Pedestrian Access to Roundabouts: Assessment of Motorists' Yielding to Visually Impaired Pedestrians and Potential Treatments To Improve Access

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FOREWORD

The FHWA'S Intersection Safety Research Program is focused on improving highway safety through increasing knowledge and understanding of the effects of intersection design on safety and operational efficiency. Roundabout intersections have been shown to have both safety and operational benefits compared to alternative stop-controlled and signalized intersections; however, these benefits do not necessarily extend to all users. In particular, pedestrians who have visual impairments have reported difficulty using the pedestrian facilities at some roundabouts. The present studies were intended to document some of the difficulties pedestrians with visual impairments face and test potential treatments to improve roundabout accessibility for all users.

Michael Trentacoste
Director, Office of Safety
Research and Development

NOTICE

QUALITY ASSURANCE STATEMENT

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16. Abstract

This report describes two related studies intended to address double-lane roundabout accessibility issues for visually impaired pedestrians. The first study was conducted on a closed course to evaluate the feasibility of a pavement treatment to alert blind pedestrians when vehicles have yielded to them. The second study examined drivers' yielding behavior at a two-lane roundabout and the effectiveness of the same roadway treatment in an operational environment.

In the first study, there were two experimental conditions: a control condition and a treatment condition in which rumble strip-like devices were placed on the roadway surface. Seven individuals who have severe visual impairments participated. Participants stood at a crosswalk and used hand signals to indicate when they detected vehicles stopping or departing after a stop. Compared to the control condition, the sound strips treatment increased the probability of detecting stopped vehicles, and decreased by more than a second the amount of time needed to make a detection; however, the treatment did not reduce the number of false detections. False detections could result in the pedestrian crossing when moving vehicles are approaching the crosswalk.

The second study was an experiment conducted at an operating roundabout. In that environment the rumble strip-like treatment was not effective, probably because the majority of vehicles stopped in the circular roadway before crossing over the rumble strips. A Yield to Pedestrians, State Law sign that was placed in the roundabout exit between the two travel lanes resulted in an increase in drivers' yielding from 11 percent of vehicles in the control condition to 16 percent in the experimental condition.

It was concluded that the treatments explored in these studies do not appear promising for double-lane roundabouts, but should be explored further to see if they might work at single-lane crossings.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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CHAPTER 1. INTRODUCTION

This report describes two related studies intended to address double-lane roundabout accessibility issues for visually impaired pedestrians. The first study was conducted on a closed course to evaluate the feasibility of a pavement treatment to alert visually impaired pedestrians when vehicles have yielded to them. The second study examined drivers' yielding behavior at a two-lane roundabout and the effectiveness of the same roadway treatment in an operational environment.

BACKGROUND

People who are visually impaired may experience difficulty using roundabout crosswalks.[1,2] Recent research has documented this difficulty, at least for cases where traffic volumes are high.[3] The problem, as summarized by the U.S. Access Board, consists of three parts:[1]

1. Motorists do not yield to pedestrians where the crossing is not signal controlled.
2. At roundabouts, noise from circulating traffic may make aural detection of gaps difficult.
3. Gaps large enough to be aurally detected may be infrequent.

The Americans with Disabilities Act (ADA) requires equal access to transportation facilities. The U.S. Access Board, which is responsible for developing guidelines for implementing the ADA, currently is considering guidelines for providing access at roundabouts.[4] The studies reported here are intended to contribute to an empirical basis for those guidelines.

The Prevalence of Visual Impairment

According to statistics compiled by the National Center for Health Statistics of the U.S. Centers for Disease Control and Prevention, as summarized by the American Foundation for the Blind™, in 1996, there were approximately 1.3 million legally blind people in the United States.[5] Of these, approximately 109,000 people use long white canes, and another 7,000 use guide dogs. Approximately two-thirds of the people who use a long white cane or a guide dog are less than 65 years old, and about half are employed full time. Although statistics are not available on the number of visually impaired individuals who travel independently on streets and sidewalks, the statistics on long cane and guide dog users suggest that this number is around 100,000. As the number of roundabout intersections grows, so will the importance of accessibility. Furthermore, treatments to improve access at roundabouts might also apply to other types of uncontrolled crosswalks, such as midblock crossings and right-turn slip lanes. With improvements to access at uncontrolled crossings, the number of visually impaired individuals who travel independently might increase.

Roundabout Overview

Roundabouts are circular intersections with specific traffic control and design features. These features include yield control at entry, channelized approaches, and geometric approach curvature (deflection) to induce entering traffic to slow to the design speed of the circular pathway. The typical location for crosswalks at roundabouts is illustrated in figure 1. Note that one end of each crosswalk terminates on a splitter island (a median) so that the pedestrian crosses only one direction of traffic at a time. Because the crosswalks are set back from the intersection, conflicts with turning vehicles are minimized. Also, because all traffic is forced to travel on a curved path, vehicle speed is minimized, typically to between 32 kilometers per hour (km/h) (20 miles per hour (mi/h)) and 44 km/h (30 mi/h). Additional information on the design of roundabouts may be found in the Federal Highway Administration (FHWA) publication *Roundabouts: An Informational Guide*.[6]

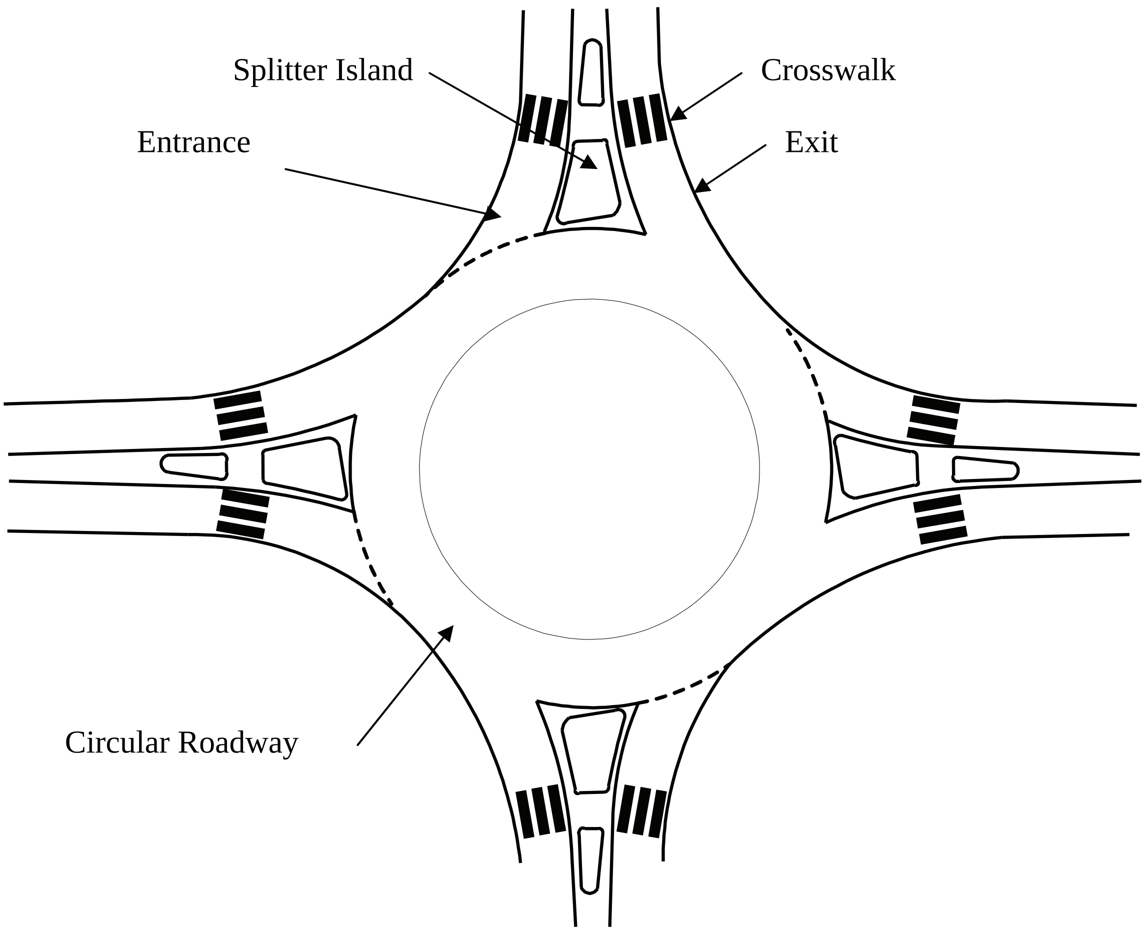


Figure 1. Illustration of single-lane roundabout with crosswalks.

Roundabouts are appearing with increasing frequency in the United States, primarily because of their benefits to traffic operations and safety. Roundabouts usually result in less traffic delay than a signalized intersection, and they may have operational benefits as alternatives to intersections that are not signalized.[6] Numerous studies have shown that roundabouts have fewer injury-related crashes when compared to conventional intersections, and most studies also show that the overall crash rate is reduced when conventional intersections are replaced with roundabouts.[6,7] Furthermore, pedestrian death and serious injury rates are lower at roundabouts than at conventional signalized and nonsignalized intersections.[6]

Motorists' Yielding Behavior

It has been widely observed that motorists frequently fail to yield to pedestrians in crosswalks, even though most motorists are aware of this legal requirement.(8,9) For instance, at five uncontrolled crossings in Madison, WI, the percentage of vehicles yielding to pedestrians who were starting to cross ranged from 0 to 10.6 percent.(10) Huang et al. reported greater variation in the percentage of pedestrians to whom approaching motorists yielded.(11) Their results, from 11 different uncontrolled crossings in 4 States, ranged from 0 to 87 percent, with a mean of 50 percent. Huang and Cynecki also reported on the percentage of pedestrians yielded to by approaching motorists.(12) Their study included data from eight uncontrolled crossings in seven States. Yield rates ranged from 0 to 58 percent and averaged 19 percent.

