Visually Impaired Pedestrian Safety at Roundabout Crossings

SAFETY RESEARCH USING SIMULATION

UNIVERSITY TRANSPORTATION CENTER

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Abstract

Pedestrians are some of the most vulnerable road users. This becomes more apparent at intersections, where pedestrians are unprotected and interacting with vehicles. While pedestrian phases that are commonplace at most signalized intersections facilitate their safe movement through intersections, roundabouts by nature provide little protection to pedestrians, who must judge safe gaps in traffic before crossing. This presents problems for visually impaired users, who must rely on auditory cues. The constant movement of traffic from many directions can be confusing to visually impaired pedestrians. The objective of this project is to develop a new pedestrian-activated sign that can alert drivers of the presence of pedestrians at roundabout crosswalks, in an effort to increase driver yielding behavior. A thorough literature review was performed, which investigated roadway treatments at roundabouts that improve visually impaired pedestrian safety. Given the limitations of existing studies that often put the burden of responsibility on the pedestrian, a novel pedestrian-activated yield sign was designed and an experimental design was developed for testing the effectiveness of this sign through driving simulation in combination with participant questionnaires. The goal is to determine whether drivers will intuit the meaning of the new roundabout signage after repeated exposure. Anticipated results should confirm the initial hypothesis that drivers will observe the new sign and respond by yielding to pedestrians. With multiple encounters of the new signage, an increase in yielding rates is expected compared to yielding rates associated with conventional yield signs at roundabout crossings. This study can help inform design, education, and other countermeasures for safer roundabout operations for all users.

1 Introduction

Pedestrians, and in particular disabled pedestrians, are some of the most vulnerable users of transportation systems. Safety concerns increase at crosswalks of alternative intersection designs (e.g., roundabouts), which are more complicated environments for visually impaired pedestrians to navigate. Roundabouts are a more complex environment for drivers as well because they have to navigate interactions with pedestrians and crossing traffic as they enter or exit a roundabout.

Existing research has focused on investigating pedestrian (both sighted and visually impaired) gap acceptance behavior near roundabouts, the impact of signalization treatments for pedestrians on roundabout operations, or evaluation of roadway treatments on visually impaired pedestrian safety. No study to date has investigated the compliance level of drivers yielding at roundabout crossings under various signage types.

The objectives of this research were to design a novel pedestrian-activated sign that can be implemented to improve the safety of visually impaired pedestrians and to develop an experimental driving simulator design to test the effectiveness of the sign and compare it to conventional yielding signs commonly used at roundabout crossings. This research is not limited to visually impaired pedestrians; it could be extended to include any type of disabled users.

The study consisted of three parts. First, the research team performed a thorough review of existing signage and other control devices and roadway treatments that have been proposed for roundabout crossings and specifically for improving visually impaired pedestrian safety at such crossings. Then, given the limitations observed in the literature, a novel pedestrian-activated sign was designed to be implemented at roundabout crosswalks for improving driver yielding behavior. Finally, an experimental design was developed that included driving simulator experiments coupled with pre- and post-study questionnaires to assess the effectiveness of the proposed sign in improving driver compliance of yielding at roundabout crossings. The experiment puts participants through two simulated drives to compare their pedestrian yield behavior with conventional yield signage and proposed pedestrian-activated signage. Driving simulation was selected as it facilitates testing any driving scenario and collecting drive data at a resolution not easily feasible in the field. The rest of the report describes these efforts in more detail.

2 Background

Roundabouts are a very elegant solution to traffic flow operations, but can come at the cost of pedestrian safety. This is particularly true for pedestrians with visual impairments who may rely on auditory cues from traffic and signals for safe crossings. These cues become difficult or impossible to detect with continuously flowing traffic, a problem further exacerbated by hybrid and electric vehicles. From the driver's perspective, it can be difficult to detect pedestrians at crosswalks while handling the cognitive load of navigating a roundabout with traffic.

