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Smith, Kip; Källhammer, Jan-Erik

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Experimental Evidence for the Field of Safe Travel

Regression analysis of driver ratings of alerts issued by an in-vehicle active safety system during a field operational test identified contextual factors that influence driver acceptance of system alerts. A nominal characterization of pedestrian location and two quantitative measures of pedestrian motion predict more than 60% of the variability in driver ratings and do not interact. This finding is empirical support for the classic notion of the field of safe travel (Gibson & Crooks, 1938).

Kip Smith, Naval Postgraduate School, Monterey, CA
Jan-Erik Källhammer, Autoliv Research, Vårgårda, Sweden

INTRODUCTION

In this presentation, we discuss the second stage of our ongoing investigation of the influence of context on drivers' willingness to accept the alerts issued by a Far Infra-Red (FIR) night-vision pedestrian-detection system. The first stage was recently published in *Human Factors* (Källhammer & Smith, 2012). The aim of this project is to identify factors that should influence the alerting strategy for active safety systems.

Our work and that of others (e.g., Marshall, Lee, & Austria, 2007) have found that ratings of the appropriateness of alerts depend on the driving context. Further, those ratings may indicate relatively high levels of acceptance in "alarming" situations, even when the driver would have been able to avoid the accident (Farber & Paley, 1993).

The observations by Schmidt and Färber (2009) and the model constructed by Himanen and Kumala (1988) led us to focus on five contextual factors that may influence driver acceptance of alerts to pedestrians issued by an FIR night-vision system. The five factors and their constituent categories are listed in Table 1.

All other factors being equal, we expect alerts to pedestrians to receive higher ratings (to be judged more acceptable) in situations where pedestrians are encountered relatively infrequently. Accordingly, we expect alerts in Rural Locales to be rated higher than alerts in Urban or Suburban Locales. We distinguish between Urban and Suburban by the high level of continuity of buildings in urban areas. We use the presence of street lights to differentiate between Suburban and Rural locales.

We also expect ratings to be higher when pedestrians are seen to be within or moving toward the driver's field of safe travel (Gibson & Crooks, 1938). The field of safe travel is an indefinitely bounded field consisting of all unimpeded paths that a vehicle can take at any moment. The relative likelihood of pedestrian incursion into the field supports the hypothesis that the acceptance of alerts would be higher when the pedestrian is In the street or on its Right edge than when on the Left side of the roadway or beyond it on either side.

Table 1. Contextual Factors in Vehicle-Pedestrian Interactions analyzed in this Study

Factor	Categories
Locale	Urban, Suburban, Rural
Pedestrian Location	In street, on Left edge/side, on Right edge, on Right side (beyond curb)
Pedestrian Motion	Same, Into street, Standing, Opposite
Vehicle Direction	Straight, Turning
Road Direction	Straight, Turning

With regard to Pedestrian Motion, the categories Same and Opposite are reserved for pedestrians walking in a direction predominately parallel to the vehicle's path in either the same or opposite direction as the vehicle. We expect alerts to receive higher ratings when the pedestrian is walking (running, jogging, etc.) Into the street. The category Into street implies that the pedestrian was walking essentially perpendicularly to the direction of vehicle travel and into its field of safe travel. An example is a pedestrian approaching or in a zebra crossing. The category Into street does not differentiate between pedestrians crossing from the

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left (the far-side) or from the right (the near-side).

Visibility concerns support the hypothesis that ratings to alerts would be higher when a pedestrian is encountered while the driver is making a turn or on a winding road than while driving down a straight road.

METHOD

The study had two parts: a field operational test (FOT) that gathered a set of 57 video clips of pedestrian alerts, and an experiment in which volunteers viewed the clips and rated the relative acceptability of the alerts. Details of the method are presented in Källhammer and Smith (2012).

Field Operational Test

Ten male drivers (age: M 49.2 years; SD 6.8; range 40 to 59) participated in the FOT. All had considerable driving experience (M 30.9 years; SD 6.8; range 22 to 41), corrected-to-normal vision, and reported driving at least 25,000 km annually (M 34,800 km; SD 5,996; range 25,000 to 40,000). The drivers applied voluntarily to the study. Subject participation conformed to ethical guidelines (Swedish Research Council, 2002).

Volunteers drove their own passenger cars without restriction on a daily basis for a period of approximately two months. The drivers were free to not use the system if they chose. Frequency of use was not collected for privacy reasons. We did not prime the drivers in any way. No structured questionnaire was used to collect driver feedback.

Each car was instrumented with a prototype FIR night-vision system. The system consists of a sensor system mounted in the grille of the car and a video display mounted on the upper part of the center console. An integrated GPS provided the time stamp and location of the alert. A computer mounted in the trunk recorded the video clips in a time window before and after the system generated an alert.

The integrated pedestrian recognition software takes a vehicle-centric view. Its alerting criteria are based solely on the location and motion of pedestrians relative to the car and do not consider pedestrian location and motion relative to the roadway. It updates the display screen at 30Hz with a black and white FIR image. The image was augmented by a flashing yellow alert symbol and by red rectangle(s) that highlighted the pedestrian(s) that the system had detected. A snapshot of a pedestrian alert is shown in Figure 1.