Street Crossing by Visually Impaired Pedestrians

The U.S. Access Board Web site provides a detailed description of the process a visually impaired person would typically engage in to prepare for and make a street crossing.(1) Although this process has many implications for roundabout accessibility, the present study addresses only one of these implications: the need to provide detectible gaps in traffic. A gap is any pause in traffic flow during which a pedestrian can cross a roadway without encountering vehicle conflicts. At signalized crossings, visually impaired pedestrians rely on the signals to create gaps, and may use surges in traffic flow to detect the signal phase. At uncontrolled crossings, such as at roundabouts, the visually impaired cannot predict gaps, and they must rely on other environmental cues to detect gaps. For a visually impaired pedestrian to make a safe crossing at a roundabout, a gap in traffic must occur; the pedestrian must be able to recognize when gaps are present; and the pedestrian must be able to recognize when gaps are not present.

Gaps may occur in two ways:

1. No vehicles arrive for the length of time necessary for the pedestrian to cross.
2. Vehicles stop for the pedestrian.

For gaps to be usable by pedestrians, the gap must be of sufficient length, and the pedestrian must be able to detect them. Sighted pedestrians detect gaps by looking in the direction of traffic. Visually impaired pedestrians detect gaps by listening. The visual and auditory information of approaching traffic can be blocked for either sighted or visually impaired pedestrians by obstructions such as landscaping, hills or bends in the road, and buildings. Although in certain circumstances the approaching traffic can be heard before it is seen, more often the sighted pedestrian can detect the approaching traffic long before the traffic can be heard, even under ideal listening conditions, because of features that affect the acoustics such as road surfaces and reflecting surfaces. Although visual information for sighted pedestrians can sometimes be obscured by fog or glare, the sounds upon which visually impaired pedestrians rely are much more easily masked by other sounds. Masking sounds often include the noise of receding vehicles or traffic at nearby intersections, but they can also come from many other environmental sources.(13,14,15)

Thus, there are many situations in which sighted pedestrians can easily determine gaps, but visually impaired pedestrians are unable to reliably identify the same gaps. Whereas sighted pedestrians may be able to see gaps behind approaching vehicles, the visually impaired cannot hear such gaps. Furthermore, because the sound of receding vehicles masks gaps, the visually impaired may not recognize gaps for several seconds after they begin.[3] At a double-lane roundabout with 3.7-meter (m) (12-foot (ft)) lanes, a sighted person who walks at 1.2 meters per second (m/s) (4 feet per second (ft/s)) might accept a gap of little more than 6 s; however, the gap required by a visually impaired pedestrian must be larger. Vehicles passing the crosswalk create noise that can mask the silence of gaps behind them, and Guth et al. observed that it frequently takes 3 s or more before the noise of vehicles that have passed is diminished enough to allow detection of a following gap.[3] Thus, a visually impaired person may require a gap of 9 s or more. Furthermore, although the splitter island may represent a protected location for a sighted person to cross by looking in one direction at a time, the sound of traffic approaching and receding on the other side of the island is not masked by the island. Thus, the visually impaired pedestrian may require a 9 s gap in both directions before beginning to cross. After reaching the splitter island, visually impaired pedestrians may again require 9 s gaps in both directions because the sounds of traffic behind them will mask gaps in the entrance lanes.

Given that simultaneous gaps of 9 s or more at both entry and exit lanes may be required for detection of naturally occurring gaps in moving traffic, and that gaps such as these may be rare during peak traffic at double-lane roundabouts, it may be necessary to stop traffic to provide access to visually impaired pedestrians. The U.S. Access Board recognized this when it drafted a proposal to signalize roundabouts.[4] Signals might not be necessary if drivers would stop for pedestrians with long white canes or guide dogs, and if those pedestrians could detect the resulting gaps in stopped traffic. The purpose of the present study was to examine treatments that might make this latter approach feasible.

RESEARCH GOALS

The goals of the present studies were to: (1) evaluate a method of aurally indicating when vehicles have yielded in both lanes of a double-lane roundabout exit (2) evaluate a method for increasing motorists' yielding to visually impaired pedestrians, and (3) quantify motorists'-yielding behavior at double-lane roundabouts.

Study 1

Study 1 addressed only the first of the three goals: to evaluate a method of aurally indicating when vehicles have yielded in both lanes of a double-lane roundabout. Not all visually impaired pedestrians will cross in front of idling vehicles; without the benefit of eye contact with the driver, it is difficult to determine a driver's intent or the reason that the driver stopped in the first place. To cross a single lane, the visually impaired pedestrian listens for the idling engines of stopped vehicles. Some visually impaired pedestrians will cross in front of stopped vehicles. Crossing two lanes is more problematic than crossing one lane, because the pedestrian will normally want to determine that drivers have stopped in both lanes. However, the sound of one idling vehicle may mask the sound of another approaching vehicle, and the driver of that vehicle may not be looking for (or be able to see) a pedestrian stepping out from in front of a previously stopped vehicle. Unfortunately, as the results of this study show, the sound of one idling vehicle may also mask the sound of a second idling vehicle, especially when the first vehicle is in the lane closest to the pedestrian.

In the treatment condition of this study, strips were placed on the pavement to generate a sound that could be heard over the sound of idling vehicles and other traffic. The strips were needed to: (1) alert the pedestrian when vehicles approached in each of two lanes; (2) indicate when a vehicle passed the crosswalk (i.e., departed); and, most important, (3) indicate when an approaching vehicle did not pass and, by implication, was stopped. To ensure that all of the conditions of interest could be tested effectively, this study was conducted on a closed course where drivers yielded, failed to yield, and departed according to a script.

Study 2

Study 2 addressed all three goals (listed above). The study was conducted at a double-lane roundabout in Maryland. As with study 1, the effectiveness of sound-generating strips was evaluated. In addition, two traffic control signs were deployed to evaluate their effect on motorists' yielding behavior.

One of these signs was placed at the upstream edge (from a vehicle perspective) of the crosswalk on the demarcation between the travel lanes. This sign, designated R1-6 in the *Manual on Uniform Traffic Control Devices* (MUTCD), was 90 centimeters (cm) (36 inches) high by 30.5 cm (12 inches) wide, with the sign bottom mounted 61 cm (23 inches) above the pavement on a breakaway post.[(16)] The sign, depicted in figure 2, shows a red triangular yield icon above the word "TO," which is above a pedestrian icon, all on a white (i.e., regulatory) background. The white background is surrounded by yellow with the words "STATE LAW" above and the words "WITHIN CROSSWALK" below. Combining the words and icons in English, the sign reads, "State law, yield to pedestrian within crosswalk."

The second sign was placed below an existing crosswalk warning sign located to the right of the crosswalk. This white sign, designated R1-5 in the MUTCD (depicted in figure 3), had an arrow that pointed, roughly, to the upstream crosswalk demarcation line, a yield symbol, the words "HERE" and "TO," and a pedestrian icon. By combining the words and icons, the sign reads, "Yield here to pedestrian." The sign was 61 cm (24 inches) square. The purpose of adding this sign was to encourage drivers to stop at the crosswalk rather than at a distance away from the crosswalk, which might prevent the pedestrian from hearing idling engines.

Figure 2. MUTCD R1–6.

Figure 3. MUTCD R1–5.

CHAPTER 2. STUDY 1: CLOSED-COURSE EVALUATION

There were two experimental conditions in this study: a control condition and a treatment condition. In the treatment condition, rumble strip-like devices were placed on the pavement surface. Seven severely visually impaired individuals participated. These individuals regularly take pedestrian trips without sighted companions and at least occasionally make such trips to locations that they have not visited before.

METHOD

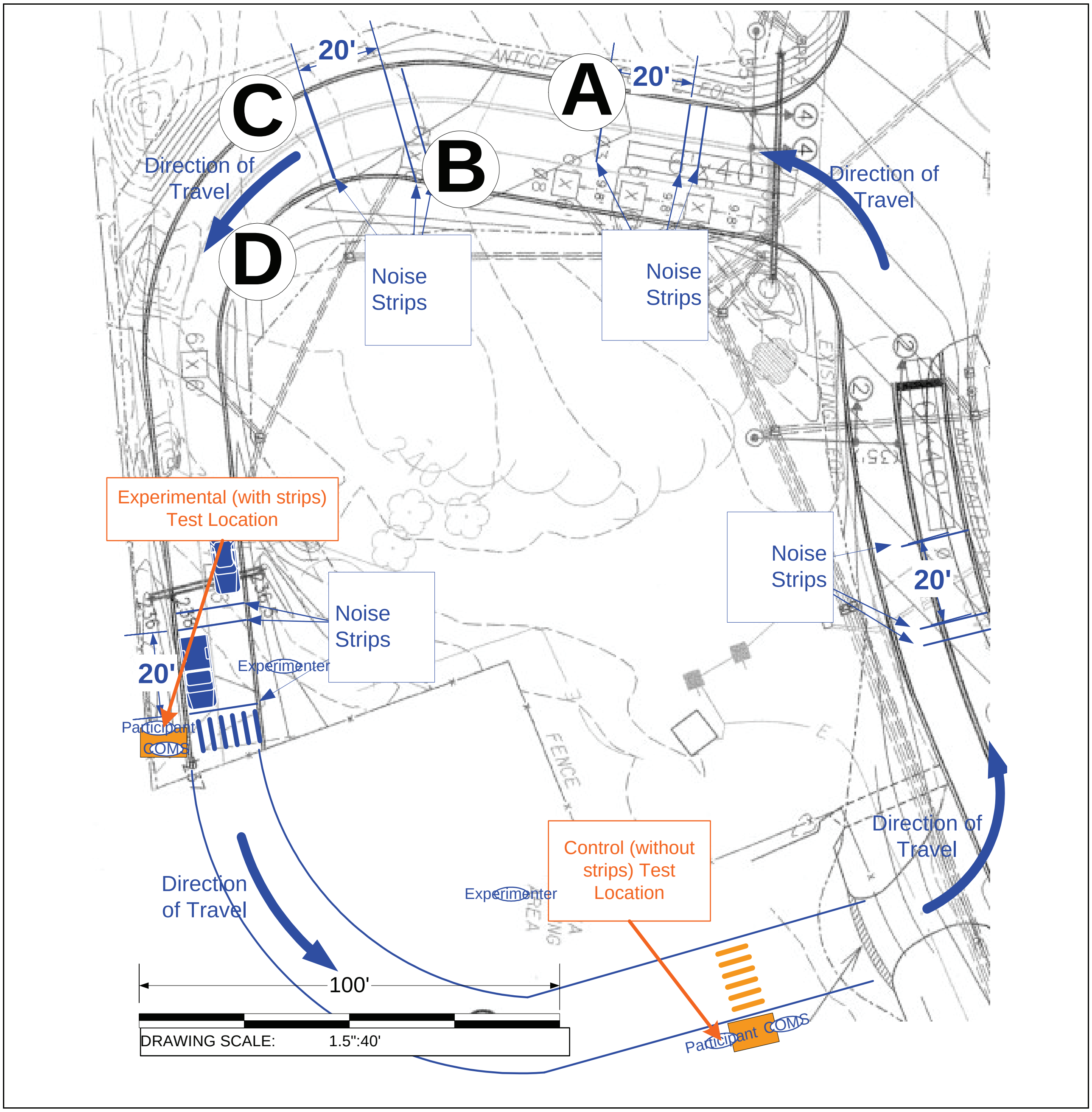
The basic requirements for a sound cue were: (1) vehicles approaching the crosswalk would trigger it, (2) the treatment would be relatively inexpensive to implement, and (3) the sound cue would provide distinctly audible cues in a roundabout environment. Initially, commercially available rumble strips, traffic counter tubes, and garden hoses were considered. The first challenge encountered was that cars about to yield at a crosswalk might be traveling at very low speeds. The rumble strips, tubes, and hoses that were evaluated failed to make sufficient noise when passed over at 3 to 11 km/h (2 to 7 mi/h). A treatment was eventually derived that appeared promising for testing, but it would need additional development to serve as a permanent engineering solution. That solution was to cut 3.8 cm (1.5 inch)-diameter polyvinylchloride (PVC) pipe lengthwise into thirds, then secure the pipe, concave side down, to the roadway with asphalt tape. Asphalt tape is normally used to secure traffic counting tubes. To prevent heavy vehicles from crushing the pipe, pieces of dowel cut lengthwise were placed between the PVC pipe and the roadway to provide additional support. Even when the approaching vehicle was driven at 3 km/h (2 mi/h), the PVC pipe device produced a clacking sound that could be heard over ambient traffic noise from a distance of about 20 m (66 ft).

