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DRIVER PERCEPTION OF POTENTIAL PEDESTRIAN CONFLICT

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16. Abstract

The objective of this study was to provide information about drivers' needs and preferences for the characteristics of pedestrian detection systems that would be useful to the designers of cars and of pedestrian detection systems. In this study, we varied parameters that determine a pedestrian's path relative to a moving vehicle, and we collected subjects' responses to determine to what extent pedestrian alerts are likely to be perceived as important in various situations. In a laboratory setting, subjects were shown video clips of a pedestrian taken from a driver's point of view and were asked to rate how much a driver would need to monitor the pedestrian. Their subjective ratings indicated that, for pedestrians who are not moving toward the road, the subjective need to monitor pedestrians falls off sharply as a function of lateral distance from the edge of the road. The subjective need to monitor pedestrians who are crossing the road remains high even if their future path is such that by the time the vehicle crosses their path, the pedestrian has already completed crossing the road. Implications for the design of adaptive pedestrian detection systems are discussed.

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INTRODUCTION

Background

In 2006, 4,784 pedestrians were killed in the United States, constituting about 11% of all road-traffic fatalities. In other parts of the world, pedestrians constitute even larger proportions of fatalities. For example, the percentage of pedestrian fatalities was 18% in the European Union (CARE, 2006), 25% in China (Zhang, Tsimhoni, Sivak, & Flannagan, 2008), 34% in Japan (National Police Agency, 2008), and 48% in Delhi, India (Mohan, Tsimhoni, Sivak, & Flannagan, in preparation). The technological ability to detect pedestrians from moving vehicles has been improving steadily in the last few years (for a review, see Gandhi & Trivedi, 2007). With these technological advances, pedestrian detection systems are likely to be commercially available at affordable prices in the near future. The focus of pedestrian detection system research has been on improving algorithms to correctly identify pedestrians, but not much has been done to identify pedestrian safety needs and the driver's expectations for pedestrian warnings. More specifically, not much attention has been given to characterizing the scenarios under which drivers would benefit from pedestrian warnings and would perceive them as useful. Providing information about drivers' expectations from such safety systems is a critical step in developing systems that provide the driver with information that is not only objectively accurate but also perceived by the driver as being useful.

Goal

The objective of this study was to provide information about drivers' needs and preferences for the characteristics of pedestrian detection systems that would be useful to the designers of cars and of pedestrian detection systems

METHOD

In this laboratory study, subjects were shown video clips that contained a pedestrian and were asked, "How much would a driver need to monitor the key pedestrian in order to avoid hitting them?"

Subjects

Sixteen licensed drivers participated in this study: eight younger drivers (ages 21 to 29, mean 24) and eight older drivers (ages 60 to 71, mean 65). Within each age group, there were four women and four men. All subjects' corrected vision was 20/40 or better, as tested using an Optec 2000 Stereo Optical Vision Tester.

Apparatus

Video Collection

Digital video footage of pedestrians was collected by an experimenter who drove a passenger vehicle. A video camera (Sony DCR-TRV-30) with a wide lens (Sony x0.6, VCL-0637) was secured, facing forward, to the front hood of the car just below the line of sight of the driver. The vehicle was equipped with a differential global positioning system (DGPS) to record the vehicle's position, direction, and speed. The pedestrian walking in the scripted clips was equipped with a similar DGPS, installed on a Tablet PC (Lenovo X60). The collected video was downloaded and edited into short clips, one for each pedestrian encounter.

Scripted Video

Scripted video clips of a volunteer acting as a pedestrian (about 50th percentile female in height, and just below 50th percentile in weight) were recorded in daylight during late October 2007 on a two-lane, divided arterial road in Ann Arbor, Michigan. The pedestrian was videotaped from the view point of a driver in an experimental vehicle. From about six hours of collected video, 96 encounters between the experimental vehicle and the pedestrian were selected.

Naturalistic Video

Naturalistic video clips were used to provide context for the scripted video clips. In these video clips, actual pedestrians were recorded in daylight during September and early October of 2007. An experimenter drove around Ann Arbor, on campus and on main arterial roads that have had a relatively high number of pedestrian crashes in recent years (Packard Road, Huron Street, Washtenaw Avenue, and South University Avenue; determined by using the Michigan traffic crash facts data query tool, (Michigan Office of Highway Safety Planning, 2008)). From about eight hours of collected naturalistic video, clips of 82 encounters with pedestrians were selected.

Video Projection

The video clips were presented to subjects on a large screen (180 x 180 cm) in a dark laboratory. Subjects were seated about 3.3 m from the screen and the screen subtended about 30 degrees horizontally at their eye position. A control program, written in Microsoft Excel and Visual Basic for Applications, was used to play the video clips in the desired sequence.

Procedure

Subjects were randomly divided into four groups, each balanced by age and gender, so that the order of video clip presentation could be balanced across those groups. In those groups, they were shown the edited video clips in a dark laboratory room and were asked to rate each clip using the question, “How much would a driver need to monitor the key pedestrian in order to avoid hitting them?” (When there was more than one pedestrian in the clip, the “key pedestrian” was highlighted on the screen by the experimenter.) After each clip was shown, subjects were asked to rate the clip on a scale of 0 to 100, where 0 indicated a driver would not need to monitor the pedestrian at all, and a rating of 100 indicated that a driver would need to monitor the pedestrian continuously. In the instructions, subjects were asked to try to be consistent in their ratings and to use as much of the scale as possible so that scenarios that appeared to them as different would, indeed, be distinguished by their ratings.

