concerns is that the more often participants are outside of the crosswalk, and the farther from the crosswalk they are, the higher the risk of serious injury or death resulting from conflicts with vehicles. In the current research, safety interventions were performed by the O&M specialist when she judged that the participant was proceeding into direct conflict with moving vehicular traffic. Although performance with respect to remaining within the crosswalk was by no means perfect, there was a very low incidence of interventions in this research. Average percentage of trials in which participants required an intervention due to heading error that caused significant safety concern was between 1.4% (both beaconing conditions) and 2.8% (APS condition) [F(2,34)<1.0].

Independence, Pushbutton Use, Crossing Initiation, and Crossing Completion

With the standard APS features present at all crossings (and beaconing sometimes available), participants consistently completed crossing subtasks independently. Moreover, as APS at all crossings were configured the same way with respect to locator tones and WALK indications, there was little a priori reason to assume that condition effects would occur with respect to pushbutton use, starting position, or crossing initiation timing variables.

As expected, average rates of independently finding and using the correct pushbutton were uniformly quite high (above 91% in all conditions) [F(1.4,23.8)=1.831, p>.05]. Participants also determined their starting position independently on the vast majority of trials (average rates of independence were over 97% in all three treatment conditions, [F(2,34)=2.125, p>.05]); however, participants success independently determining an accurate starting position (i.e., within the crosswalk) was not particularly good (average rates were 47.2% with standard APS, 52.3% with beaconing APS, and 52.8% with potential beaconing confusion). These

FIGURE 4 The effect of three conditions on average distance from the center of the crosswalk at four points during street crossing.
differences in the rates of determining an accurate starting position are not statistically
significant [F(2,34)<1.0].

With respect to the timing of crossing initiations, participants initiated every crossing
independently, and the rates of initiating a crossing during a WALK interval (the first or
subsequent) were uniformly high (standard APS – 94.4%, beaconing APS – 93.1%, potential
beaconing confusion – 93.1%; [F(2,34)<1.0]). Moreover, there were also no significant
differences in the average latency to initiate crossings following the onset of WALK (standard
APS – 2.4 sec, beaconing APS – 2.6 sec, potential beaconing confusion – 2.6 sec; [F(2,32)<1.0]).
Successful completion of a crossing before the end of the pedestrian interval and onset of
perpendicular traffic can be influenced by starting timing and latency as well as by initial
heading and wayfinding accuracy. In this study, the average percentage of trials completed
before the onset of perpendicular green was uniformly quite high (standard APS – 93.1%,
beaconing APS – 98.6%, potential beaconing confusion – 95.4%; [F(2,34)<1.0]). Thus there
were no adverse consequences attributable to either beaconing condition on any of these
measures.

DISCUSSION

Research on street crossing behavior of pedestrians with visual impairments, and reports from
visually impaired individuals and rehabilitation professionals, indicate that a growing number of
U.S. intersections and crosswalks pose significant barriers to pedestrian travel for this
population. With the increasingly complicated geometry of modern intersections, the tasks of
finding the crosswalk, aligning to cross, and maintaining an accurate heading while crossing
have become increasingly difficult (19,20,21,22). Recent evaluations of APS systems which
have been configured in such a way as to provide unique audible information from far-end
speakers to assist with crossing alignment and heading have been promising (14,16,17).
However, concerns have been voiced regarding the effectiveness and suitability of audible
beaconing systems at acoustically complex urban intersections and where multiple beacons
might be active simultaneously.

The research reported here found no evidence of negative effects of multiple active
beacons on pedestrian crossing behavior. This is true despite using a relatively small intersection
that was rather “closed in” by the presence of buildings which resulted in the presence of
substantially greater echoes than are present at more open intersections, and true despite the fact
that beacons for different crosswalks were relatively close to each other and the angle between
concurrently active beacons was always less than 90 degrees. All of these features heightened
the possibility of acoustic confusion, yet participants’ rates of accurate alignment were higher
with the potential beaconing confusion (68.1%) than with only the intended target beacon active
(54.6%, a non-significant difference). Likewise, participants were no more likely to be aligned
towards the intersection (and towards the second beacon) in the two-beacon condition (19.9%)
than in the single-beacon condition (25.5%). During crossing, participants were actually within
the crosswalk a greater percentage of the time in the potential beaconing confusion condition
(79.1%) than in the single-beacon condition (59.3%). At all four distances relative to the
crossing starting point at which position data were recorded, the average percentage of trials in
which participants were positioned towards the intersection relative to the centerline of the
crosswalk (and thus also towards the second beacon if present) was lower in the potential
beaconing confusion condition than in the beaconing APS condition. Thus on all wayfinding
measures used in this research, the accuracy of participant performance was equivalent or in fact
better in the potential beaconing confusion condition as compared to the beaconing APS condition. Additionally, with respect to rates of being within the crosswalk and average distance from the center of the crosswalk, the presence of the beacon in the potential beaconing confusion condition led to significant improvements in participant performance as compared to the standard APS which did not have any beaconing features.