To provide a meaningful sound pattern that visually impaired pedestrians potentially could use, three rows of sound strips were laid transversely across the roadway. One row was placed on the upstream edge of the crosswalk, a second row was placed 6 m (20 ft) upstream of the first row, and a third row was placed 7.3 m (24 ft) upstream of the first row. A two-axle passenger car that passes over the strips generates a rapid “clack, clack, clack, clack” sound as the two axles pass over the two upstream rows, and then, after a brief delay, another “clack, clack” as the vehicle enters the crosswalk and departs. If the first four clacks are produced, but not the latter two, a stopped vehicle is signified. A pair of clacks that are not preceded by four closely spaced clacks indicates that a previously stopped vehicle has departed.

Test Facility

The test was conducted on a rounded, rectangular roadway at FHWA’s Turner-Fairbank Highway Research Center in McLean, VA. A scale drawing of the course is provided in figure 4. Although the circuit was somewhat larger than that of a double-lane roundabout, and the 2.9-m (9.5-ft) lanes were somewhat narrow, the course provided a method for approximating traffic movement at a double-lane roundabout. Because the sound-strip treatment could not be easily put down and removed, with- and without-strips test conditions were located at different points on the course, separated by approximately 50 m (165 ft). Platforms were placed 61 cm (2 ft) back from the outer edge of the roadway, adjacent to the two simulated crosswalks. These platforms, intended to simulate a curb, were 20 cm (8 inches) high.

Because only four cars were available to simulate traffic, it was believed that the ambient noise level on the closed course did not adequately represent the noise level at actual roundabouts. Therefore, during testing two loudspeakers were used to broadcast recorded traffic sounds. These loudspeakers were placed approximately 3 m (10 ft) from opposing sides of the pedestrian platforms, such that the *A*-weighted sound level was 68 decibels at the site where participants stood. This sound level approximated that measured during peak traffic at the roundabout used in study 2.



1 inch = 25.4 millimeters (mm), 1 ft = 0.305 m.

Figure 4. Layout of closed-course test facility.

Participants

Seven individuals with severe visual impairments were recruited (four reported having no vision, one reported minimal central vision only, one reported minimal peripheral vision only, and one had some perception of light). Although none of the participants who reported having some residual vision reported using visual cues when traveling, the participant with residual central vision said that he could sometimes detect crosswalk edges if there is high contrast between the pavement and the painted line. All participants who reported having some vision wore a blindfold during the tests. All participants received a hearing screening. All had hearing within the normal range except for one older male (participant 2), who had a low frequency hearing loss in his right ear. Further participant demographic information is provided with the individual debriefing results. Participants were paid $35 per hour, and they completed participation in about 3 hours.

Procedures

Before data collection began, the participants were briefed and provided an opportunity to explore the mock intersection. The briefing did not include mention of the sound strips, and no participant asked about them during the test session. An orientation and mobility specialist was always present during the pretest, test, and debriefings.

A series of 36 test trials followed 4 practice trials. Scripts governed the behavior of the four vehicles in each trial. The top speed was 24 km/h (15 mi/h), and the speed on turns was lower. The scripts comprised 18 trials that were repeated at each of the 2 crosswalks. Three participants (numbers 2, 4, and 7) were tested in the control condition first, followed by the treatment condition. The remaining four participants were tested in the treatment condition first. The drivers, who were paid for their participation, provided the four vehicles. The same four vehicles were used for all trials of individual participants; each participant performed the control and treatment trials with the same four vehicles; however, different participants worked with different sets of four vehicles. Most of the vehicles were late-model midsize or compact cars. One full-size sport utility vehicle and two full-size pickup trucks were also used; however, not more than one of these was used with any particular participant.

Of the 18 trials, 8 trials called for a vehicle in the near (right) lane to yield first, 6 called for a vehicle in the far (left) lane to yield first, and 4 trials called for vehicles in each lane to yield at the same time.

Throughout the remainder of this document, the *near* and *far* lanes are referred to rather than right and left lanes respectively because our focus is from the viewpoint of the pedestrian. For this study, the relationship of the vehicles to the pedestrian is more important than the nominal lane designations from a driver's perspective. In both studies, the pedestrian stood on the sidewalk side of an exit lane. That is, as the pedestrian faced the road while standing on the sidewalk, a vehicle approached from the participant's left side. If the participants had stood on the splitter island side of the exit lane (so that the left lane was the near lane), it is assumed that the near-far relationship would hold with respect to the participant's performance; however, in that case, the vehicles would have approached the crosswalk from the participant's right side.

The scripts roughly balanced the lanes that each of the four vehicles used, and the order in which each vehicle passed the crosswalk. In any given trial, a specific vehicle made between zero and four complete laps. In some trials, one or two of the vehicles did not move. The scripts were designed to obscure the number of vehicles, the amount of time between the start of a trial and its completion, and the time between the first vehicle yield and the second yield. In two trials, the first vehicle to yield pulled away after 10 s, so that in those two trials, both crosswalk approach lanes were never blocked at the same time. The scripts also directed vehicle speed (normal or slow) as vehicles passed the crosswalk. A different randomized order of trials was used for each participant and at each crosswalk.

Figure 5 is an example of the script of one driver for one trial. In the example, vehicle 3 was assigned to the near (right) lane and yielded the first time it arrived at the crosswalk. Vehicle 1, which began at station ‘A’ upstream (behind) vehicle 3, stopped behind vehicle 3. (The station letters in figure 5 designate the locations where the vehicles waited for trials to begin. These letters correspond to the locations marked by those letters in figure 4.) Vehicle 4 started at station D, which was the closest starting location to the crosswalk, and passed the crosswalk twice (the second time slowly). Vehicle 2 passed the crosswalk once, and then yielded on its second approach to the crosswalk. After the trial was over, the vehicles returned to different stations, so that from trial to trial, a given vehicle would travel in different lanes and a different order with respect to the other vehicles. Each vehicle remained in the same lane throughout a trial and did not pass other vehicles, except when those vehicles stopped at the crosswalk and the trailing vehicle was to continue on another lap.

Trial 16

Begin from **Station C**

Yield immediately.

	Vehicle			
	1	2	**3**	4
Lap	Station A	Station B	**Station C**	Station D
1	Stop	Go	**Right (1st)**	Go
2		Left (2nd)		Go (slow)
3	Station C	Station D	**Station A**	Station B

Key:

	Go:	Drive past the pedestrian without stopping
	Go (slow):	Drive slowly (< 5 mph) past the pedestrian
	Yield:	Stop for the pedestrian.
	Stop:	Stop behind a car already stopped at the crosswalk
	Left(1st)	Yield (stop for pedestrian)
	Left(2nd)	Yield (stop for pedestrian)
	Right(1st)	Yield (stop for pedestrian)
	Right(2nd)	Yield (stop for pedestrian)

*Grey shading indicates that vehicle will not move during trial.

Figure 5. Example of driver's script.

During each trial, a participant stood on the platform and used hand signals to indicate when he or she detected vehicles stopping or departing after a stop. The participant's signals and the vehicle movements were video-recorded for later scoring.

QUANTITATIVE RESULTS

The primary observed variables were accuracy in detecting blocked lanes (stopped vehicles) and wait time to detect stopped vehicles. Accuracy in detecting when stopped vehicles departed while the other lane remained unblocked was also recorded. Accuracy measures included:

- Percentage of correct detections of stopped vehicles.
- Percentage of misses (i.e., failure to detect stopped vehicle within 10 s).
- Percentage of false alarms (i.e., incorrect detection of stopped vehicle).
- Number of correctly detected departures of stopped vehicles.

Participants were instructed to use hand signals each time a vehicle stopped at the crosswalk and indicate which lane it occupied. To signal detection of vehicles stopped in the far lane, participants were to point at the vehicle. To signal detection of vehicles stopped in the near lane, participants were to point to their own right. To indicate that two vehicles were stopped side-by-side (i.e., the crossing was blocked), they were to hold a hand over their head. The primary measure of effectiveness for this experiment was accuracy in the detection of both lanes being blocked. This measure was chosen because it was assumed that, with both lanes blocked by stopped vehicles, it might be judged appropriate for a visually impaired pedestrian to make a crossing. With only one lane blocked, a crossing would be less appropriate, because the presence of one idling vehicle creates noise that can mask the approach of other vehicles that might not stop. In the experiment, the participants did not actually make a crossing. The trials ended when the participant indicated that two vehicles were stopped (regardless of whether that indication was correct), or when the participant failed to indicate two stopped vehicles within 10 s of both lanes being blocked. In two trials, the first vehicle to yield waited for 10 s and then drove away before a second vehicle yielded in the other lane. Those trials ended when the participant indicated the second vehicle had stopped, or when the participant failed to indicate that vehicle was stopped within 10 s.