To familiarize subjects with the range of clips that would be presented, 14 example clips were shown twice at the beginning of the experiment. During the first round of example clips, subjects were asked to simply watch the clips without rating them. The second time through the example clips, they were asked to record their responses. Next, they were shown the test video clips. Video clip duration ranged from 3 to about 15 seconds, followed by 5 to 10 seconds for recording responses. After the subjects had viewed all the clips and recorded their responses, each subject was asked to complete a post-test questionnaire. Table 1 shows some sample images from naturalistic and scripted clips representing three levels of expected ratings.

Table 1.
Sample images for naturalistic and scripted clips representing a range of expected ratings.

Expected Pedestrian Importance	**Scenario Type**	
	Naturalistic	**Scripted**
Low		
Medium		
High		

Experimental Design and Data Analysis

Each subject viewed 178 video clips. Of these, 96 were scripted pedestrian clips and 82 were naturalistic pedestrian clips. Scripted and naturalistic clips were presented in a randomly interleaved order. The experimental design examined the effect of five independent variables on the rating of the need to monitor a pedestrian in the scripted pedestrian clips. These five independent within-subject variables are illustrated in Figure 1.

Pedestrian direction. Four pedestrian directions were used to represent a pedestrian's path. The pedestrian walked into the street, away from the street (perpendicular to the vehicle path), away from the car, or towards the car (parallel to the vehicle path).

Pedestrian lateral position. Four levels of initial pedestrian lateral position were selected to represent various levels of threat to the driver. They were selected nonlinearly, with more emphasis on the positions close to the edge of the road (-1, 0, 2, and 4 m to the right of the right edge of the lane).

Pedestrian walking speed. Four levels of pedestrian walking speed were used: fast (134 m/min, 5 mph), normal (80 m/min, 3 mph), slow (27 m/min, 1 mph), and standing still. The normal walking speed matched observed average walking speeds of pedestrians in natural settings (Bornstein & Bornstein, 1976; Finnis & Walton, 2008).

Longitudinal distance. Three levels of longitudinal distance between the pedestrian and the car when the clip started and when the pedestrian began walking were used: near (30 m), medium (60 m), and far (120 m). As a result of this variation in longitudinal distance, video clip durations were not all the same.

Car speed. Two levels of car speed represented two levels of closing speed on the pedestrian: slow (32 km/hr, 20 mph) and medium (48 km/hr, 30 mph).

Two analyses were performed. The first was based on 30 trials in which the pedestrian was either standing or walking parallel to the road. The second was based on 66 cases in which the pedestrian was either crossing the road or walking away from the road, perpendicular to the direction of the car.

The experimental design was a within-subject mixed model design, with the effects of the five factors mentioned above nested within subject. Linear mixed-effects models were used to model the ratings using Proc Mixed (SAS Software, 2008).

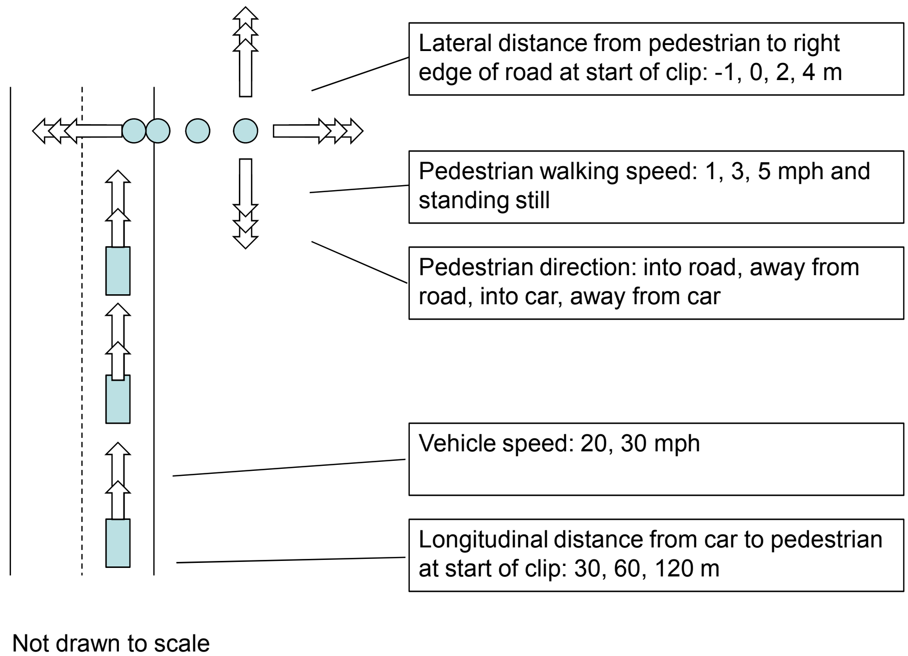


Figure 1. Illustration of the five factors examined.