While such findings seem to demonstrate the positive influence of the beaconing features and a lack of negative effects under conditions when multiple beacons are simultaneously active, participant performance in the beaconing APS condition was consistently intermediate to performance in the standard APS and potential beaconing confusion conditions. Although participants appeared to perform more accurately on wayfinding measures in the beaconing APS condition as compared to the standard APS condition (see Figures 2 and 4), analyses did not reveal the statistically significant improvements in performance that have been documented in previous research using beaconing APS of the same design (14,16,17). When considered in isolation, this might suggest that the acoustic complexity of this intersection was in fact greater than at the intersections used in other research and this fact affected the usefulness of the beacons. However, if that were true, it does not explain why significant wayfinding improvements were found when comparing the potential beaconing confusion and standard APS conditions, comparisons that suggest significant benefits of the presence of the beaconing.

It is important to note that the current investigation was designed to specifically assess the potentially negative effects of auditory confusion and thus an intersection was chosen at which such confusion seemed most likely to occur. In previous research on this particular beaconing system (14,16,17), the evaluations were focused on investigating whether beaconing APS could support accurate wayfinding performance under simulated conditions or at intersections that lacked many of the traditional alignment and heading cues used by pedestrians who are blind. In Scott et al. (16), participants made “crossings” in a parking lot under simulated conditions. All simulated crosswalks were very long, and there was no traffic or other environmental cues beyond the specific cues being evaluated (e.g., beaconing APS, tactile guidestrips, etc.). For evaluations of the beaconing, the beacons were the only heading cue once the participant left the simulated curb ramp. Barlow et al. (17) demonstrated significantly more accurate wayfinding performance with beaconing APS than with standard APS at three intersections. However, there are characteristic differences between the intersection used here and those used in Barlow et al. based on the intended nature of the evaluations. For example, the crosswalks used here were between 35 and 70 ft. long (10.7 to 21.4 m) and crosswalk widths varied between 11 and 12 ft. (3.4 and 3.7 m). For the three intersections used in Barlow et al., crossings were on average longer (ranging from 56 to 115 ft (17.1 to 35.1 m)) and all crosswalks were narrower (8 or 10 ft (2.4 or 3.0 m)). Moreover, the crosswalks used in the study described herein were on average more aligned with vehicle travel lanes (either perpendicular or parallel; see Figure 1) than the crossings used in Barlow et al. Thus it is not entirely unexpected that the current research did not show significant improvements in wayfinding when comparing beaconing and standard APS. The wayfinding information and wayfinding simplicity provided by traffic, road geometry, crosswalk lengths and widths, etc. was fairly good without beacons, and so there was little reason to expect a large difference in participants’ wayfinding performance with or without beacons. Note that at the level of average performance, participants did consistently perform wayfinding tasks more accurately in the beaconing condition as compared to standard APS, but if they reflect actual improvements in performance (as would be suggested by previous research), the magnitude of the improvements at this particular
intersection were not large enough to be statistically significant under the current evaluation conditions.