Detection of Vehicles Blocking Both Lanes

Table 1 shows the results for the detection of double yields (i.e., vehicles blocking each of the lanes). A hit was scored if the participant indicated that both lanes were blocked within 10 s of the second of two vehicles' stopping. A false alarm was scored if at any time before both lanes were blocked, the participant indicated that both lanes were blocked and did not retract that decision within 1 s. A miss was scored if the participant did not detect that both lanes were blocked within 10 s.

Table 1. Percentage of detection accuracy for vehicles blocking each lane.

Participant	Hits Without	Hits With	False Alarms Without	False Alarms With	Misses Without	Misses With
1	47	87	7	7	47	7
2	19	69	13	13	69	25
3	50	50	13	13	38	38
4	19	38	6	13	75	50
5	44	63	0	13	56	25
6	63	56	31	13	6	31
7	13	38	0	19	88	44
Mean	36	57	10	13	54	31

As can be seen in table 1, five of the seven participants had superior hit rates with the sound strips in place compared to the results without the strips. This difference approaches statistical significance ($z = -2.0$, $p < 0.05$ by the Wilcoxon signed ranks test).[17] However, every participant had at least one false alarm in the treatment condition. False alarms are cause for concern because they imply that the individual might make a crossing in the belief that both lanes are blocked by stopped vehicles when, in fact, they are vulnerable to vehicles approaching at speed. False alarm rates with and without the sound strips were roughly the same. The slightly superior hit performance in the treatment condition came from a corresponding reduction in misses. In the two trials in which both lanes were never blocked because one of the yielding vehicles departed after 10 s, all departures were detected except one. That one failure was in the treatment condition.

In the treatment condition, participants also detected that both lanes were blocked more quickly than in the control condition (F (1, 6) = 26.4, $p < 0.01$). The mean time to report that both lanes were blocked was 3.5 s in the control condition and 2.3 s in the treatment condition. The standard deviation in both the control and treatment conditions was 1 s. The sound-strip condition accounted for 81 percent of the within-subjects variance.

Unexpectedly, participants did not appear to have more trouble detecting two vehicles stopping at the same time than they did detecting two vehicles stopping with an intervening delay. Table 2 shows the number of correct detections of both lanes being blocked by stopped vehicles when those vehicles arrived at approximately the same time. The control and treatment rates of simultaneous yield detection, 27.5 percent and 53.5 percent, respectively, are similar to the overall hit rates shown in table 1. As with the overall rates, the detection of simultaneous yields was significantly better in the treatment condition compared to the control condition (t (6) = 2.3, $p < 0.05$).

Table 2. Correct detection of pairs of vehicles yielding side-by-side at the same time.

Participant	Without	With
1	3	3
2	0	3
3	1	1
4	0	2
5	2	3
6	2	3
7	0	0

Detection of Individual Stopped Vehicles

To this point, results have been provided for the detection of two vehicles stopped side-by-side at the crosswalk or stop bar. These data were emphasized because the focus was on the accessibility of double-lane roundabouts, and it was assumed that crossing when only one vehicle has stopped at a two-lane crossing increased the risk of not hearing the approach of a second vehicle. However, participants indicated when they detected a vehicle stopping and in which lane. A hit was scored whenever the participant correctly identified, within 10 s, the presence and lane position of a stopped vehicle.

A miss was scored if a stopped vehicle was not identified as stopped in the specified lane within 10 s. A false alarm was scored when a vehicle was identified as stopped in a particular lane when it was not. If participants indicated that a response was incorrect within 1 s of making that response, then the first response was ignored whether or not it was correct. When a stopped vehicle was associated with the wrong lane, a miss was scored for one lane and a false detection was scored for the other. This was the case with approximately 19 percent of the misses in the control condition and 13 percent of the misses in the treatment condition.

Some participants incorrectly reported stops in a particular lane more than once within a trial (i.e., multiple false alarms). Multiple false alarms were possible in the single-lane case because participants could recognize that a vehicle was not stopped in that lane and could then falsely identify a subsequent stop. This was not the case in scoring for detection of both lanes blocked because in that scoring, a trial ended as soon as the participant indicated that both lanes were blocked. Because of the complexity of false alarm interpretation in the single-vehicle case, only hit rates are reported, and these should be interpreted with caution.

Figure 6 shows the proportion of correct identifications of stopped vehicles by condition, lane, and the lane in which the first yield occurred. Overall, performance was better in the treatment condition than in the control (F (1, 6) = 15.4, $p < 0.01$).

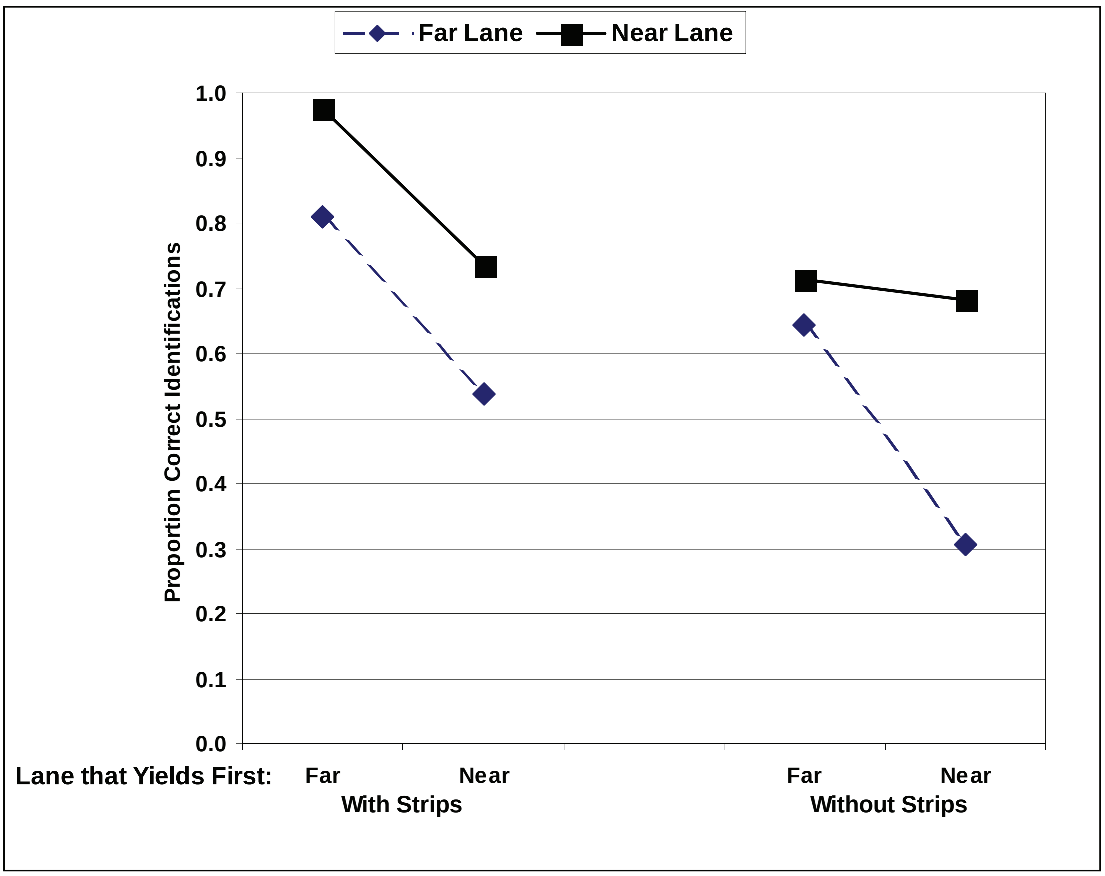


Figure 6. Proportions of correct identifications of stopped vehicles shown by test condition, the lane in which the first vehicle to yield stopped, and the lane identified.

Identification tended to be more accurate when the first yield was in the far lane (F (1, 6) = 12.3, $p < 0.05$). The first vehicle to yield creates noise as it idles at the crosswalk. When it idles in the near lane, that noise can mask the later arrival of a second vehicle in the far lane. Participants were able to detect only 30 percent of the vehicles that stopped in the far lane when there was a vehicle already idling in the near lane. When the first vehicle to yield is in the far lane, its idling is somewhat attenuated by its greater distance from the participant, and the participant can usually detect the arrival of a second vehicle that comes between the participant and the vehicle in the far lane. When a vehicle yielded in the near lane, detection of which lane the vehicle was in was better if there was already a vehicle stopped in the far lane.

Overall, performance in the detection of stops was better for vehicles in the lane nearest the participant (F (1, 6) = 8.2, $p < 0.05$); however, these effects were not additive, since the three-way interaction of condition, lane to yield first, and lane was significant (F (1, 6) = 10.4, $p < 0.05$). In the control condition, detection performance for near-lane yields was affected very little by the presence of a stopped vehicle in the other lane. Conversely, in the control condition, detection performance for far lane yields was very sensitive to whether there was a vehicle already stopped in the near lane. The worst performance was for detection of vehicles stopping in the far lane when there was a vehicle idling in the near lane.

In the treatment condition, there were no interactions. Detection of stopped vehicles in the near lane was consistently better than detection of stopped vehicles in the far lane. When a vehicle was already stopped in the far lane, detection of a vehicle stopping in the near lane was nearly perfect (only one participant missed one yield in this case). The sound cue treatment appears to have had two beneficial effects: (1) the detection of the presence of vehicles improved, and (2) given detection, lane identification accuracy was improved. The near perfect detection of near lane yields when a vehicle was already stopped in the far lane is primarily attributable to the first benefit. The improvement in detection of far-lane stops when the far lane vehicle was first to stop is primarily attributable to increased accuracy in locating those stops as being in the far lane.

Debriefing Results

After completing the test procedure, participants were debriefed. The debriefing sought impressions of the differences in the two crossing conditions as well as additional information on the participants' experiences in making street crossings. The information obtained in these debriefings may be of interest to scientists and engineers who are concerned with accessibility.