To date, there has been a substantial amount of work done to evaluate and develop various roadway treatments at roundabouts for visually impaired pedestrian safety [1-4]. Adding traffic signals to a roundabout has also been proposed, but it essentially undermines the very benefits of the passive control design of roundabouts. However, studies have found that novel design approaches, such as combining zig-zag or offset crosswalks with signals, can minimize operational impacts [5].

The assumption that push-button-activated signals are the most effective treatment for visually impaired pedestrians may have been overstated. A study by Liao et al. [6] showed that in many situations visually impaired pedestrians fail to even find the push-button or, worse, attempt a crossing not during a walk signal. A pedestrian-activated signal for roundabout crossings is an ideal situation for the use of automatic pedestrian detection, through traditional detection (e.g., video, pressure, infrared, etc.) or emerging technologies such as mobile devices.

Overall, the majority of the studies that have been aimed at improving safety are from the pedestrians' perspective, putting the burden of responsibility on the pedestrian. To date, very little research has been done to investigate this issue from the drivers' perspective. The goal of improving safety by informing drivers of potential pedestrian hazards in a roundabout is aligned with NCHRP report 674 [7], which recommends focusing future research on treatments geared towards reducing speeds and increasing yielding behavior.

3 Methodology

3.1 Pedestrian-Activated Yield Sign

After a thorough review of existing warning signs, a novel pedestrian-activated warning sign was designed to warn drivers before they enter the roundabout if and where pedestrians are attempting to cross. The sign is a yellow diamond warning sign with a circle to indicate the roundabout and symbolic crosswalks for each approach of the roundabout; it is intended to replace the conventional yield to pedestrians sign often located in advance of a roundabout crosswalk. If a pedestrian is about to cross a roundabout approach, the associated crosswalk symbol on the sign will flash to warn drivers which crosswalk is active (i.e., has pedestrians present); see Figure 3.1.

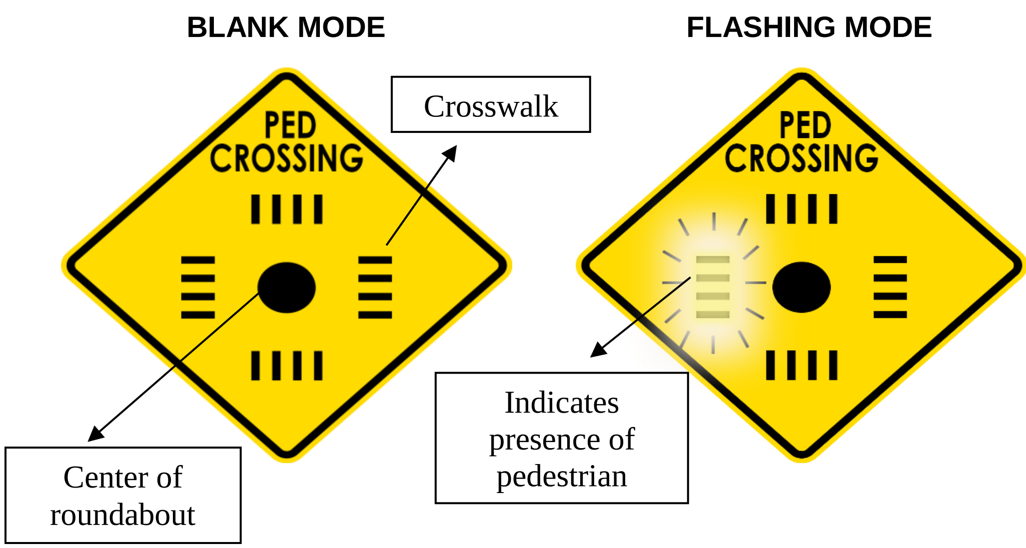

Figure 3.1 – Pedestrian-activated warning sign

The sign is intended to improve situational awareness and reduce cognitive load by providing drivers with warnings of expected hazards before entering the roundabout. This may not only improve universal access and safety for pedestrians at roundabouts, but is also expected to allow drivers to adjust their planned trajectory in anticipation of an event. This will promote smoother traffic flow operation and potentially reduce emissions.