An alternative representation of the scenarios that were tested is shown in Figure 2. The variety of pedestrian paths relative to the car, resulting from combinations of the independent variables, is shown by a set of straight lines, each representing the starting point of the pedestrian and direction of motion relative to the car. The direction (or slope) of each line reflects the ratio between vehicle speed and pedestrian walking speed (e.g., a fast moving vehicle combined with a slow walking pedestrian appear in the figure as a line with a high slope). The initial position of the pedestrian relative to the car combines the lateral distance from the road edge and the longitudinal distance at which the pedestrian started walking. The intersection of lines with the x-axis represent the lateral position of the pedestrian relative to the car at the time the car (the front bumper) reached the pedestrian's path. Lines that intersect with the lateral position of the car (denoted by a line between -2.8 and -0.8 m from the right edge of the lane) represent intersecting paths, which could result in a crash if the driver and the pedestrian do not change their speeds and paths. For simplicity, Figure 2 presents only scenarios that had an initial pedestrian lateral position of 4 m. Other scenarios, with initial lateral positions of -1, 0, and 2 m, would appear translated to the left on the figure by 5, 4, and 2 m, respectively.

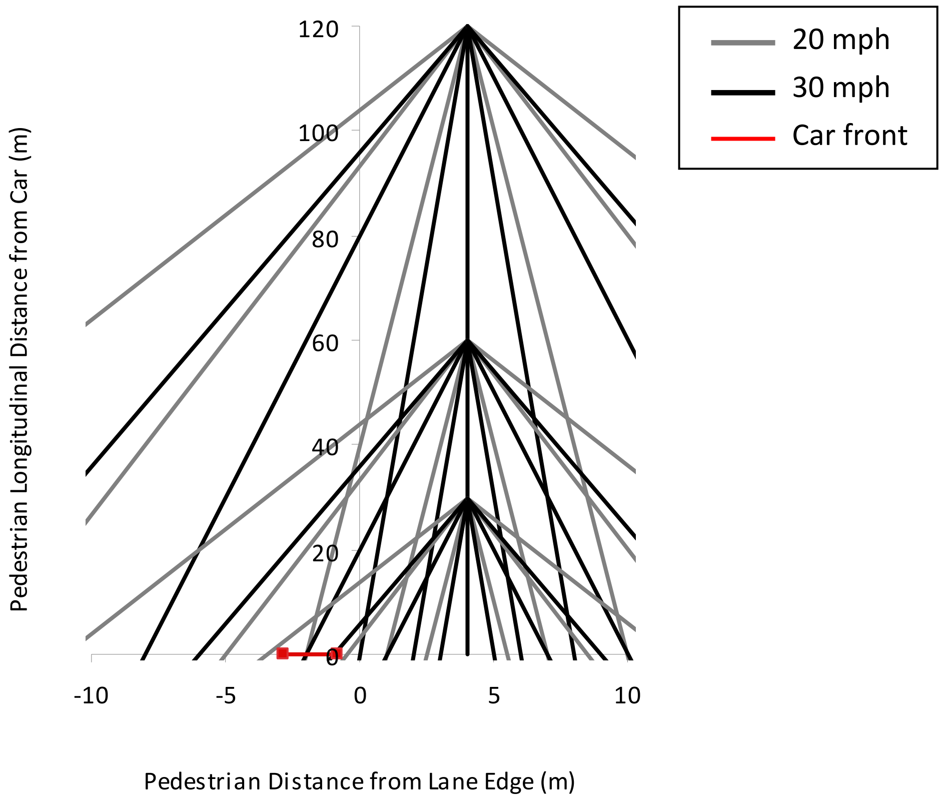
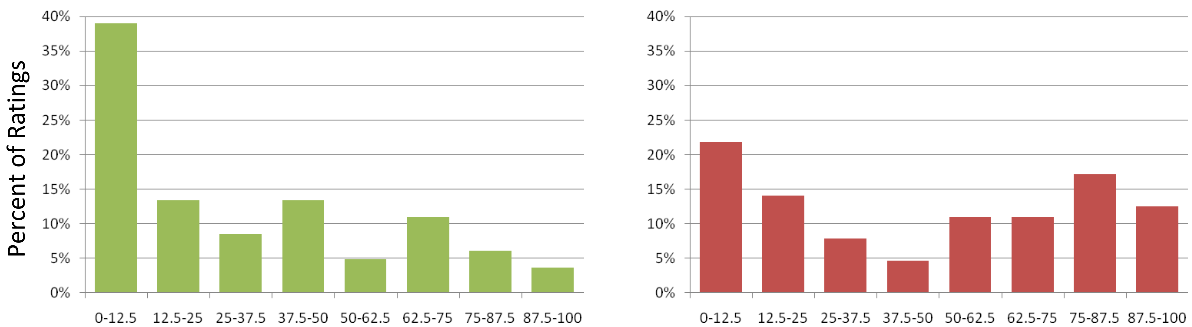


Figure 2. Illustration of relative motion vectors for a subset of the experimental conditions, in which the pedestrian started at 4 m away from the road and either crossed the road or moved in parallel to it.

RESULTS

Distribution of Ratings

A comparison between the distribution of ratings of naturalistic and scripted video clips revealed a proportionally higher number of low ratings for the naturalistic video clips than the scripted video clips (Figure 3). Nevertheless, there was considerable variance in the ratings of the two sets of clips. The analyses that follow pertain only to the scripted video clips.



Ratings of naturalistic clips | Ratings of scripted clips

Figure 3. Histograms for ratings of naturalistic and scripted clips.