Participant 1

Participant 1 is a middle-aged male. He takes walking trips outside his home or office every day. He travels alone during most of these trips. Many of these trips, almost every day, are to places he has not visited previously. He has some residual peripheral vision, but he relies primarily on hearing for street crossings.

Despite his superior performance in the sound-strip trials, he reported that the "seams in the pavement" made it more difficult to hear the car engines for which he has been trained to listen. He said that he consciously tried to ignore the noise from the seams. When he was told that his only false alarm occurred when a second vehicle drove over a strip when pulling up behind a vehicle that had already yielded, he appeared to be surprised. He said that he thought that he had entirely ignored the seams, but that perhaps he had not done so.

One issue in the accessibility of roundabouts is the amount of delay they impose on visually impaired pedestrians before these pedestrians identify an acceptable gap. In considering signalization versus other treatments, it may be worthwhile to consider the delay imposed by traffic signals. Participant 1 estimates that at signalized intersections, even those with which he is familiar, he is delayed by at least 4 minutes. This is because he always waits through at least one signal cycle to be sure he knows what is happening.

At some intersections where pedestrian call buttons are installed, he does not use them. His reason is that by the time he travels from the button to the crosswalk threshold and aligns himself with the crosswalk, the pedestrian phase has expired. At other crossings, he is unable to tell which crossing the accessible signal is indicating. In particular, he provided an example of an intersection he frequents where crossings are allowed only on one side of the intersection, but the accessible signal can be heard from both sides.

Participant 2

Participant 2 is an older (more than 65 years of age) male. He travels alone outside of his home or office every day. He estimates that about once a month he takes a pedestrian trip to a location that he has not been to before.

He indicated that he noticed the sound strips, but did not realize that they were intended to help detect yielding vehicles. He said that he tried to use the information these strips provided. He indicated that he did not know the number or location of the strips, but that such knowledge would have helped.

This participant said he sometimes crosses at uncontrolled crosswalks that have more than two lanes, even when only one lane is blocked. For instance, if it is otherwise quiet, he will walk in front of a vehicle that has yielded in the near lane so that he can better hear traffic in the far lane.

Participant 3

Participant 3 is a young adult female. She takes 6 to 12 pedestrian trips outside of her home or office every week. About half of these trips are with a sighted companion. She estimated that about once a month she takes a pedestrian trip to an unfamiliar location.

She indicated that she learned a lot during the test. For instance, she says that she learned that it is easier to detect vehicles in the near lane. She volunteered that the "bumps" made it harder to hear the car engines. She said that at uncontrolled crossings, if a car yields for her, she normally waves it on. Initially she said that she would never cross in front of a yielding vehicle if there were more than one lane. Later, she amended this by saying that if she could tell that there were no other cars, she would cross in front of a single yielding vehicle, but added that her experience with the test indicates that she could probably never tell if there were no other vehicles.

Participant 4

Participant 4 was a middle-aged female who said that she takes about 15 pedestrian trips outside of her home or office during an average week. Most of those trips are without a companion. She said that she travels to unfamiliar locations almost every week. She said she does not use visual cues when traveling, but that she can perceive some light, which is mainly useful at night.

She indicated that the test was difficult because she could not tell from which direction the cars were coming. She noticed the sound of the strips and said they were useful, especially when two vehicles arrived at the same time. When asked what she does when vehicles yield for her at uncontrolled crossings, she said she just waits until they leave and it becomes quiet. She does not signal drivers to move on, because she is unsure how they will react and cannot see them to adjust to their reactions. She avoids crossing at intersections without signals. She hates stop-controlled intersections because she never knows what cars are going to do. That is, she does not know whether they have stopped for her or whether they will remain stopped if she decides to cross. She avoids streets with more than two lanes if they do not have signals. At signalized intersections, she always waits through at least one cycle so that she is certain about what is occurring. She prefers crossing midblock to crossing at nonsignalized intersections. When roundabouts were described to her, she remarked that the crosswalks were too close to the intersection; it would be better if the crosswalk were midblock and away from the noise of the intersection.

Participant 5

Participant 5 is a middle-aged male. He estimated that he takes about 10 pedestrian trips per week outside of his home or office, all without a sighted companion. Of these trips, perhaps two per month would be to locations that he had not visited previously. He indicated that he uses his residual vision to locate the white lines that demarcate crosswalks, and also to follow sidewalks.

Participant 6

Participant 6 is a middle-aged female. She reported taking about three pedestrian trips per week without companions, and walking to a location she has not visited previously about once per month.

She referred to the noise that the sound strips made as a “bubble wrap sound,” because they reminded her of the sound generated when her children pop the chambers in bubble wrap packing material. She stated that she preferred having the strips to not having them because they were helpful in detecting when cars had stopped. She also indicated that she sometimes does cross the two-lane street in front of her place of employment if vehicles stop for her.

Participant 7

Participant 7 is a middle-aged female who estimated that she makes one or two walking trips per week not near her house or office, usually with a sighted companion. She estimated that she takes walking trips alone to unfamiliar locations about six times per year.

She indicated that detecting the vehicles was easier with the sound strips than without them. She said that she would cross at crosswalks when she could hear car engines idling in both lanes. Although she was the only participant in this study who acknowledged having previously crossed at an actual roundabout, she said that she would not do that again on her own.

DISCUSSION

Study 1 indicated that a sound-strip installation could help some visually impaired pedestrians to detect yielding vehicles. The sound strips not only increased the probability of detecting stopped vehicles, but also decreased by more than a second the amount of time needed to make the detection.

However, in planning this study, a very low false alarm rate was set as a goal (i.e., a low rate of indications that a vehicle was blocking a lane when it was not). This goal was set to avoid a situation where the existence of sound cues would create a false sense of security. The false alarm rate in the control (without strips) condition was 10 percent. With the strips, the false alarm rate was 13 percent (essentially unchanged). This level of false alarms would not be acceptable for a deployable system.

Participants in this study were not trained to use the sound cues provided by the pavement treatment, nor were they informed of the treatment before the debriefing. It is conceivable that with training, detection performance with the sound strips would have been better, and false alarms might have been reduced. It is also possible that training would have no effect on performance, so the hypothesis that training would improve performance would need to be empirically verified.

Training was not included in the study because adopting a treatment that requires training would require an ambitious and expensive outreach. The most desirable treatment would be one that is self-explanatory, and this study's goal was to test whether the present treatment would work without training.

The finding that the detection of individual stopped vehicles was greatly improved with the presence of the sound strips suggests that the strips are effective in alerting participants to the presence of individual stopped vehicles. If only one lane of traffic had to be monitored, performance with the strips might approach that for right-lane detection in this study (80 to 90 percent correct detection). A sound-strip pavement treatment may be effective in single-lane roundabouts or right-turn slip lanes, even though the present results are not encouraging for the double-lane condition. The treatment has not been shown to work in the single-lane condition. The present results suggest that single-lane tests may be fruitful if some of the challenges identified in study 2 can be overcome.

CHAPTER 3. STUDY 2: FIELD EVALUATION

In study 1, the drivers followed a script and were instructed to stop at the crosswalk, which they did. To ensure that there would be crossing opportunities; both lanes were blocked at some point in 16 of the 18 trials. In study 2, the drivers were untrained and presumably unaware that they were participating in a research study. The pedestrian participants were five of the seven participants from study 1. Thus, the pedestrians had been exposed previously to the sound strips, were aware of their purpose, and had been briefed on the layout of the strips from the previous study.

Because a thorough evaluation of the sound strips required that vehicles yield, and because the literature suggested that yielding might be rare, a yield sign was placed in the street between the lanes at the edge of the cross walk. In exploratory visits to the roundabout, it was observed that vehicles yielded well upstream of the crosswalk; therefore, the yield sign was supplemented with a sign that indicated where to yield (see figure 3).

METHOD

The research design included one control and one experimental condition. All control observations were made before the experimental observations. Data collection took place in fall 2004. Control observations were made between 5 p.m. and 6:30 p.m. in the 2 weeks that preceded the end of daylight savings time. Treatment observations were made between 3:30 p.m. and 5 p.m. during the 2 weeks that followed the switch to standard time. Traffic counts taken in spring 2004 showed that the traffic volume at the exit peaked at 5 p.m. at a rate of about 800 vehicles per hour, and that the volume was symmetrically distributed about the peak. Because of the switch from daylight savings time to standard time, lighting conditions were approximately the same for the baseline and treatment conditions. Because all data were collected at the same roundabout, and since an adjacent commuter rail station generated traffic, it was likely that most of the drivers traversed the same exit daily at approximately the same time. By shifting the data collection time between the control and treatment conditions, an attempt was made to maximize the probability of observing different drivers from the same population. Because there were 10 days of testing (5 in each condition), some drivers were observed more than once. The trials averaged 1.5 minutes in length, and there was an average of 15 trials per day. Thus, over the 90-minute test interval, the participant and the mobility specialist were only at the crossing for about 23 minutes. It is estimated that on any given test day, a daily roundabout user had about a one-in-four chance of participating.

Roundabout Treatment

The roundabout exit in the control condition is shown in figure 7. Figure 8 shows the exit after the installation of the sound strips and the mount for the street sign. As in study 1, one sound strip was placed at the upstream edge of the crosswalk and extended across the road approximately 10.7 m (35 ft). The second and third strips were placed parallel to the first, 6.1 m (20 ft) and 7.3 m (24 ft) upstream, respectively. The street sign was bolted to the pavement on the lane marking at the upstream edge of the crosswalk. The sign mount can be seen in figure 8 as the opening in the pavement where the center white line meets the crosswalk.

Figure 7. Roundabout exit in baseline configuration.

Figure 8. Sound-strip installation and mount for the street sign.

Study 2 Procedures

Three video cameras were mounted atop an 8.5-m (28-ft) mast. The mast was located on a knoll on the side of the street opposite the exit of interest and about 15 m (49 ft) downstream from the exit crosswalk. One camera was used to videotape the participants, the certified orientation and mobility specialist, the crosswalk, and the vehicles approaching the exit. This camera was the only one used to capture the data reported here. A second camera was used to videotape traffic in the circular roadway, and a third camera filmed traffic that approached the roundabout entry adjacent to the exit.