As mentioned earlier, actuation of the sign could be achieved through either active (e.g., push button or smartphone application) or passive (e.g., infrared technology) detection and can be used by all pedestrians.

3.2 Driving Simulator Experimental Design

The experimental design consists of two drives per participant, where a driving participant encounters four roundabouts per drive. The first drive contains conventional pedestrian yield signage, as seen in Figure 3-2, while the second drive will contain the proposed pedestrian-activated yield signage. Each drive has two roundabouts with no pedestrian present and two roundabouts with a pedestrian present. Therefore, there are four pedestrian and signage combinations: 1) a control roundabout with no pedestrian present and a conventional pedestrian yield sign; 2) a roundabout with a pedestrian present and a conventional pedestrian yield sign; 3) a roundabout with no pedestrian present and the proposed sign not activated; and 4) a roundabout with a pedestrian present and the proposed sign in flashing mode. Combinations 1 and 2 will be seen in the first drive, while combinations 3 and 4 will be seen in the second drive. Pedestrians, if present, are located on the exit leg of roundabouts.

Figure 3.2 – Conventional pedestrian yield sign

Each drive scenario consists of approximately 2 miles (3.2 kilometers) of simulated roadway with 16 midblock roadway segments placed between four roundabouts. The long sections of straight roadway were placed to give drivers time to recover from making turns in a roundabout, knowing that excessive turns could cause simulation sickness in some drivers. The four intersections were connected into a continuous drive sequence, and the participant was prompted by an on-screen display to make a left or right maneuver for each of the four intersections. There was a total of two left turns and two right turns.

Four drive scenarios were created to include every combination of turn movement with the presence or absence of a pedestrian. These scenarios are depicted in Figure 3.3. Straight lines indicate the roadway, and circles indicate roundabout locations. Roundabouts with stick figures depict where participants encounter pedestrians. Directional arrows indicate turn instructions given to participants. The scenario is populated with light oncoming traffic, which is limited to the opposing direction so as to not interfere with the participants' driving path.

Again, the participant is to perform two drives: 1) through one of four drive scenarios with the existing roundabout signage (conventional pedestrian yield sign), and 2) through the identical drive scenario with the proposed roundabout signage (pedestrian-activated yield sign).