Pedestrian Standing or Walking Parallel to the Road

When the pedestrian was either standing or walking parallel to the road, pedestrian lateral distance from the road had a significant effect on subjects' ratings of the need to monitor pedestrians, $F(3, 45.3) = 95.1$, $p < 0.0001$. The difference between standing and walking parallel to the road was not significant. In a separate analysis that excluded the cases in which the pedestrian was standing, pedestrian direction (toward the car or away from the car), pedestrian walking speed, car speed, and their interaction with lateral position were not significant.

Figure 4 shows the ratings as a function of the pedestrian's lateral position relative to the edge of the lane when the pedestrian was either standing or walking on a path that was parallel to the road. Bonferroni-adjusted comparisons among the four tested levels found all pair-wise comparisons significant ($p < 0.05$), except for the comparison between 2 m and 4 m.

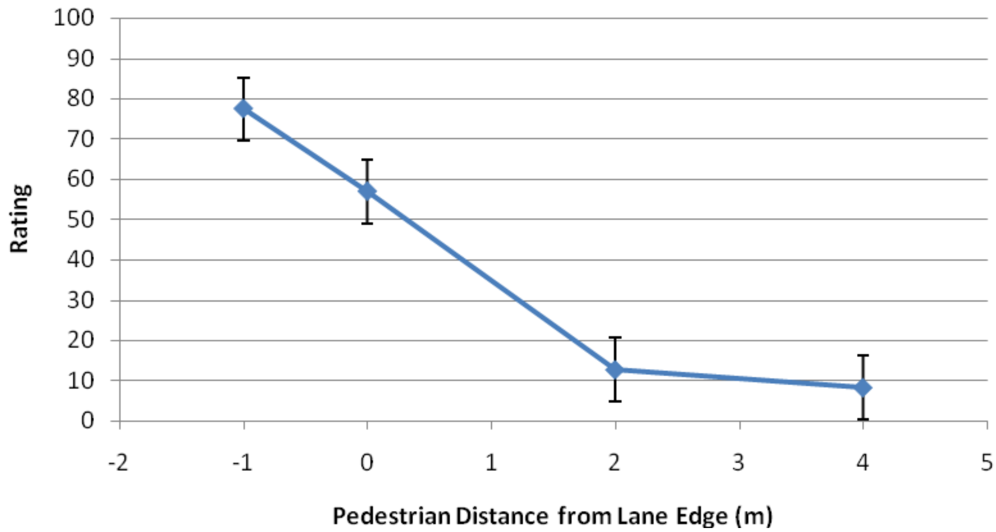


Figure 4. Ratings for a pedestrian, who is either standing or walking parallel to the road, as a function of distance from lane edge. Bars represent 95% confidence intervals for the mean of each condition.

Pedestrian Walking

Figure 5 includes all the cases in which the pedestrian was walking, either perpendicular or parallel to the road. As expected, the pedestrian's walking direction had a significant effect on the ratings $F(3, 52.2) = 81.1$, $p < 0.0001$. Pedestrians walking into the road (crossing) were rated highest. Bonferroni-adjusted comparisons among the four tested directions found all pair-wise comparisons significant ($p<0.05$), except for the comparison between walking parallel to the road away from the car and walking parallel to the road toward the car.

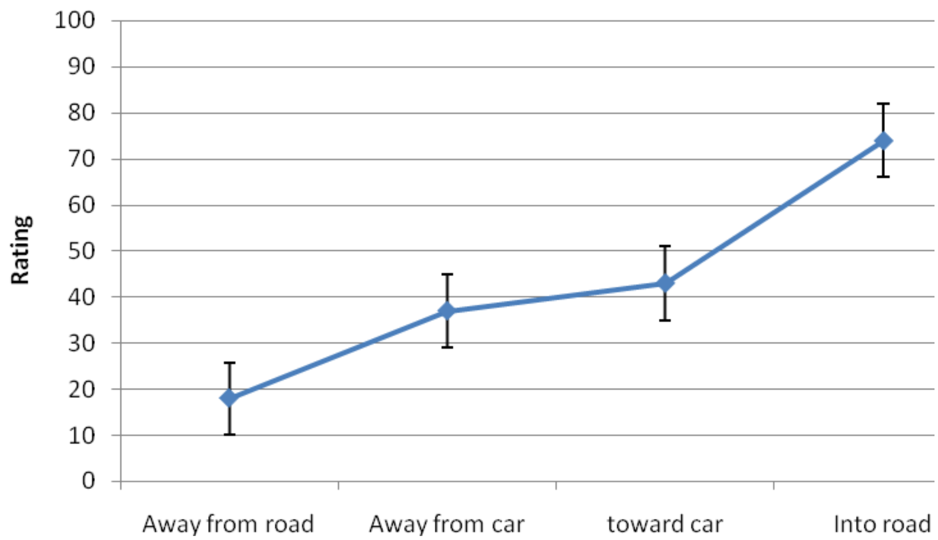


Figure 5. Ratings for a walking pedestrian as a function of their walking direction. Bars represent 95% confidence intervals for the mean of each condition.

Further analysis of ratings as a function of the direction of the pedestrian and pedestrian lateral distance revealed a strong interaction, $F(9,171) = 37.6$, $p < 0.0001$ (Figure 6). When the pedestrian starting position was 2 m or more from the road edge, ratings were very low, except when the direction was into the road. Conversely, when the pedestrian began 1 m into the road, ratings were very high, except when the direction was away from the road. When the pedestrian began on the road edge (0 m), walking parallel to the road was rated higher than walking away from the road but lower than walking into the road (Bonferroni-adjusted $p<0.001$). The difference between walking on the road edge toward the car or away from the car was not statistically significant.