Before data collection began, the certified orientation and mobility specialist crossed with the participants several times so that the participants could familiarize themselves with the roundabout layout and traffic sounds. Although she was not visually impaired, the certified orientation and mobility specialist carried a long white cane and wore sunglasses. Every participant had either a long white cane or a guide dog. Before each trial, the participant and certified orientation and mobility specialist waited on the sidewalk approach to the exit crosswalk. When no vehicles were within about 15 m (49 ft), they stepped to the edge of the crosswalk ramp, and the certified orientation and mobility specialist began tapping her long white cane in the street at a rate of one tap per second. The red-tipped end of the cane traveled about 1 m (3.3 ft) vertically with each tap. The certified orientation and mobility specialist stood with one foot over the curb edge, in the gutter, so that she was technically in the crosswalk. The participant stood completely on the sidewalk to the left and upstream of the certified orientation and mobility specialist.

The tapping of the cane signaled the beginning of a trial. A trial ended when one of the following events occurred:

- The participant indicated that both lanes were blocked by stopped vehicles.
- One of the lanes was blocked for 10 s or more and traffic was backing up.
- Both lanes were blocked and the participant failed to indicate this occurrence within 10 s.
- A pedestrian or motorist stopped to help the participant and certified orientation and mobility specialist cross.
- Three minutes elapsed.

In most cases, the certified orientation and mobility specialist and the participant made a crossing at the end of a trial. Although a crossing was not required for data collection, a crossing was performed to avoid confusing drivers who had clearly yielded or to reward those who had stopped to help. In a few cases, the certified orientation and mobility specialist and the participant stepped away from the crossing and waved on any drivers who might have stopped or slowed. Rest periods between trials varied from several seconds to several minutes; however, new trials were never started until all drivers who might have seen the end of the preceding trial had departed. This precaution was important because vehicles making a right turn into the exit sometimes formed long queues at the adjacent exit and were in a position to see the end of the preceding trial, albeit from some distance.

Participants carried a wireless microphone so that their verbal responses could be recorded on the video recorder. Participants were instructed to indicate verbally when vehicles were stopped and when both lanes were blocked. Unlike the previous experiment, they were not asked to indicate the lane in which vehicles stopped. However, participants were instructed to indicate when stopped vehicles departed.

RESULTS

Across all participants, 151 trials were observed (65 in the control condition and 86 in the treatment condition). As shown in table 3, during these trials, 1,944 vehicles approached the observed crosswalk. Most of those vehicles (1,671) passed the crosswalk without stopping. Only 273 vehicles (14 percent) stopped, even if only momentarily, before passing the crosswalk. In the control condition, 11.5 percent of the vehicles stopped. In the treatment condition, 16.7 percent of the vehicles stopped. The results were consistent with the hypothesis that the "YIELD TO PEDESTRIAN" sign that was placed between the lanes induced a greater proportion of the drivers to stop ($X^2 = 24.4$, $p < 0.0001$).

Table 3. Drivers' responses to the presence of visually impaired pedestrians in the crosswalk.

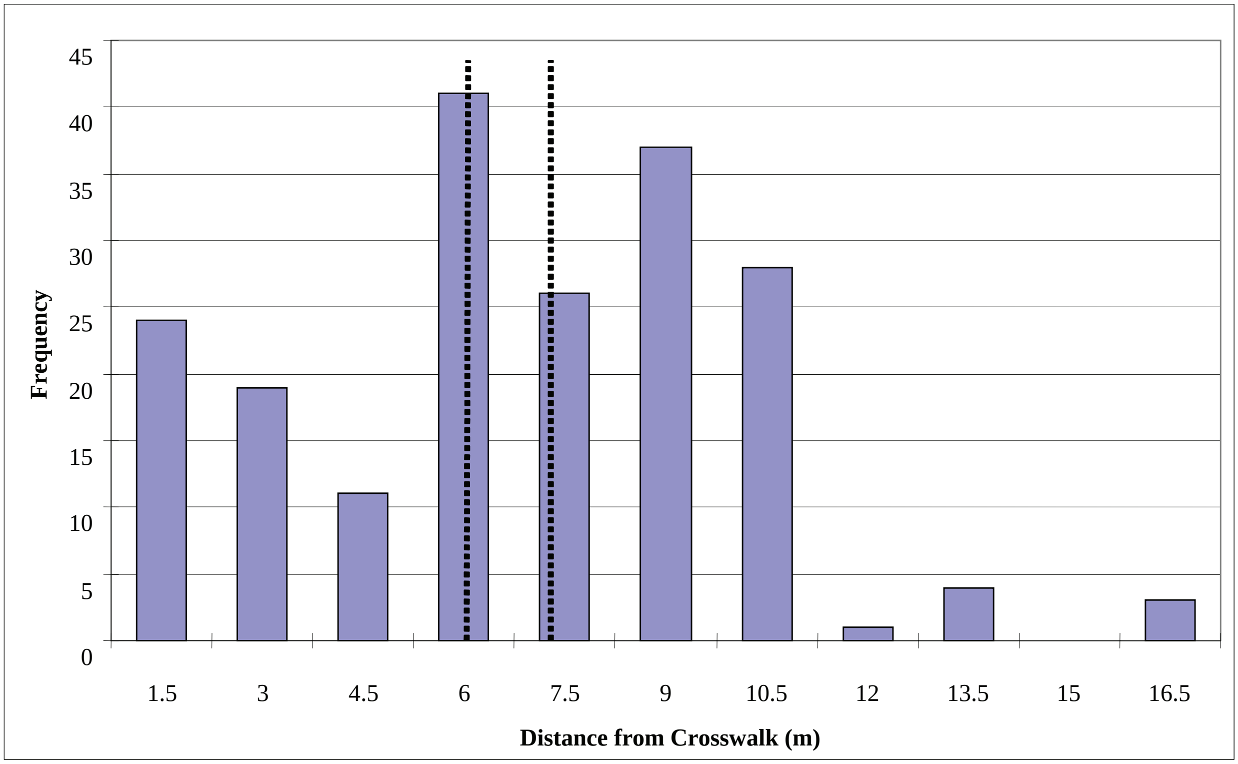
Driver Behavior	Control	Treatment	Total
Stopped	115	158	273
Continued without stopping	881	790	1,671
Total	996	948	1,944

Table 4 shows in which lanes vehicles were stopped. The far lane category includes some vehicles that may have been straddling the two lanes. As reported elsewhere, drivers who are traveling straight through a roundabout tend to take the shortest path, which results in drivers who enter and exit in the near lane shifting to the far lane as they travel through the circular part of the roadway.[(18)] Some of the drivers in this study stopped within the circular roadway. Thus, some of the drivers who were classified as having stopping in the far lane may have been on a path that would have placed them in the near lane when they eventually reached the crosswalk.

Table 4. Lateral position of vehicles that stopped for pedestrians.

Lane	Control	Treatment	Total
Near	77	117	194
Far	38	41	79
Total	115	158	273

Although the sign placed between the lanes resulted in a small but statistically reliable increase in yield compliance, the nature of the compliance was less than optimal for the effectiveness of the pavement sound-strip treatment. Figure 9 shows the longitudinal distance from the crosswalk to the front of vehicles that stopped in the near lane. Dotted lines in the figure represent the distance of the sound strips from the crosswalk. It can be seen that the majority of the vehicles in the near lane did not fully traverse the strips. Figure 10 shows a video capture of two vehicles that stopped well upstream of the crosswalk and, thus, did not cross the sound strips. Vehicles that stopped 6 m (19.7 ft) from the crosswalk would have crossed the farthest upstream strip with their front axle. Their rear axle would not have crossed either of the upstream sound strips. Only drivers that stopped within 3 m (9.8 ft) of the crosswalk likely would have triggered sounds from both upstream strips with both their front and rear axles. Thus, only 24 of the 194 vehicles that stopped in the near lane were likely to have generated the desired sound pattern.



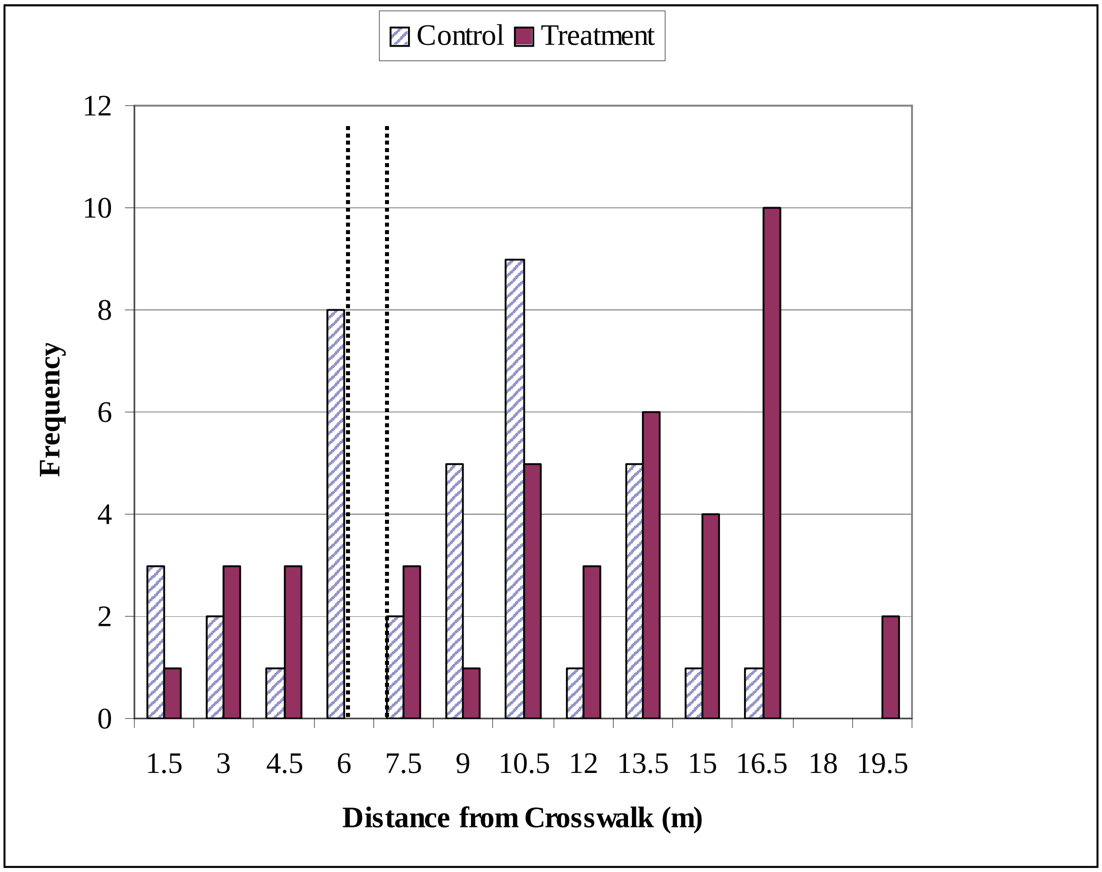
1 m = 3.28 ft

Figure 9. Distance from crosswalk of vehicles stopping in the near lane.