Given the lack of significant wayfinding improvements in comparisons between standard and beaconing APS, it is a bit surprising that in the potential beaconing confusion condition, in addition to a lack of negative effects attributable to the presence of concurrently active beacons, there was evidence of statistically significant improvement in wayfinding performance as compared to the standard APS condition. Participants could clearly hear both beacons; the beacons were not synchronized with each other and the spatial separation between the two was readily detectible despite the smaller than 90 degree angular separation. Given the difference in the proximities of the two beacons to the participant, as well as the orientations of the beacons relative to their intended crosswalk, participants seemed well able to determine which beacon was the one relevant to their crossing. One could speculate that the presence of the second beacon may have in fact drawn participants’ focus to the beaconing features in general (and specifically to the target beacon). This might have somewhat paradoxically caused them to better use the appropriate beacon in the potential confusion condition than they did in the one-beacon condition where they may have been more focused on other traditional wayfinding cues and thus perhaps somewhat ignored the beacon. Note that the number of interventions due to significant participant safety concerns during crossing was very low in all conditions (i.e., between 1.4% and 2.8%), likely due to streets which were not particularly wide, relatively low turning vehicle speeds due to street widths, and somewhat low traffic volume. So it may have been that participants felt rather confident in the accuracy and safety of their crossings even when beaconing features were absent, thus leading them to be less likely to focus much attention on the beacon when present. It may be that the potential beaconing confusion condition actually highlighted the salience of the “correct” beacon to the participants, and that they used it more than they did in the standard beaconing condition.

While there have been a number of concerns raised regarding the general concept of audible beaconing (see introduction), the specific design described herein (see methods section) addresses many and perhaps most of them. This design has now been evaluated in five cities and has produced generally consistent evidence of its effectiveness with respect to wayfinding measures (14,16,17) where traditional cues are largely absent or misleading. In the research reported herein, the magnitude of significant improvements when comparing the potential beaconing confusion condition to the standard APS condition are fairly well aligned with previous research (14,17); the potential beaconing confusion condition is still an evaluation of the core features of this beaconing design. Moreover, in this first evaluation of the effects of multiple active beacons on participant performance at a relatively “closed in” and acoustically complex intersection, there is no evidence to suggest participants are negatively influenced by the second beacon. In fact, there is some evidence to suggest that where properly installed and aligned, a second beacon may actually increase the salience of beaconing information from the target beacon. However, with this being the first evaluation of this particular concern, and given that it occurred at a single intersection, some form of conceptual replication performed at intersections which are in some ways different than that used in this study but which are selected with the concerns regarding audible beaconing in mind, would be quite valuable with respect to demonstrating the validity of the conclusions while also improving the generalizability to intersections with different characteristics.
SUMMARY AND CONCLUSIONS

This research evaluated whether the use of beaconing APS at a relatively small intersection, and one that had sound-reflecting buildings close to the corners, would result in confusion about which crosswalk had the walk indication or about the orientation of the crosswalk relative to the starting position—findings that would support the cautious use of beaconing APS recommended by the MUTCD \cite{MUTCD} \section{4E.13, paragraphs 5-6}. The researchers chose an intersection and designed a protocol intended to, in an ecologically valid manner, maximize the likelihood of confusion about which crosswalk had the walk indication and where the end of the crosswalk was located. However, on no trial did any participant begin to cross with the wrong walk indication, highlighting the value of a system that restricts the presentation of audible walk information (e.g., rapid tick) to the near-side APS, while consistently using a separate indication (e.g., once-per-second tone) to provide directional information be it from the near-side APS (i.e., pushbutton locator tone) or far-side mounted speakers (i.e., alignment and heading cue). There was also no evidence to suggest that a full installation of the beaconing system described herein, and simultaneous activation of beaconing features for multiple crossings, would lead to confusion that negatively impacts pedestrian safety with respect to crossing initiations or wayfinding. Taken in conjunction with the results of research by the same authors which has repeatedly demonstrated strong beneficial effects of beaconing on accuracy in maintaining a correct heading while crossing streets that are highly complex with respect to wayfinding \cite{Scott2008, Scott2005}, and which lack other quality wayfinding cues, the cautions in MUTCD 4E.13 \cite{MUTCD} with respect to the use of beaconing APS may be unwarranted.

ACKNOWLEDGMENTS

This project was supported by Grant #5 R01 EY12894-07 from the National Eye Institute, National Institutes of Health. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the National Eye Institute.

The authors thank all the participants for completing challenging street crossings and providing frank opinions about many issues; the city of Portland staff for their support in installing and adjusting the prototype APS devices, particularly Jason McRobbie and Peter Koonce; and John McGaffey, Les Beckwith and Lynn Mack of Polara Engineering for their assistance in developing the prototype systems used in this research.

REFERENCES


17. Barlow, J. M., A. C. Scott, B. L. Bentzen, D. A. Guth, and J. Graham. The Effectiveness of Audible and Tactile Heading Cues for Pedestrians who are Blind at Complex Intersections.