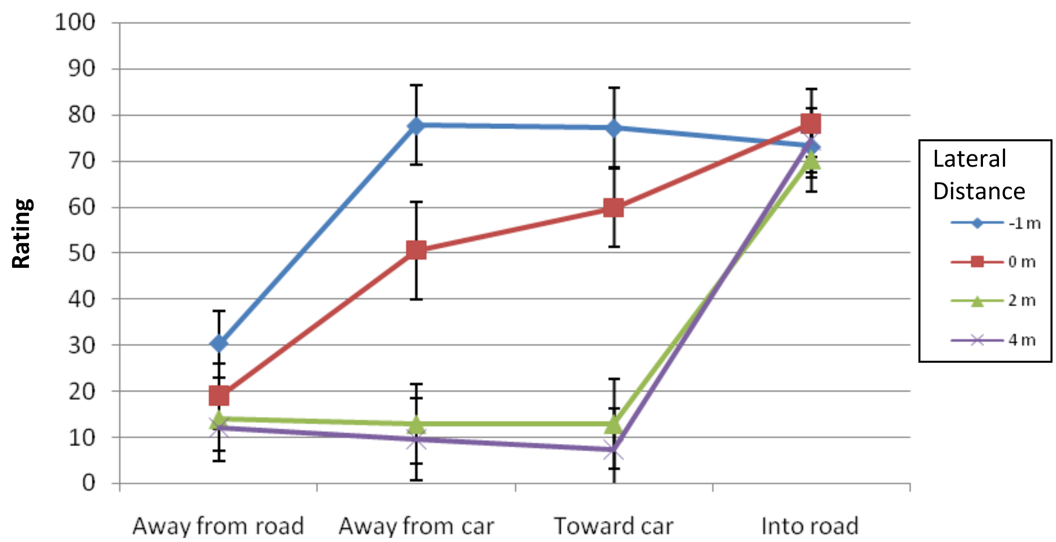


Figure 6. Ratings for a walking pedestrian as a function of walking direction and initial lateral distance from the right edge of the road. Bars represent 95% confidence intervals for the mean of each condition.

Analysis of Combined Factors

The significant interaction between walking direction and initial lateral distance warrants further exploration. At least part of the interaction may be explained in terms of a measure that combines all of the independent variables in a way that appears to be strongly related to objective risk: the lateral position of the pedestrian at the time the car intersects the pedestrian path (Figure 2). For each clip, this position was calculated using the starting location of the pedestrian and the car, the speeds of the pedestrian and the car, and the direction of the pedestrian, using equation (1).

$$X_1 = X_0 - V_x * Y / V_y \quad (1)$$

where:

- X_1 is the lateral distance between the pedestrian and the right edge of the road when the car intersects the pedestrian's path
- X_0 is the lateral distance of the pedestrian when the motion is initiated
- V_x is the pedestrian walking speed in the direction of the road
- Y is the longitudinal distance from the pedestrian to the car when the motion is initiated
- V_y is the longitudinal speed of the car

Figure 7 shows ratings as a function of pedestrian lateral position at the time of path intersection. Ratings of scenarios in which the pedestrian was in the road at the time of path intersection were significantly higher than when the pedestrian was on either side of the road, $F(2,35.1) = 5.73$, $p < 0.01$ (statistics using a within-subject linear mixed model). As expected, when the pedestrian was walking away from the road (consequently ending up beyond the right side of the road), ratings were consistently low. When the pedestrian ended up on the left side of the road, clearly beyond the lane (and even outside the road limits) ratings were rather high. It is possible that ratings were not only affected by the pedestrians' expected final position, but also by their crossing in front of the car even when the car was still a good distance away, and by considerations of possible stumbling or speed variations.

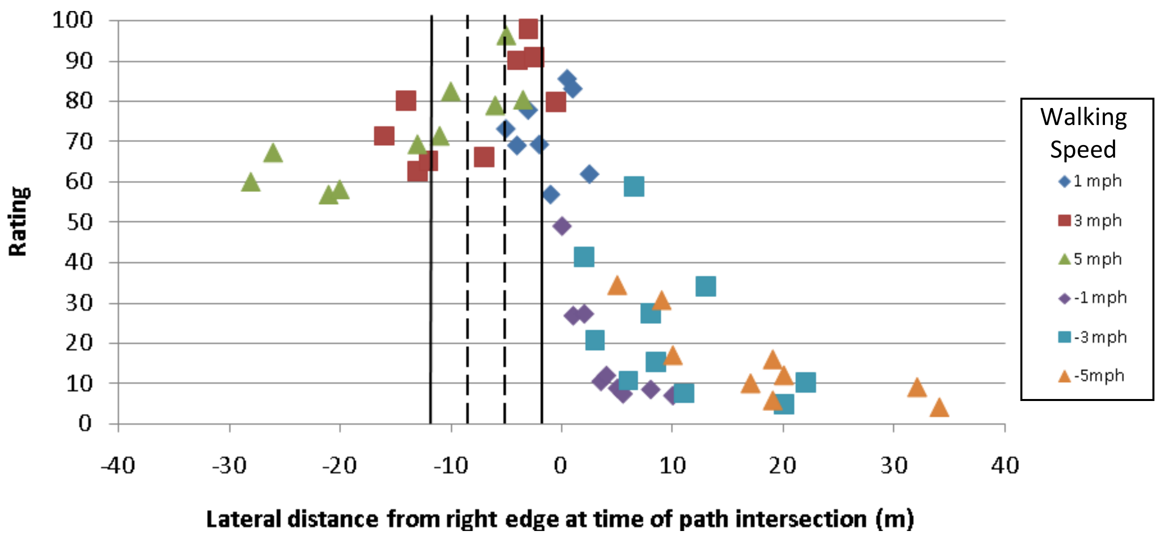


Figure 7. Ratings by pedestrian walking speed and the pedestrian's lateral location when the car would pass the pedestrian.