Figure 10. Two vehicles that stopped for the pedestrians.

In the near lane, the stopping distance from the crosswalk did not vary significantly with treatment ($p > 0.10$). However, the vehicles that stopped in the far lane stopped farther from the crosswalk in the treatment condition than in the control condition ($t\ (77) = 3.4$, $p < 0.01$). Figure 11 shows the distribution of stopping distances for the far lane in the control and treatment conditions.

The in-street and roadside signs appear to have induced more motorists to stop, but these signs were not effective in inducing motorists to stop closer to the crosswalk. Given that the majority of the yielding vehicles did not cross over the upstream strips before stopping, and that very few vehicles passed over the pair of strips with both axles, the effectiveness of the sound strips in cuing the visually impaired pedestrians to the presence of yielding vehicles clearly was compromised.



Note: 1 m = 3.28 ft.

Figure 11. Distance between the crosswalk and a vehicle stopped in the far lane is shown as a function of treatment condition.

Table 5 shows the outcome of the 151 trials. Five of the seven participants in study 1 returned to take part in study 2. Individuals retained the same participant number assigned from study 1.

Table 5. Trial outcomes.

Participant	Control Hits (%)	Treatment Hits (%)	Control False Alarm (%)	Treatment False Alarm (%)	Control Time Out (%)	Treatment Time Out (%)	Control Miss (%)	Treatment Miss (%)	Control Good Sam (%)	Treatment Good Sam (%)
2	19	20	19	7	13	7	19	27	31	40
3	43	14	36	14	14	43	0	24	7	5
4	8	6	17	0	8	50	33	25	33	19
5	15	6	0	0	38	56	0	13	46	25
7	10	11	0	6	50	28	0	39	40	17
Mean	19	12	14	5	25	37	32	21	10	25

Table 5 includes an outcome not anticipated in the research plan—many trials ended when a passing pedestrian or motorist stopped to assist the pedestrians in crossing (act of a Good Samaritan). These were labeled “Good Sam Crossings.” A crossing was given this designation when: (1) a pedestrian stopped to provide assistance, (2) a driver got out of his/her car to provide assistance, (3) a driver engaged in some overt behavior to influence other drivers to stop, or (4) a driver interacted with the pedestrians in a way that disrupted their ability to listen for other traffic. Each day during the study, at least one passing pedestrian stopped to offer assistance. In some cases, they were told that an experiment was being conducted and assistance was not needed. In other cases, it was not practical to explain the situation; such was the case when a pedestrian stepped into the street and flagged down traffic. Drivers, too, often stopped to offer crossing assistance. Other drivers maneuvered their vehicles across the traffic lanes to form a barricade, as did several transit bus drivers. Still other drivers rolled down their windows and shouted that it was safe to cross.

The “Time Out” category included two different outcomes: (1) 3 minutes passed without two vehicles blocking the lanes, or (2) the certified orientation and mobility specialist determined that individual vehicles or traffic were excessively delayed. The latter occurred when a vehicle or series of vehicles yielded in the near lane, but no vehicles would yield in the far lane.

The remaining categories are similar to those used in study 1. A correct identification was scored when vehicles blocked each of the lanes and the participant indicated that this was the case. Unlike the closed-course study, it was rare for two vehicles to stop side-by-side in the roundabout exit. In most cases, both lanes were considered blocked if vehicles stopped in such a way that it would be difficult for subsequent vehicles to maneuver into the roundabout exit. Figure 12 shows a video image of a treatment-condition crossing in which the participant correctly identified that both lanes were blocked. In this image, the vehicle blocking the left lane stopped about 12 m (39.4 ft) upstream of the crosswalk.

Figure 12. Pedestrians crossing after a correct detection of both lanes blocked.

A false alarm was scored when the participant indicated that both lanes were blocked when, in fact, only one lane was blocked. A miss was scored when both lanes were blocked for 10 s, but the participant failed to indicate that both lanes were blocked. The proportion of the trials in each category differed significantly between the control and treatment conditions (X^2 (4) = 34.3, $p <$ 0.0001). However, it is unlikely that these differences are because of the treatment, since most yielding vehicles were not producing the desired sound cues by running over the sound strips. Practice, or a shift in response criteria, is a more likely cause to explain the performance differences. In any case, the observed changes were not in the predicted direction.

Although 16.7 percent of the vehicles in the treatment condition stopped for the pedestrians, most of these stops were not useful and did not result in a detected crossing opportunity. There are several possible reasons for this. One is that the pedestrians did not immediately respond when the drivers stopped. Figure 13 shows the distribution of the delays between the time both lanes were blocked by fully stopped vehicles and the time when participants indicated that the lanes were blocked. One unexpected finding was that in three cases, participants identified the blocked lanes 2 s before both vehicles came to a complete stop. This apparent anomaly may have been attributed to participants shifting from the strategy that they normally use to detect stopped vehicles (idling engines) to listening for silence after detecting approaching vehicles. This strategy worked when there was no traffic approaching the opposing entrance and when all traffic in the circle stopped. Note that in figures 10 and 12, both of which show correct detections, there were no vehicles entering the roundabout from the opposing direction. Detection times in study 2 were comparable to the detection times found in study 1.

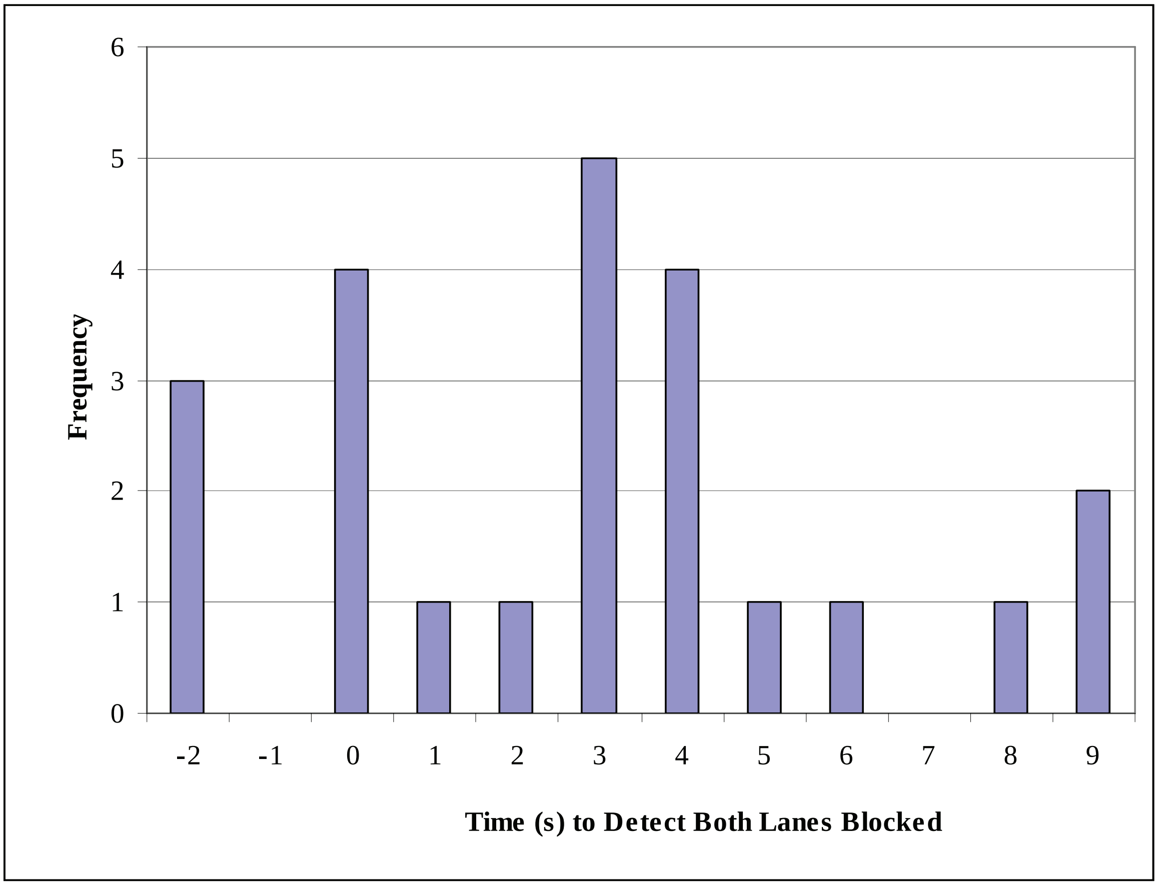


Figure 13. Frequencies of delays between the time both lanes were blocked and when participants indicated both lanes were blocked.

When pedestrians did not begin to cross immediately, drivers sometimes moved on. To estimate how long drivers may wait, the amount of time that stopped drivers waited was tabulated. If the pedestrians crossed or stepped away from the curb, then the amount of time drivers waited was not included. This procedure yielded delay times for 28 drivers in the control condition and 56 drivers in the treatment condition. A histogram of the wait times is provided in figure 14. In the control condition, drivers waited an average of 10.8 s. In the treatment condition, drivers waited an average of 4.7 s. In the control condition, wait times varied between 1 and 25 s. In the treatment condition, wait times varied between 1 and 20 s. The difference in wait times, not assuming equal variances between groups, was statistically reliable (t (39) = 5.1, $p < 0.01$). The difference in willingness to wait may have been because drivers who were induced to stop by the yield sign were not as committed to waiting as were drivers who stopped without the added inducement. If this hypothesis is correct, then the benefit for visually impaired pedestrians of yield signs is diminished. The bulk of the drivers who are influenced by the sign appear to be willing to wait only 3 to 6 s. Thus, these drivers may be pulling away just as the pedestrian with visual impairment begins to cross.

