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Detection of Emergency Vehicles: Driver Responses to Advance Warning in a Driving Simulator

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Objective: This research evaluated the effects of an advance warning device (AWD) on the safety of driver interactions with emergency vehicles (EVs). The AWD was intended to provide drivers with advance warning of an approaching on-call EV via visual and auditory warnings when the EV was within a 300- to 400-m radius. **Background:** Research suggests that drivers can experience difficulty accurately detecting the distance and direction of approaching on-call EV. In-vehicle technology has not previously been explored as a means of overcoming the limitations of existing EV lights and sirens and improving driver detection of EV. **Method:** An experimental study using an advanced driving simulator examined the effects of the AWD on driving performance in a range of circumstances in which real-world EV crashes and near-misses commonly occur. Each event contained a combination of scenario type (adjacent lane, turning across, car following) and warning condition (control, standard, advance). **Results:** Data from 22 participants were collected, including measures of speed, braking, and visual scanning. For adjacent-lane and turning-across events, the AWD was associated primarily with reductions in mean speed. The AWD resulted in an earlier lane change to clear a path for the EV in the car-following event. **Conclusion:** The reduction in speed observed was a positive finding, given the relationship between impact speed and injury severity. Response priming emerged as the mechanism underpinning these effects. **Application:** Response priming may result in safety benefits in other settings when an advisory warning is presented before the threat can be perceived.

INTRODUCTION

Emergency vehicles (EVs) often engage in high-risk tasks, including traveling at high speed and driving against the flow of traffic (Wheeler, Campbell, & Kinghorn, 1998). Although the use of lights and sirens is instrumental in allowing EVs to make safe and timely responses (Emergency Medical Response Task Force, 1994), crashes involving EVs with lights and sirens have resulted in a significant number of injuries and fatalities and large financial costs. In the United States between 1991 and 2000 there were 301,404 EVs involved in nonfatal crashes and 1,565 involved in fatal crashes. Intersections, where up to 85% of EV injury crashes occur, pose the greatest safety risk (Custalow & Gravitz, 2004). These statistics reveal a significant road safety concern, in addition to patient safety and occupational health and safety issues.

Opportunities exist to address the limitations in responses to existing EV lights and sirens, which may not always attract the attention of other road users and can be obscured at intersections. Sirens cannot project over a long distance and overcome other traffic and ambient sounds, and closed car windows and in-vehicle noise can mask the information needed to estimate the distance and direction of an approaching EV. Drivers can also experience difficulty localizing sirens and overestimate the distance from the siren by a factor of two (Caelli & Porter, 1980).

The potential for in-vehicle devices to improve the identification and localization of EVs, although noted previously (Lee & Kantowitz, 1998), remains

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unproven. Whereas existing sirens provide a first level of warning to an approaching on-call EV, the use of in-vehicle devices to provide an earlier advisory warning would provide a two-stage warning, which has been shown to have safety benefits in other settings (Llaneras et al., 2005; Wiese & Lee, 2004).

Research over several decades confirms the influence of warning timing on performance (Posner, Klein, Summers, & Buggie, 1973) and on system effectiveness and reliability (e.g., Llaneras et al., 2005; Parasuraman, Hancock, & Olofinboba, 1997). If the timing between cue and target presentation is too short, then temporal conflict may result in resource and/or information-processing limitations that lead to delayed responses (Triggs, 1968; Wickens, 1992). Further, a warning that is too early may be ignored by drivers if the cause of the warning cannot be perceived, whereas a warning that is too late will be ineffective (Lee, McGehee, Brown, & Reyes, 2002).

Previous research provides insight into the theoretical mechanisms underpinning these effects, which include increased alertness, preparatory responses, and response priming (e.g., Bertelson, 1967; Ho & Spence, 2005; Posner & Boies, 1971). Viewed as automation that redirects attention, a warning system will alert the driver to identify the target location (primarily through increased visual scanning), and subsequent driver responses will be moderated by individual perceptions of safety (Lee et al., 2002).

The aim of this research was to establish driver responses to advance warning of an approaching on-call EV, considering both theoretical and practical implications. It was hypothesized that the safety of interactions with EVs would be increased by the advance warning device (AWD). Analysis of scanning activity was incorporated to ascertain when drivers first responded to the AWD, as compared with conventional EV warnings, and to provide insight into the mechanisms underpinning any benefits observed with the AWD.