Figure 8 shows ratings as a function of lateral position at path intersection grouped by the pedestrian's initial lateral position. When the pedestrian was predicted to end up in the center lane, to the left of the car's path, ratings were as high, if not higher, than when the pedestrian would end up in the car's lane. First, it is very likely that subjects were not making perfect predictions about the position of the pedestrian at the time the car would cross paths with the pedestrian. Second, ratings may represent a look-ahead time, which would attribute high ratings to pedestrians who were in the lane several seconds before the car was about to reach them. Third, their ratings may reflect the importance attributed to monitoring pedestrians who are in the center lane of the road.

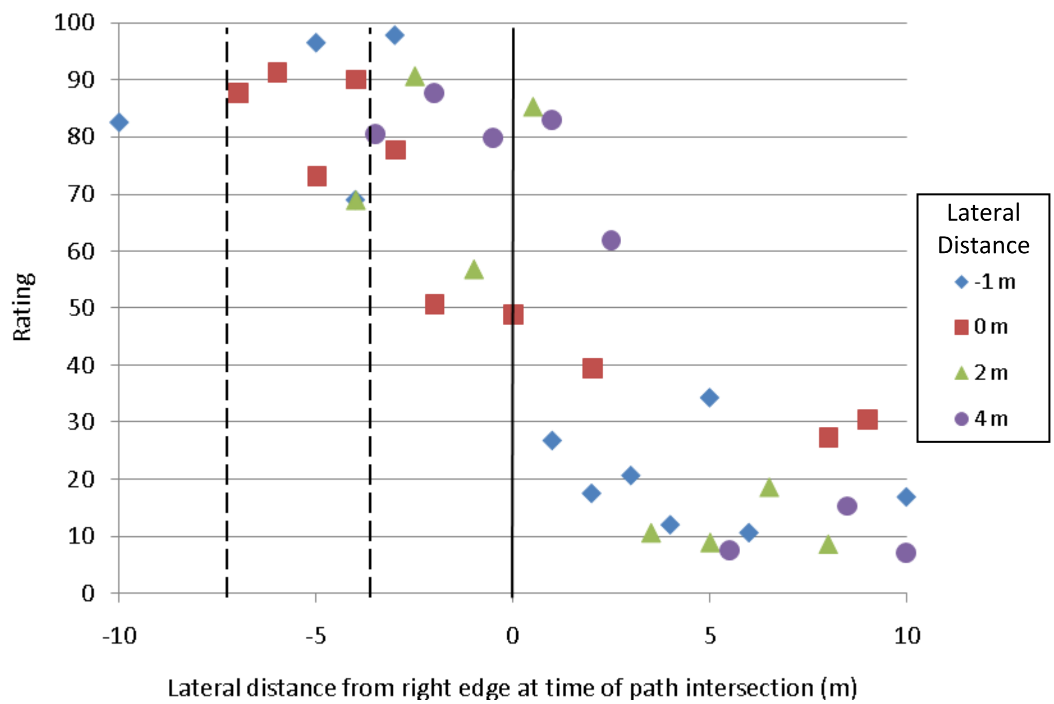


Figure 8. Ratings by pedestrian initial lateral position and the pedestrian's lateral position when the car would pass the pedestrian.

The minimum distance between the car and the pedestrian was used to further explore the factors that affect subjective ratings. For each clip, the path of the pedestrian relative to the car was drawn, and the minimum distance between the car and the path was recorded. Figure 9 shows ratings as a function of the minimum distance between the car and the pedestrian. Ratings decreased as the minimum distance decreased but remained, on average, above 55 when the pedestrian was walking into the road, and below 50 when the pedestrian was walking away from the road.