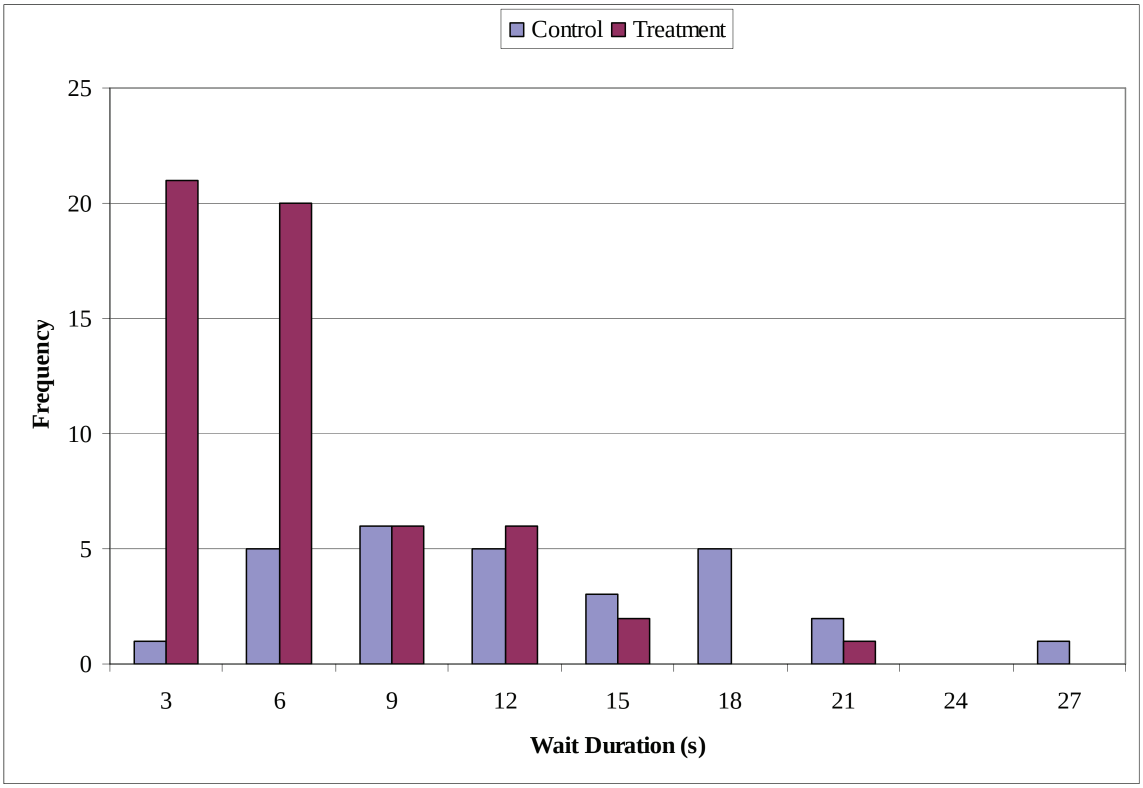


Figure 14. Amount of time drivers waited before moving on.

The goal of the sound-strip treatment was to improve the detection of stopped vehicles. One question that could be asked is: If detection were immediate and perfect, how long would the visually impaired pedestrian have to wait? To provide an estimate of the amount of delay before both lanes were blocked, 74 trials were identified that did not end in a time out before the first double yield occurred or a Good Samaritan intervened. It can be seen in table 6 that the mean time before both lanes were blocked was 63 s. The longest wait observed was 245 s. The 15th percentile wait was 16 s, and the 85th percentile wait was 125 s. Thus, even with the low yielding rates of 11 to 16 percent that were observed in this study, wait times for a double yield are comparable to wait times at signalized intersections.

Table 6. Average wait time before the first double yield.

	Time (min:sec)	Number of Passing Vehicles
Maximum	4:05	47.0
Minimum	0:00	0.0
Average	1:03	8.9
15th percentile	0:16	0.0
85th percentile	2:05	19.1
Number of trials	74	

DISCUSSION

One purpose of study 2 was to evaluate the effectiveness of an audible pavement treatment to assist pedestrians with visual impairment in detecting the presence of stopped vehicles at a double-lane roundabout exit. The treatment applied in the current study did not appear to be effective. The majority of the vehicles that stopped for the pedestrians stopped before crossing the treated area, and thus did not produce the intended sound cue. The same pavement treatment was used in study 1. In that study, performance was markedly improved by the treatment, even if it was not completely satisfactory. That study assumed that drivers would stop close to the crosswalk; however, in the field that assumption proved to be wrong. Drivers not only saw pedestrians long before they reached the roundabout crosswalk, they also frequently stopped before they entered the exit. This finding should be encouraging to those who are concerned about pedestrian conspicuity at roundabout exits. If drivers stop in the circular roadway (as was frequently observed in this study), then roundabout operations will be compromised both for motorists and visually impaired pedestrians. Moving crosswalks two car lengths away from the inscribed circle instead of the one car length, as seen at this particular roundabout, may improve vehicle operations. It is unclear that this would help visually impaired pedestrians detect yielding vehicles if drivers continue to stop one to three car lengths back from the crosswalk. For a pavement cuing system to work, vehicle behavior must be more consistent than it was in this study. The “YIELD HERE” sign used in this study did not appear to be effective in increasing consistency.

Although fewer than 15 percent of the drivers came to a complete stop for the pedestrians, it should not be assumed that the remaining 85 percent of the drivers did not see or respond to the pedestrians. There were several indications that most drivers were aware of the pedestrians—many drivers slowed, but did not come to a complete stop. The number of drivers who slowed is difficult to quantify because it would require knowing how fast they would have traveled if the pedestrians were not present. It appeared that most drivers attempted to engage in a nonverbal exchange with the pedestrians. In that attempted exchange, drivers signaled that they would yield if the pedestrians moved forward in response to their slowing. Apparently, the drivers did not perceive that people carrying long white canes or using guide dogs might not have access to this type of nonverbal exchange. Other drivers appeared to be unwilling to stop. Some honked as they accelerated past the crosswalk. Other drivers visibly altered their path to move farther away from the pedestrians. This last behavior was not unique to drivers who did not stop. A few drivers who stopped in the near lane proceeded to move on by merging into the far lane. In the treatment condition, this lane change required sharp maneuvers to avoid striking the yield sign.

Another purpose of study 2 was to evaluate the effectiveness of an in-street “YIELD TO PEDESTRIAN” sign. Although a statistically significant increase in stopping was obtained, the increase was probably too small to have practical significance. Furthermore, it appears that drivers induced to stop by the sign are less patient than those who would stop regardless of the sign. Because visually impaired pedestrians take more time to leave the curb than sighted pedestrians, they are not likely to benefit from a small increase in brief stops. The size of the increase in yielding in this study was similar to those obtained in previous studies.[10,11] Those studies also show that motorist response varies from site to site, both in overall yielding rates and in response to the in-street sign; therefore, the reader is cautioned against overgeneralizing from the current findings.

The final objective of this study was to quantify motorists' yielding behavior. In the absence of a treatment, 11 percent of the vehicles came to a full stop for two visually impaired pedestrians at the crosswalk threshold. Many more motorists slowed, and perhaps were willing to stop if the pedestrians had moved toward their path or taken more aggressive measures to take control of the crosswalk. Even with the low rate of yields, wait time for a double yield (see table 6) averaged only a minute. Thus, if a reliable sound cue were available so that visually impaired pedestrians could act immediately when two vehicles yield, then delay imposed by roundabout crosswalks would compare well with the delay imposed by traffic signals.

An unexpected finding was the proportion of trials in which pedestrians or motorists intervened to assist the visually impaired pedestrians. Although this level of altruism is encouraging, it would be better if the assistance were more effective. Some of the assistance greatly increased the risk to both the pedestrians and the motorists. For instance, some of the drivers who stopped to shout out that it was okay to cross did not monitor other traffic and did not warn the pedestrians that cars were continuing to go through the exit. When a transit bus attempted to blockade the exit, two vehicles accelerated around the bus and drove briskly through the crosswalk even though the bus obstructed these drivers' sight line to the pedestrians. Some pedestrians who stood in the crosswalk and signaled vehicles to yield watched the visually impaired pedestrians cross and turned their back to oncoming vehicles. Thus, we cannot recommend reliance on passersby to resolve accessibility challenges to the visually impaired.

CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

Study 1 showed that a pavement treatment can increase the proportion of double-lane yields that are detected and decrease the amount of time required to detect the yields. False detections of yields were not reduced by the treatment, and this problem would still need to be addressed.

Study 2 showed that motorists might stop long before they reach either the crosswalk or the roundabout exit, thus rendering pavement treatments in the exit ineffective. Before sound treatments similar to the one evaluated in these studies can be made to work, the frequency of motorists' yielding would need to increase, the location of the yields would need to be consistently closer to the crossing, motorists who yield would need to show more consistent patience, and the problem of false yield detection would need to be solved.

A reliable yield detection system that did not rely on where motorists stop might be effective without changes in motorist behavior because wait times for double yields were relatively short.

It is possible that a pavement treatment similar to that used in these studies would be effective at single-lane roundabouts. Study 1 showed that the second vehicle to yield is difficult to detect when it stops in the far lane, but is quite easy to detect when it stops in the near lane. Single-lane roundabouts do not present these challenges and might allow higher detection rates than were observed in study 1; however, single-lane operations were not observed in these studies, and the hypothesis that pavement treatments would be effective in the single-lane case requires empirical testing.

The finding that motorists tend to stop well upstream of the crosswalk may suggest that roundabout crosswalks should be moved two or more vehicle lengths from the inscribed circle. Such a design would reduce the likelihood that vehicles yielding to pedestrians would obstruct the circular roadway. It might also increase the likelihood that an effective pavement treatment to cue visually impaired pedestrians can be devised. This hypothesis, too, requires empirical testing. Moving the crosswalks farther from the circular roadway may change driver behavior in several ways. For instance, it might decrease driver willingness to yield. Moving the crosswalks farther from the circular roadway would increase pedestrian travel distance; therefore, the effects of situating the crosswalks at a great distance from the circular roadway would need to be carefully studied to ensure any benefits that might result are not offset by a loss in benefits.

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