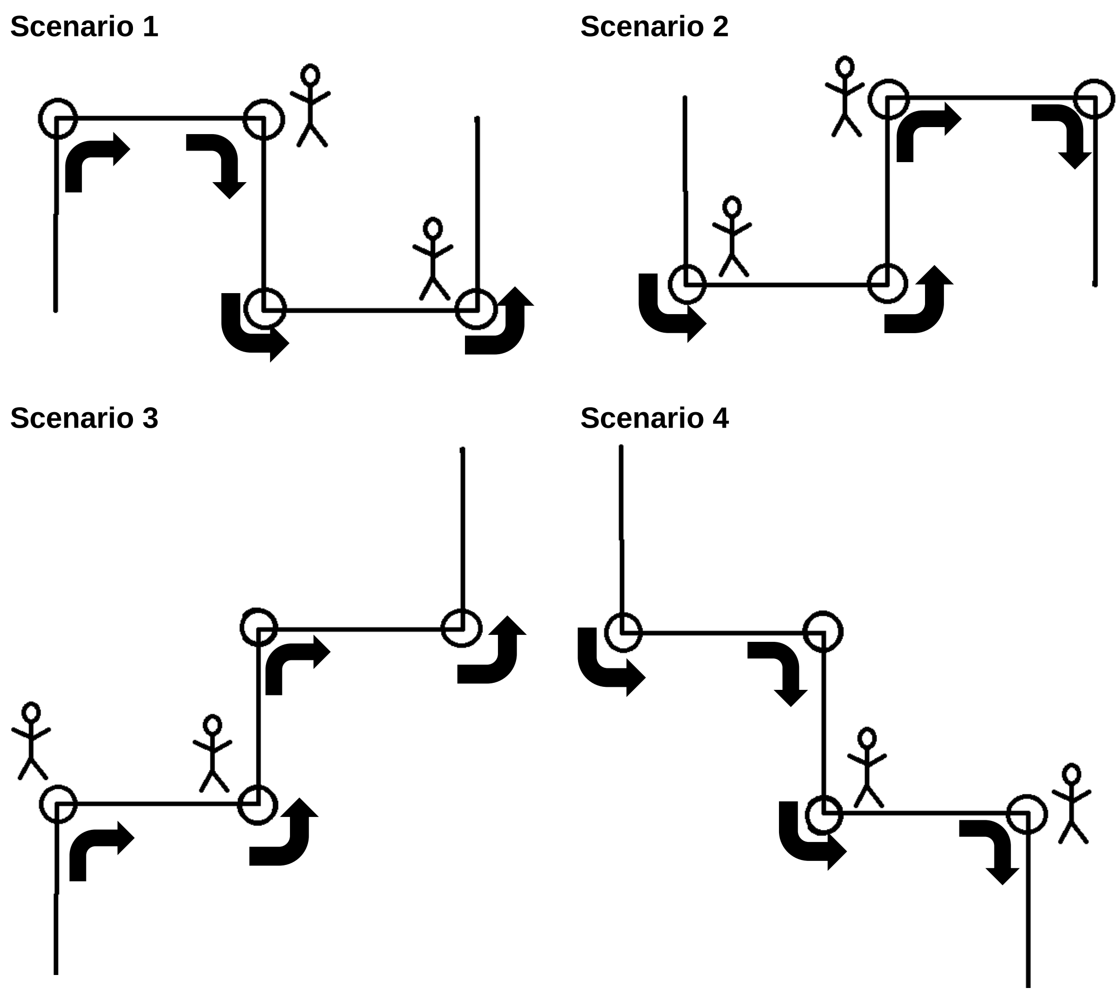

Figure 3.3 – Driving simulator scenarios

3.3 Study Procedure

The study procedure consists of four steps:

1. The participant completes initial paperwork and a pre-study questionnaire (see Appendix A), which focuses mostly on demographics and driving history and frequency.
2. The participant is seated in the driver's seat of the vehicle, is fitted with the eye tracker, and performs a demo drive to become familiar and comfortable with the

eye tracker and driving simulator. This step is also useful for determining if the participant is susceptible to simulator sickness and should therefore be excluded.

3. The participant drives through one of the four drive scenarios, encountering the current existing signage (conventional pedestrian yield sign).
4. The participant is asked to complete part one of a post-study questionnaire (see Appendix B). This questionnaire asks participants what they think is the meaning of the proposed signage.
5. The participant drives through the same scenario a second time, but with the proposed signage (pedestrian-activated yield sign) instead of the existing signage.
6. The participant is asked to complete part two of a post-study questionnaire after the last driving portion of the study (see Appendix B). This questionnaire explains the actual meaning of the proposed signage to participants and asks for feedback.

3.4 Data Collection

Data collection consists of two parts corresponding to the questionnaires that are filled out by the participants and the data that can be obtained by the driving simulator experiments.

The pre-study questionnaire allows for collection of demographic data as well as the participants' driving history and experience that can then be correlated with their yielding behavior. The post-study questionnaires provide information on comprehension of the proposed sign before and after an explanation is provided and before and after the driver experiences their last drive. The purpose of this is to determine the level of comprehension and correlate it with yielding behavior when encountering the proposed sign in the last drive. Finally, it provides feedback on the proposed sign design.

Data collected from the driving simulator fall under three categories:

1. Eye tracker data: used to determine if participants are glancing at the proposed sign and/or pedestrians at all, and how that compares to glances at the conventional signage.
2. Speed data: used to determine if participants are yielding to pedestrians and whether their speed profile as they approach the crosswalks is different when the proposed sign is in place.
3. Position data: used to identify where vehicles are stopping for pedestrians and if the proposed sign affects where they stop to yield to pedestrians.