As the AWD is an advisory warning system, the driver responses in three high-risk scenarios were not expected to be dramatic but were anticipated to involve increased visual scanning activity. For the adjacent-lane and turning-across intersection events, the primary anticipated safety benefit was an earlier and larger reduction in mean speed on approach to the intersection. The anticipated behavior in the car-following event was an earlier lane change maneuver to clear a path for the EV when the AWD was activated.

METHOD

This study was approved by the Monash University Standing Committee on Ethics in Research Involving Humans.

Participants

The study comprised 22 participants (12 men and 10 women) whose mean age was 32.8 years (SD = 9.4 years, range 21–50 years). All participants held a full Victorian driver license. Participants were compensated $15 (Australian) for their participation.

The Driving Simulator

The midrange driving simulator located at the Accident Research Centre consisted of a Holden sedan with normal interior features. A curved projection screen located in front of the vehicle provided a field of view subtending angles of approximately 180° horizontally and 40° vertically from the driver's viewpoint. The rear screen provided a field of view subtending angles of approximately 60° horizontally and 40° vertically.

A quadraphonic sound system provided realistic traffic sounds, such as tire squeals, engine noises, horn blasts, low-frequency vibrations, and EV sirens. The system simulated Doppler shift and atmospheric damping effects. Simulations were designed and run using a Silicon Graphics Indy (primarily for developing, running, and replaying simulation scenarios); a Silicon Graphics Onyx (primarily for graphics generation, handling vehicle data inputs and outputs, controlling the audio system and vehicle dynamics, and road database development); and a personal computer (for generating sounds).

The car was mounted on a motion platform, which produced realistic road feel and vehicle dynamics and had three actuators: The front two actuators were placed under the front axle, and the rear actuator was placed in the center of the rear axle, allowing for up/down movements and for pitch and roll rotations. The experimenter controlled driving simulations from a control room located adjacent to the simulation room.

Warning Signal Interface

The AWD was mounted on the lower left

(passenger side) corner of the windscreen, where in Australia the vehicle registration label would normally be placed. The prototype module was powered by an external power source and was approximately 50 mm wide by 30 mm high by 3 mm thick. It was a proximity-based warning system that was activated when the EV was approximately 350 m from the participant's vehicle (*own cab*). It had both a visual (high-intensity LEDs) and an auditory warning. When activated, the three LEDs flashed and the auditory tone pulsed (at around 80 dB) simultaneously at a rate of approximately 2 Hz.

Procedure

Participants completed a Simulator Sickness Questionnaire (SSQ; Kennedy, Lane, Berbaum, & Lilienthal, 1993) and then the first simulator drive, which familiarized them with the vehicle control dynamics. The second (practice) drive included other vehicles and traffic signs and involved a headway-maintenance task that required participants to drive at 60 m behind a lead vehicle and in the same lane as that vehicle. Participants were given instructions for the experimental drives, an introduction to the AWD and its operation, and instructions to respond to the AWD and EV as appropriate.

Experimental drives lasted for approximately 7 min and occurred over a 6.6-km length of mainly straight arterial road with two or three lanes of traffic in each direction, intersections every 300 to 600 m, and houses and factories on both sides of the road. During the drive, each participant was required to perform the headway maintenance task described previously and was requested to drive in accordance with the posted speed limit (70 kph) at other times. Following the experimental drives, each participant completed the SSQ.

Scenarios Used in the Simulator Study

It was critical that the scenarios resemble, as closely as possible, the high-risk situations in which EVs are involved in crashes and near misses. The absence of published information about EV crash types in Victoria was addressed in the first stage of this research.

Data from the State Traffic Accident Record (the database of all police-reported casualty crashes in Victoria) from 2000 to 2002 were analyzed. The crash factors of interest included crash severity, road geometry and character, crash type, speed zone, and the presence or absence of an intersection. A workshop was held with representatives from the emergency services (Victoria Police, Metropolitan Ambulance Service, Metropolitan Fire Brigade) to assess whether the crash data were consistent with their experiences.

Most (336) injury crashes involving an EV occurred within metropolitan Melbourne, as compared with the rest of Victoria (100). Most collisions involving police vehicles (58%), ambulances (66%), and fire trucks (59%) occurred at intersections. Major crash types to emerge from the analysis that could be resolved by the AWD were adjacent-lane (AL), turning-across (TA), and rear-end crashes. The discussions that follow describe the development of simulator scenarios; note that it is standard to drive on the left-hand side of the road in Australia. The road was two lanes in each direction for all events, and the posted speed limit was 70 kph (Figure 1).