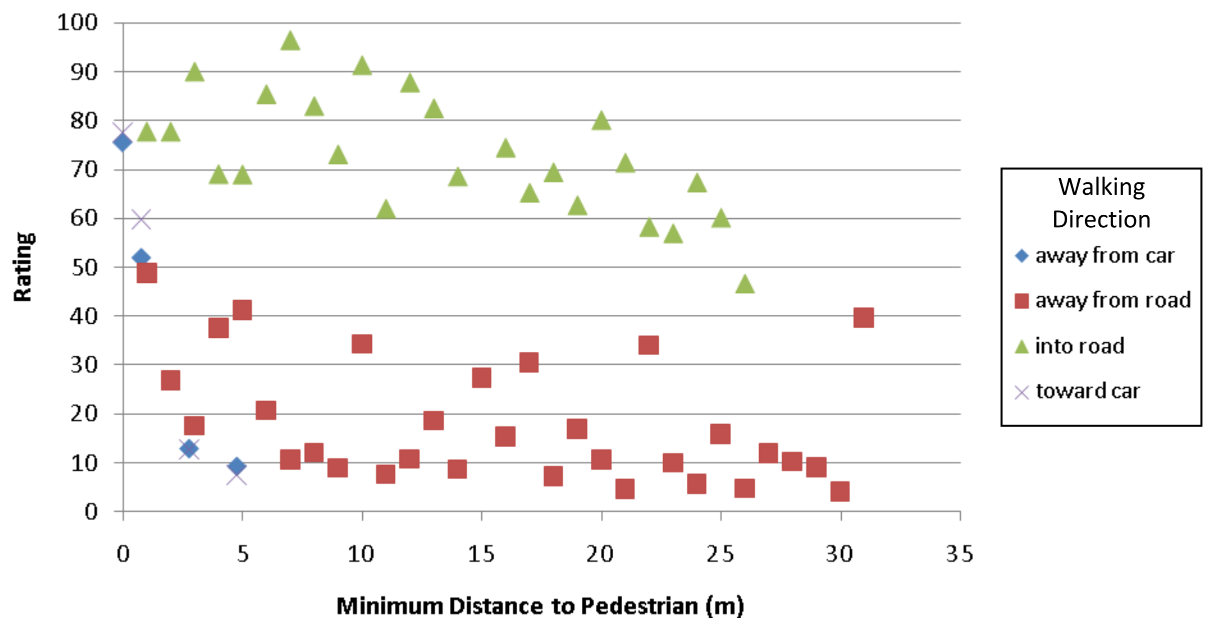


Figure 9. Ratings by minimum distance between the car and pedestrian.

Post-Test Questionnaire

A post-test questionnaire was used to calibrate the subjective ratings to driving-related actions. Subjects were asked to assign a rating value above which they would place each of four verbal anchors: "would want to be aware of pedestrians," "would want to start monitoring the pedestrian," "would probably respond to the pedestrian by slowing down or swerving," and "would definitely respond to the pedestrian by slowing down or swerving." The corresponding subjective ratings are shown in Figure 10. The anchors were not given nor mentioned before the experiment so as to avoid clustering of ratings around the anchors and so as not to influence subjects' interpretation of the primary question.

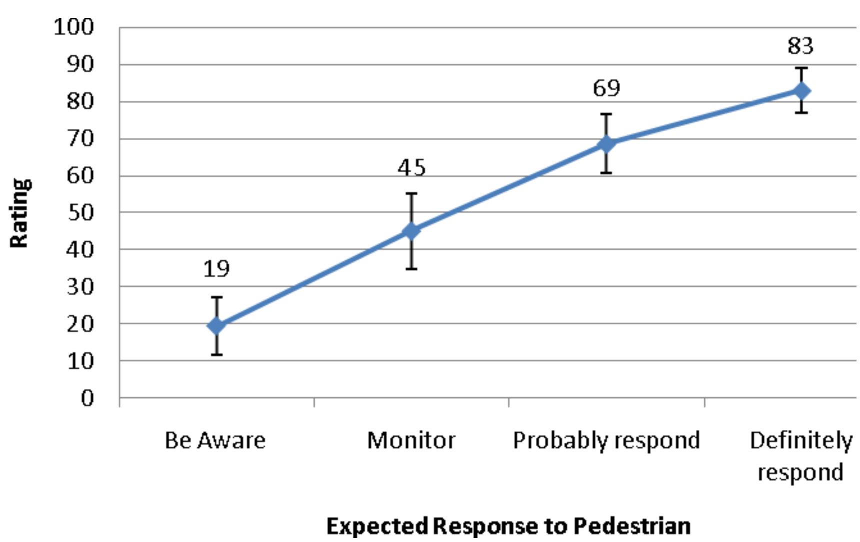


Figure 10. Self calibration of ratings to actual response to a pedestrian. Bars represent 95% confidence intervals for the mean of each condition.

The ratings were further analyzed based on the calibration of each subject's ratings to their actual expected road behaviors. Figure 11 shows the percentage of ratings that exceeded the threshold for wanting to start monitoring the pedestrian for several initial lateral distances from the road edge and several pedestrian walking speeds. For a pedestrian who was approaching the road, regardless of speed, over 70% of responses were above the threshold for wanting to monitor the pedestrian. In contrast, for a pedestrian that was heading away from the road, less than 30% of responses were above that threshold. When the pedestrian was standing, either facing the road or facing away from the road, the percentage of responses in favor of monitoring the pedestrian depended on the lateral distance from the edge of the road. If the pedestrian was standing on or farther than 2 m from the edge of the road, less than 20% of the responses were above the individual threshold for monitoring the pedestrian. If the pedestrian was standing on the right edge or 1 m inside the lane, more than 70% were above that threshold.