3.5 Participants

The experimental design includes performing tests on a group of participants between the ages of 19 and 38 years, with a desired split of 50 percent between males and females. All participants are required to have a valid driver's license and can be recruited from the area surrounding the University of Massachusetts (UMass) Amherst. The town of Amherst has several roundabouts, so most drivers are likely to have encountered roundabouts in their normal driving and be familiar with their operations. Additional information on their driving experience can be obtained through the pre-study questionnaire.

3.6 Apparatus

3.6.1 Driving simulator

The simulator is a stationary full-scale vehicle with a simulated driving environment projected onto screens located in front of and behind the vehicle, shown in Figure 3.4. The screens offer a viewing angle of nearly 360 degrees with rearview and side-view mirrors that contain small TV screens to display the environment as well. The participant in the automobile is able to move through the virtual world using the vehicle's physical controls. The simulator is capable of recording position, speed, acceleration, and driver control actuation at a frequency of 60 Hz.

Figure 3.4 – UMass Amherst driving simulator

Data provided by the driving simulator include speed and trajectory data. Speed data can be used to determine if participants are stopping for pedestrians and whether their speed behavior is different with the new signage versus the conventional one. Trajectory data can be used to identify where vehicles are stopping for pedestrians and if the new signage affects where they stop.

3.6.2 Eye tracker

In addition to tracking vehicle data, the participant is fitted with a mobile eye-tracking device. The eye tracker is an important tool that allows researchers to look at driver inputs in addition to their output actions. The eye-tracking device to be used in the experiment is a Mobile Eye XG by Applied Science Laboratories. The eye tracker is a pair of safety goggles equipped with two lightweight cameras, one to track eye movements and the other to capture the scene that the user sees. The two videos are recorded, processed, and interleaved on a device that outputs a video file with crosshairs displaying the driver's gaze and the associated coordinate data in a separate data file.

Figure 3.5 – Eye-tracking device and example video output

For this specific experiment, researchers are to analyze the eye-tracking data to investigate which drivers saw the proposed sign and pedestrians that might be present at the crosswalk and how those glances compare against the ones when the conventional signage is in place. The eye-tracking data are to be scored by two researchers, one with no prior involvement in the study. The glances are to be scored as binary variables to represent whether a participant glanced at the sign or pedestrian while approaching a particular roundabout. The rubric for scoring eye glances has two categories: whether the participant glanced at the sign itself and whether the participant glanced at either or both sides of the crosswalk looking for pedestrians.

3.6.3 Questionnaires

This study includes a survey component in which participants are asked to answer both a pre-study and post-study questionnaire. The pre-study questionnaire asks demographic questions, such as age and race, as well as the participants' driving history and experience. No mention of roundabouts or pedestrian signage is included in the first questionnaire to prevent bias in the study. The post-study questionnaire asks about participants' understanding of the new signage and provides an opportunity for feedback on what was not clear after an explanation has been provided and the drives have been completed. Blank example copies of the questionnaires are provided in Appendices A and B.

4 Discussion

The experimental design that has been developed can be used to test the hypothesis that eye glances towards roundabout signage will increase in scenarios containing the proposed sign. This would be a result of the flashing light on the new sign that indicates the presence of pedestrians. However, increased eye glances do not necessarily correspond to improved yielding behavior. Yielding behavior is expected to increase as the number of encounters with the new sign increases.

In addition to improving pedestrian safety at roundabouts by improving situational awareness, the proposed sign is expected to allow drivers to adjust their planned trajectory in anticipation of an event, which could result in improved operations and reduced emissions.

5 Conclusions

The purpose of this study was to develop a new pedestrian-activated sign to be used at roundabout crossings in an effort to improve the safety of visually impaired pedestrians. A related objective was to develop an experimental driving simulator design to test the effectiveness of this sign and compare it against conventional yield signs at roundabout crossings.

The proposed sign is a pedestrian-activated yellow diamond warning sign with a symbolic roundabout and crosswalks. If a pedestrian is about to cross on a certain crosswalk, the associated crosswalk symbol on the sign will flash to warn drivers at which crosswalk they should anticipate pedestrians to be present and therefore be prepared to yield.