Crash Scenario 1: Adjacent lane. The EV attempted to negotiate a red light at a signalized intersection through cross traffic. The EV had lights and sirens activated and proceeded through the intersection from left to right against a red traffic signal, therefore cutting across the path of own cab. Own cab approached the intersection with a green traffic signal activated. Sight-distance was restricted using trees placed on approach to the intersection. In the control condition, a car (non-EV) approached the intersection from the left on a red traffic signal and came to a stop. A control condition was included for all three events.

Crash Scenario 2: Turning across. Here, the EV was turning across the signalized intersection and own cab was traveling straight through the intersection. Own cab approached the signalized intersection with a green traffic signal activated with no other traffic obscuring the EV. The EV was heading toward own cab from the opposite direction and was programmed to turn across its path. In the control condition, a car (non-EV) moved into the turning lane with its turning indicator on but did not actually commence the turn.

Crash Scenario 3: Car following. The AWD is aimed to reduce the number and severity of EV crashes and to improve EV response times. During the workshop, EV drivers reported often traveling at high speed, approaching other vehicles from behind, and, despite having lights and sirens activated, failing to be detected. The car-following (CF) event was therefore designed to provide the participant with an opportunity to clear a path for an

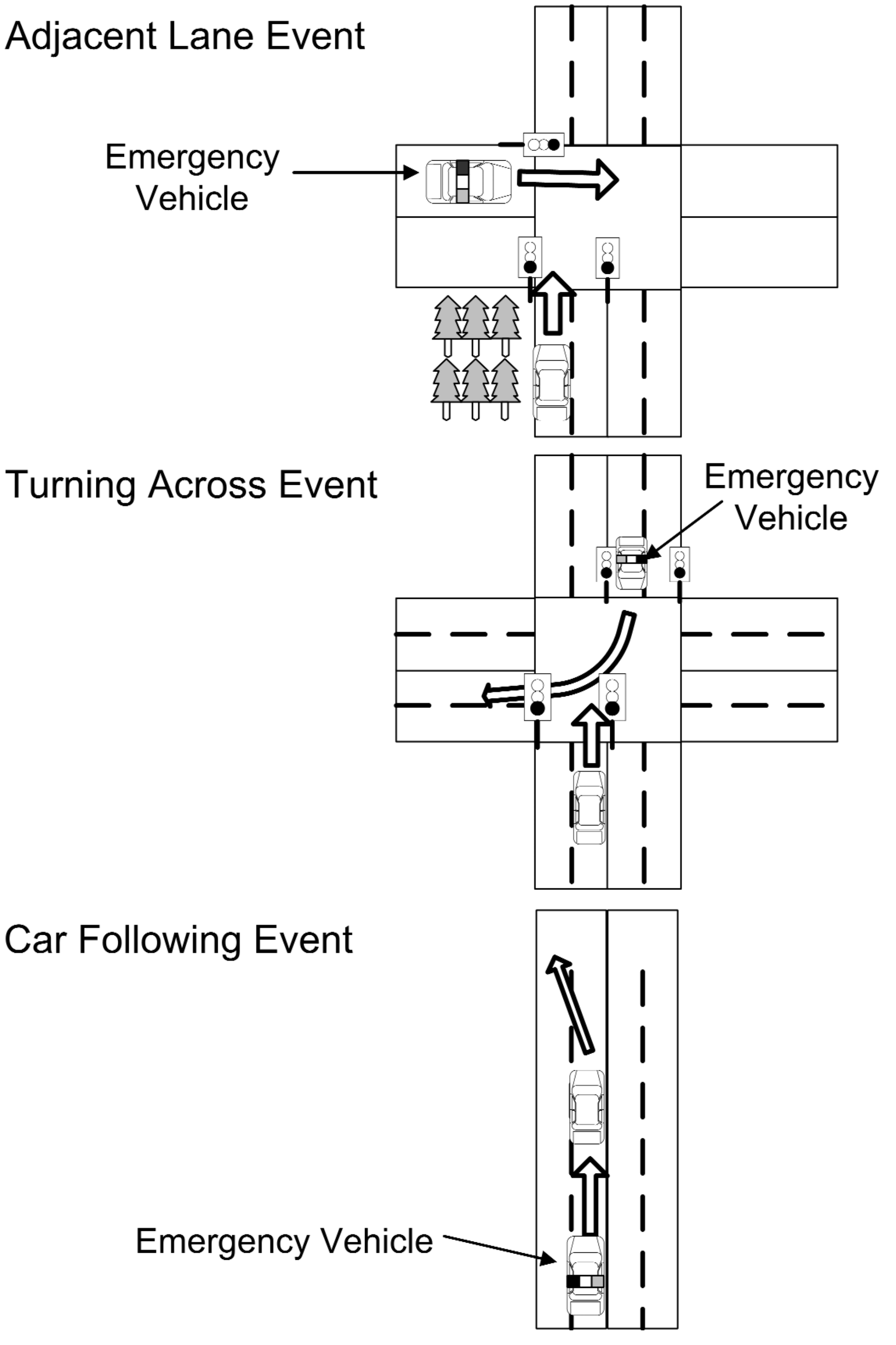

Figure 1. Illustration of the three crash types modeled in the simulator study.

EV approaching from behind. Own cab was placed in the right-hand lane, and an EV approached from behind at a speed of 105 kph. It was anticipated that drivers would move into the left-hand lane to let the EV pass through. In the control condition a car (non-EV) approached from behind at 90 kph.

Visual Scanning

The FaceLAB system (Version 3.2.1) was used to measure visual scanning through the use of two unobtrusive cameras set on the dashboard. While the conventional measure of the number of fixations/sec was not available to the investigators, a measure of cumulative saccade duration/sec was converted to a percentage for ease of interpretation. Use of this measure was based on a reasonable theoretical assumption that increases in the gross measure of cumulative saccade duration reflect increased scanning activity.

Experimental Design