Figure 1. A Typical Alert Issued by the System.

The systems flagged a total of 88 video clips with pedestrian encounters. After the FOT, the sequences were reviewed and 57 were retained for use as stimuli in the laboratory experiment. Sequences with multiple pedestrians at different locations were eliminated to avoid ambiguity regarding which pedestrian had triggered the alert. Sequences with bicyclists were excluded because there were too few to support statistical analysis.

Experiment

Thirty-five volunteers took part in the experiment. Of the 35, 10 were drivers from the field study. The other 25 (age: M 43.5 years; SD 10.4; range 30 to 66) had considerable driving experience (M 24.2 years; range 10 to 46) but had no experience with the pedestrian alert. In Källhammer and Smith (2012), we discuss the high level of agreement in the ratings provided by those who participated in the field study and those who did not. Participation in the field study does not appear to have biased the ratings.

Our approach to assessing driver acceptance of system alerts builds upon the hazard perception test used in U.K. driving tests (Jackson, Chapman &

Crundall, 2009): we present raters with a set of video clips of pedestrian events that they judge may or may not warrant an alert. In this study, the flashing alert symbol was suppressed to avoid any indication about the timing of the event that triggered the alert.

Each of the 57 clips from the FOT was reviewed and categories determined for each of the five factors listed in Table 1. The categories were the independent variables in the experiment. Following van der Laan, Heino, and De Waard (1997), the dependent measures were the relative (ordinal) levels of rater acceptance of an alert to the events in the video clips. To achieve a single measure of driver acceptance, as in the U.K. hazard perception test, we used a single scale anchored at 0 by “completely reject” and at 100 by “completely accept.” By using a single scale, we sought to minimize the influence of alternative interpretations of the multiple components of the metric proposed by van der Laan et al.

A laptop computer connected to a video projector presented the video clips on a wall at a distance of 3 m and a horizontal field of view of 40 degrees. Immediately following the presentation of each clip, the projector froze the last frame of the clip and the laptop display presented a response screen. The response screen contained the anchored scale bar and two buttons labeled Repeat and Next. To indicate the relative level of acceptance of the alert, the participants used a mouse to move a slider that initially appeared at the center of the scale bar.

No information about the traffic context other than the FIR video clips was provided to the raters. Each clip showed approximately 30 s of images from the FIR camera like that shown in Figure 1, roughly 20 s before and 10 s after the recorded alert. The 30-second length was a compromise designed to provide sufficient context for the alert while limiting the time of the experiment.

The experiment was self-paced. The raters used the Next button to queue the next clip. The 57 clips were presented in random order. Each of the 35 participants rated all the clips. No one used the Repeat option. To avoid response bias, we did not query them on their thoughts regarding their criteria for acceptance.

RESULTS

Traffic Context

In the first phase of the study, Källhammer and Smith (2012) investigated the influence of the five categories of contextual information listed in Table 1. We conducted separate nonparametric Kruskal-Wallis one-way ANOVA by ranks for each of the five factors of traffic context. The ANOVA tests whether the raters’ acceptance of alerts varied across the categories of each factor. The results are summarized in Table 2.

Table 2. Summary of Nonparametric ANOVA

Factor	***Kruskal-Wallis ANOVA by ranks***			
	df	*KW*	p	ε^2
Locale	2	4.25	> .050	.08
Pedestrian Location	3	27.06	< .001	.48
Pedestrian Motion	3	14.11	< .001	.25
Vehicle Direction	1	0.00	> .050	.00
Road Direction	1	1.72	> .050	.03

Post-hoc Wilcoxon tests found that pedestrians in rural locales did elicit higher levels of acceptance that were significant at an alpha level of .10. Neither Vehicle Direction nor Road Direction was found to influence the raters’ acceptance of alerts to pedestrians.

The ANOVA by ranks rejected the null hypothesis of no differences across the four categories of Pedestrian Location. The mean ratings and their standard errors are shown in Figure 2.

Post-hoc tests revealed that raters tended to endorse alerts to pedestrians encountered In the street and on the Right Edge. Further, they tended to respond less favorably to alerts to pedestrians who were either on the Left of the roadway or beyond the roadway on both the Left and Right sides.

The ANOVA also rejected the null hypothesis of no differences across the categories of Pedestrian

Motion. The mean ratings are plotted in Figure 3. Post-hoc tests showed that alerts to pedestrians crossing the field of safe travel (Into street) were preferentially likely to be accepted.

Figure 2. Mean and standard errors of ratings for the four categories of Pedestrian Location.