Driving simulator experiments were also designed to allow for the new signage to be tested in a controlled and safe environment. These experiments included drives through multiple roundabouts that included the conventional pedestrian yield sign or proposed pedestrian-activated sign under the presence of absence of pedestrians. Data from the driving simulator, as well as an eye-tracking device and pre- and post-study questionnaires, are intended to be used for collection of relevant information. This information can be used to assess the impact of the new sign at roundabouts on driver yielding behavior.

The ultimate goal of this research is to show that driver behavior can be altered by the adoption of new signage, which will lead to safer conditions for pedestrians. This project began with the intent of helping visually impaired pedestrians, who are especially vulnerable users.

This research is expected to provide insights for developing and testing pedestrian-activated signs to warn drivers about the presence of visually impaired pedestrians at roundabout crossings. The outcomes of this research can inform which sign designs are more effective in warning drivers about the presence of visually impaired pedestrians and therefore improve driver compliance with yielding at roundabout crosswalks. The ultimate vision is to utilize this information to connect visually impaired users with the new signage, potentially through the use of smart phone technology. Future work will develop and test such smart phone applications through field tests.

6 References

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Guidebook (NCHRP Research Report 834). Washington, DC: Transportation Research Board.

Appendix A: Pre Study Questionnaire

Date: __________

Participant ID: _______________
(HPL Admin. use only)

HUMAN PERFORMANCE LABORATORY
PRE-STUDY QUESTIONNAIRE

This is a ***strictly confidential*** questionnaire. Only a randomly generated participant ID number, assigned by the research administrator, will be on this questionnaire. No information reported by you here will be traced back to you personally in any way. **You can skip any questions you do not feel comfortable answering.**

Section 1: Demographics

Gender: ☐ Male ☐ Female

Date of Birth (month/day/year): _____/_____/______ **Age:** ______

Race / Ethnicity:
(check all that apply)
(question asked for reporting purposes)
☐ Black / African American ☐ Asian
☐ Caucasian ☐ American Indian / Native Alaskan
☐ Hispanic / Latino ☐ Other

Have you participated in a study at this laboratory in the past? ☐ Yes ☐ No

Section 2: Driving History

Approximately how old were you when you got your driver's license? _____ **Years** _____ **Months**

About how many miles did you drive in the past week?
☐ Less than 50 ☐ Less than 100 ☐ 100-200 ☐ 200-300 ☐ 300-500 ☐ 500 or more

About how many miles did you drive in the past 12 months?
☐ Less than 5,000 ☐ 5,000 to 10,000 ☐ 10,001 to 15,000 ☐15,001-20,000 ☐ More than 20,000

Do you usually wear glasses or contacts while driving?
☐ No
☐ Yes, glasses
☐ Yes, contacts

Do you ever get motion sickness symptoms while driving or riding in a car? ☐ Yes ☐ No
(If you respond Yes to this question, please bring it to the immediate attention of the experimenter.)

Do you have any other restrictions on your driver's license? ☐ Yes ☐ No

If yes, please describe: ____

Is there anything related to your background or health, including any medications that might cause to you drive much better or worse than other drivers?
☐ Yes ☐ No