A two-factor within-subjects design was used with the factors condition and distance on approach to the intersection. The three levels of condition were control, or no warning (NW), involving no EV; standard warning (SW), which employed an EV with traditional lights and sirens active; and advance warning (AW), which incorporated the SW condition with the addition of the AWD. The AWD was always activated prior to the SW (73 dB). Typical road noise registered around 60 dB. The distance factor represented distance on approach to an event and was analyzed in 10-m (AL and TA events) and 50-m (CF event) intervals.

Three experimental drives were completed in a counterbalanced order. Each drive consisted of three events containing a specific combination of crash scenario and condition (Table 1). The design chosen was a Latin square design whereby the combinations of crash scenario and condition were distributed in a counterbalanced manner across the three drives (Keppel, 1991).

RESULTS

For the AL and TA events, measures of driving performance were mean speed (in kilometers per hour) and brake pressure (percentage actuation). These measures were selected because the anticipated driver reaction was a gradual reduction in speed. For the CF event, the measures of performance were time (in seconds) and distance (in meters) from the onset of the AWD until own cab changed lanes, as well as mean speed for the duration of the event. The gross measure of visual scanning activity is presented as cumulative saccade duration (percentage per second) across the 10-m distance intervals. Eye movement data were not available for the car-following event.

Two-way ANOVAs were performed for each crash scenario with the within-subjects variables condition (NW, SW, AW) and distance from the intersection (defined in profiles; Keppel, 1991). For AL and TA events, speed and scanning data were analyzed across 10-m distance profiles from 100 m prior to the AWD being activated through to the point at which the EV crossed the path of own cab (resulting in 35 and 25 profile segments, respectively). Brake actuation was analyzed over a smaller distance because of the preponderance of zero values (18 and 13 distance profiles for AL and TA events, respectively). The NW condition was not included in the analyses for brake pressure because of the preponderance of zero values. In the case of there being a significant interaction, main effects were not interpretable and thus are not reported, and a univariate analysis framework was used to test for specific contrasts of interest.

Crash Scenario 1: Adjacent Lane

Mean speed. As shown in Figure 2, there was

TABLE 1: Crash Type and Warning Condition Across the Three Experimental Drives

	Event 1		Event 2		Event 3	
Drive	Crash Type	Condition	Crash Type	Condition	Crash Type	Condition
1	AL	NW	CF	SW	TA	AW
2	TA	SW	AL	AW	CF	NW
3	CF	AW	TA	NW	AL	SW

Note. Each drive contained three events: AL = adjacent lane, TA = turning-across, CF = car-following. NW = no warning, SW = standard warning, AW = advance warning.