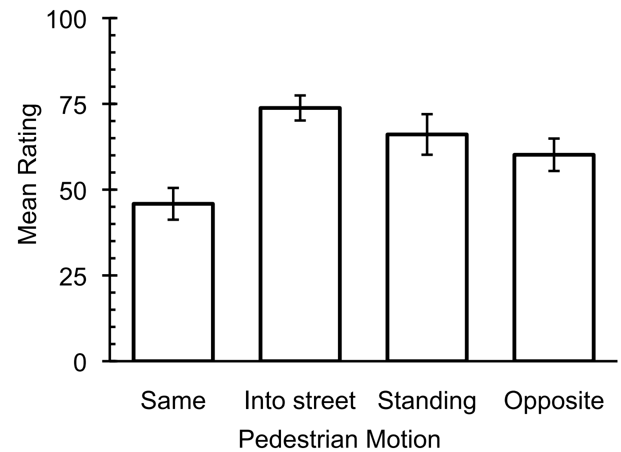

Figure 3. Mean and standard errors of ratings for the four categories of Pedestrian Motion.

Regression Analyses

In the second phase of the investigation, we used regression to ascertain the degree to which the two significant categories of traffic context – Pedestrian Location and Motion – explained the observed variability in driver ratings. Given the results shown in Figure 2, the four categories of location were partitioned into a single nominal (dummy) variable at two levels. The variable was set to 0 for video clips with a pedestrian on either the Left or Right side of the roadway and to 1 for clips with a pedestrian In the street or on its Right edge. The analysis of the motion data used the observed distance in meters between the pedestrian and the car. The observed radial distance was decomposed into orthogonal components where the X direction was the direction of the vehicle's travel and the Y direction was perpendicular to its field of travel. By convention, X is positive in the direction of travel and Y is positive to the right. Because the FIR sensor was directed ahead of the car, X distances to pedestrians are always positive.

The regression equation is shown in Equation 1 and summary statistics are shown in Table 3. The three parameters explain nearly 61% of the variability in the drivers' ratings of the alerts issued in the 57 video clips. None of their interactions are significant. The ability to explain 61% of the variability in human judgment is both unusual and, we believe, impressive.

$$\text{Rating} = 66.5 + 21.5\ \text{Location} + 1.6\ \text{Motion} - 0.8\ \text{Min X} \quad (1$$

Table 3. Summary of Regression Analysis

Variable	*B*	*t*	*p*
Intercept	66.49	8.68	
In street or Right edge	21.48	3.53	.001
Minimum Y Velocity	1.58	1.66	.103
Minimum X	-0.83	-2.34	.023

As expected, Pedestrian Location proves to be a highly significant predictor of alert acceptance. The measure of Pedestrian Motion that significantly increases the percentage of variance explained by the model is the pedestrian's minimum velocity in the +Y direction. This is the slowest rate at which the pedestrian crosses the driver's field of safe travel from left to right. A strongly positive (negative) value of the minimum Y velocity indicates consistently rapid motion to the right (left). The positive beta weight increases the predicted rating of pedestrians moving rapidly to the right and reduces the rating of pedestrians moving rapidly to the left.

The third parameter in the regression equation is a second measure of Pedestrian Location – the minimum observed value of X. This measure of proximity (and risk) never reaches zero in our dataset because the pedestrian detection algorithm does not resolve pedestrians at distances less than approximately 10 m. The negative beta weight decreases the predicted rating of pedestrians who remain relatively far from the car.

DISCUSSION

All three parameters in the regression model pertain directly to the classic notion of the field of safe travel (Gibson & Crooks, 1938). The Pedestrian Location variable differentiates between two types of locations (a) In the street and its near Right edge, where an alert is generally welcomed, and (b) to the left of the car's path and beyond the roadway to the right, where it is often not. This difference is generally bounded by a curb, a sidewalk, a physical barrier, or the transition from paving material to turf. While these distinctions are often apparent to the experienced driver, they were not implemented by the system. The high significance that drivers appear to give to Pedestrian Location supports the argument that detecting the side of the road should become a priority for the developers of alerting strategies.

Our participants found the direction of Pedestrian Motion to be important. They tended to give relatively high ratings to alerts to pedestrians walking quickly into the field of safe travel from the left to the right; that is, encroaching on the field of safe travel from the far-side of the roadway. In contrast, they tended to give relatively low ratings to pedestrians crossing rapidly from the right to the left. The positive value of the beta weight increases (decreases) the predicted rating for pedestrians entering the field of safe travel from the far side (near side) of the road. We suspect that the sign of beta would change for a study conducted in a nation where vehicles drive on the left side of the road.

The final predictor of driver acceptance of alerts to pedestrians was proximity in the direction of the vehicle's travel. This makes sense. If the FIR sensor detects a pedestrian very close to the car, then that pedestrian is potentially in danger.

To test the robustness of the model, we are replicating this study using pedestrian data and driver ratings of approximately 300 new video clips collected as part of a recent FOT. The model will predict ratings based on pedestrian location and motion and the elicited ratings will be used to validate / refine the model.

In sum, all three predictors in the regression equation support the argument made more than 70 years ago that drivers seek to maintain a clear field of safe travel. The field of safe travel appears to guide drivers' acceptance of alerts issued by an FIR night vision active safety system and should drive the design of alerting strategies.

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