If yes, please describe: ____

Figure A.1 - Example of Pre Study Questionnaire

Appendix B: Post Study Questionnaire

Date: ___________

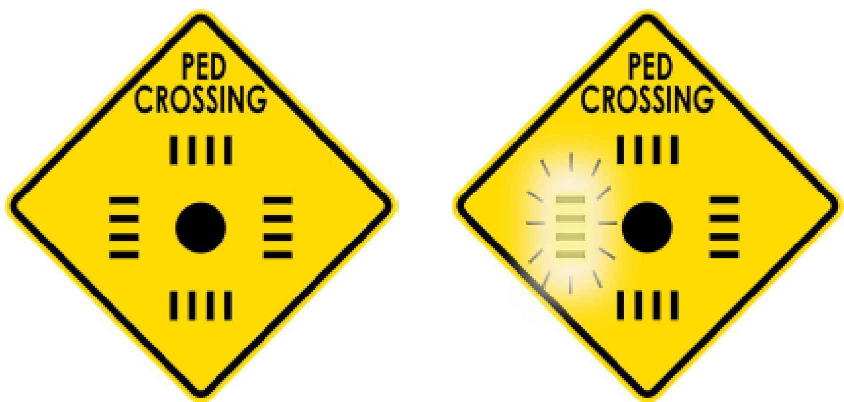
Participant ID: _______________
(HPL Admin. use only)

HUMAN PERFORMANCE LABORATORY
POST-STUDY QUESTIONNAIRE PART 1

This is a ***strictly confidential*** questionnaire. Only a randomly generated participant ID number, assigned by the research administrator, will be on this questionnaire. No information reported by you here will be traced back to you personally in any way. **You can skip any questions you do not feel comfortable answering.**

This study examines the use of new signage to indicate to drivers the presence of pedestrians in roundabout crosswalks. In particular, this research focuses on car driver behavior and performance when approaching this unfamiliar signage. The specific focus of this study was not fully disclosed to you at the beginning of your participation so as to not influence or bias your behavior during the simulator drives.

Section 1: Understanding of Signage



What do you think is the meaning of this signage?

____

____

____

Figure B.1 - Example of Post Study Questionnaire Part 1

Date: __________

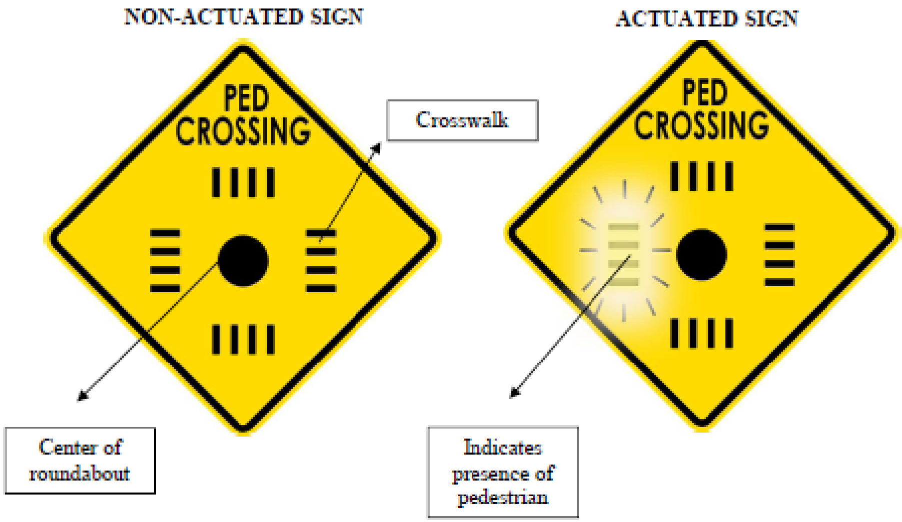
Participant ID: ______________
(HPL Admin. use only)

HUMAN PERFORMANCE LABORATORY
POST-STUDY QUESTIONNAIRE PART 2

This is a ***strictly confidential*** questionnaire. Only a randomly generated participant ID number, assigned by the research administrator, will be on this questionnaire. No information reported by you here will be traced back to you personally in any way. **You can skip any questions you do not feel comfortable answering.**

Section 1: Explanation of Signage

The new signage works as follows: the unactuated sign incorporates four rectangles which represent the crosswalks of the four approaches. A circle in the center of the rectangles indicates that the intersection is a roundabout. When a pedestrian activates a button at the crosswalk, the corresponding rectangle on each approach sign will light up. This indicates to drivers at which approach they can expect a pedestrian.



Section 2: Clarity of Signage

What about the treatment made it difficult to understand?

____

____

____

Any additional comments?

____

____

Figure B.2 - Example of Post Study Questionnaire Part 2