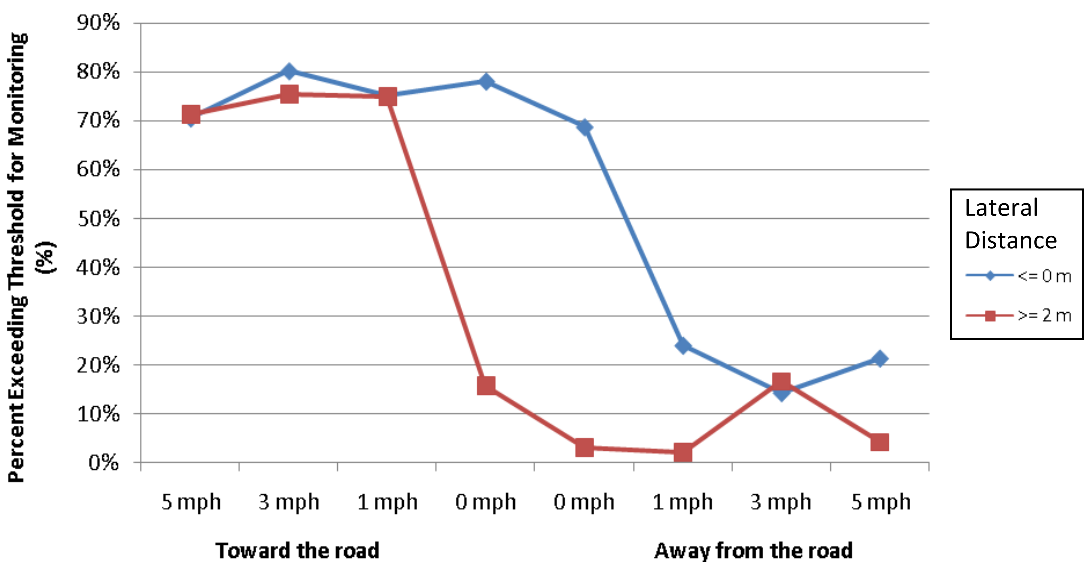


Figure 11. Percentage of ratings that exceeded the threshold for wanting to start monitoring the pedestrian as a function of the initial lateral position and walking speed of the pedestrian.

CONCLUSIONS

As pedestrian detection systems mature, the notification and warning algorithms that they use may have to adapt so as not to overwhelm the driver with unnecessary (and distracting) information. An adaptive pedestrian detection system is one that does not warn about all pedestrians. Rather, it adapts the warning algorithm to account for a combination of the potential for a collision and the driver's expectations. A potentially valuable benefit of an adaptive pedestrian detection system is that the number of warnings, and consequently false warnings, is reduced. The important question, however, is which pedestrians the driver should be warned about. If the warning/notification is unobtrusive, perhaps it can occur for all pedestrians. A safety analysis (Tsimhoni, Flannagan, Mefford, & Takenobu, 2007) favored notifying drivers of all pedestrians by means of an unobtrusive notification icon, but not actively warning about any of them. If, however, the system includes an active warning by way of an auditory tone, a haptic signal, or any other potentially obtrusive means, there is a potential advantage in not warning about all pedestrians. The present study addresses the driver's expectations for a pedestrian detection system in terms of what pedestrians perceive as important to monitor.

A driver's rating of the need to monitor pedestrians is affected by many factors, some of which were examined in this experiment. Our findings suggest that when the pedestrian is standing or walking parallel to the road, lateral distance from the road is the primary factor to affect ratings of the need to monitor the pedestrian. In the experiment, when the pedestrian was 2 m or farther away from the right edge of the road, ratings were very low (below 20). When the pedestrian was on the road edge (standing, or walking on the edge) ratings were about 60. The exact distance from the road at which a driver would want to monitor a static pedestrian in a realistic situation is expected to be within 0 to 2 m, but would likely vary with other factors and among drivers.

Not surprisingly, when the pedestrian crossed the road, ratings were always high (about 70), and when the pedestrian walked away from the road they were low (about 20). An analysis of the future position of the pedestrian at the time of a possible collision did not fully explain subjects' ratings. Pedestrians who were crossing the road were rated high even if their eventual position at the time the car crossed their path was far to the left of the vehicle.

Some general conclusions can be drawn from this experiment with regard to an adaptive pedestrian detection system:

1. Pedestrians who are standing away from the road and are not moving toward the road are not perceived as important to monitor in terms of potential conflict. In those cases, the direction the pedestrian is facing does not seem to affect the driver's perceived need to monitor the pedestrian as long as the lateral separation is above about 2 m.
2. Pedestrians who are walking parallel to the road beyond about 2 m are not perceived as important to monitor in terms of potential conflict. In those cases, whether the pedestrian is walking toward the car or away from it does not appear to make a major difference.
3. Pedestrians who are walking away from the road are perceived as important to monitor only if their path begins less than about 2 m laterally from the edge of the road.
4. Pedestrians who are crossing the road are perceived as important to monitor even if their future position at the time the car passes them is far beyond the left edge of the road.

The validity of these conclusions is limited to the context in which the experiment was conducted. These conclusions can serve as a first-order estimation of subjects' understanding of their need to monitor pedestrians. An additional potential benefit of this experiment is in setting up a method to evaluate drivers' understanding of their needs in terms of the detection of pedestrians. Several limitations of extrapolating results from this study to an actual pedestrian detection system should be considered. First, the importance of monitoring pedestrians was assessed indirectly and was likely biased by the subjects' interpretation of what they normally do when they drive. Second, many factors were not examined in this experiment: pedestrian age, road curvature, pedestrian approach from left of road, day versus night, sun position, and perceived intentions of the pedestrian, to name a few. Third, although the environment in which pedestrians were viewed was varied by adding naturalistic clips, the results from the scripted pedestrian clips in this report are based on one road location with specific attributes that are not representative of all situations. Furthermore, pedestrians and drivers in various geographical locations and from various cultural backgrounds may have different expectations and different behaviors. In that regard, this experiment is only a first step into quantifying the cultural and geographical differences in driver behavior and expectations.

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