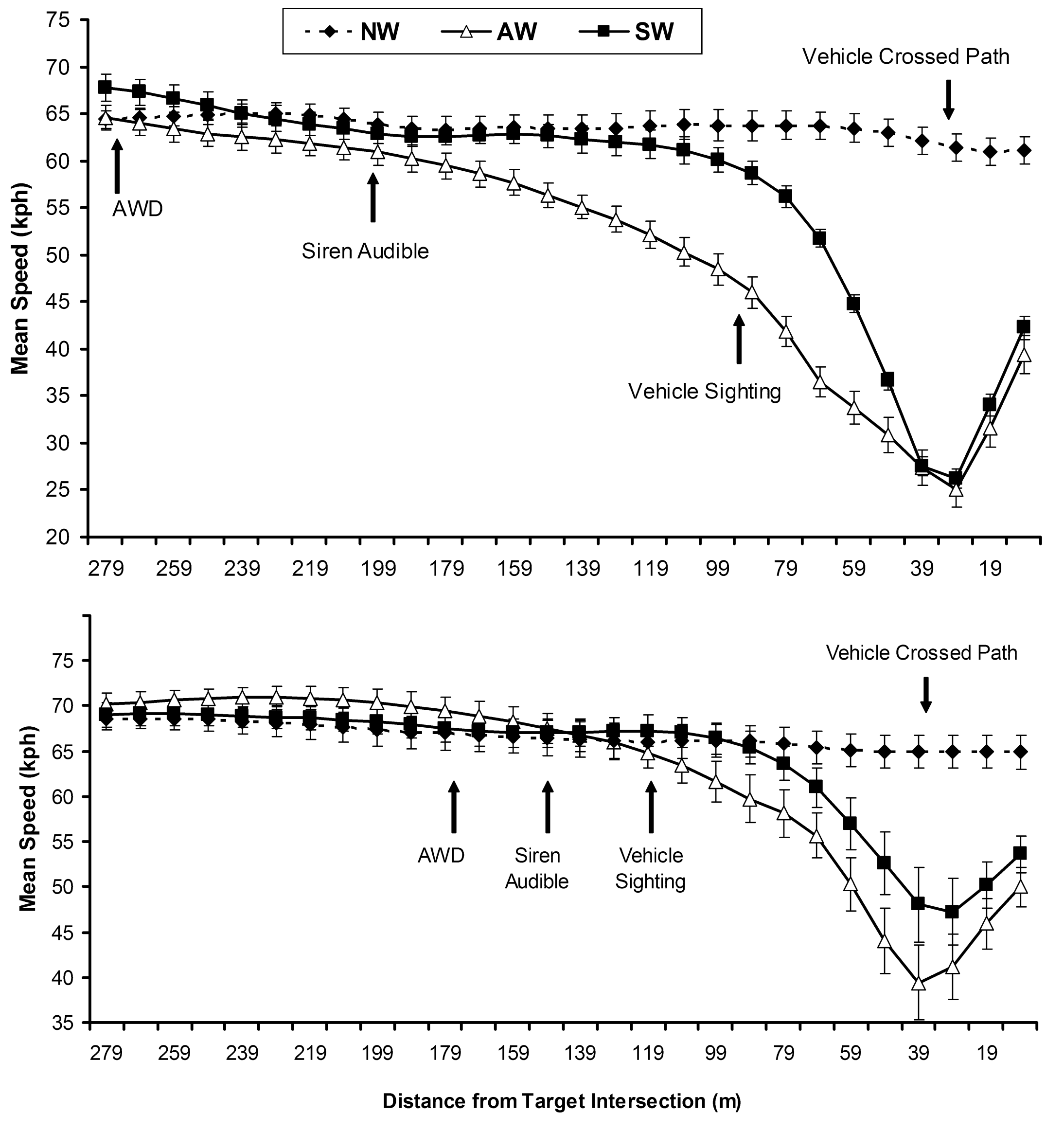

Figure 2. Mean speed (in kilometers per hour ± *SE*) on approach to the adjacent-lane (top) and turning-across (bottom) events for each warning condition (NW = no warning, AW = advance warning, SW = standard warning). Each distance on the *x* axis represents a 10-m segment from the stated value. AWD = advance warning device.

a significant interaction of Condition × Distance, $F(68, 1428) = 27.54$, $p < .001$. In the SW and AW conditions, speed did not drop as compared with the control condition (NW) until after the EV siren was audible: SW, 109- to 89-m intervals ($p < .05$), 79- to 29-m intervals ($p < .001$), AW, 169- to 139-m intervals ($p < .05$), 129- to 29-m intervals ($p < .001$). Participants did reduce speed earlier with AW than with SW (119- to 89-m intervals, $p < .05$, 79- to 69-m intervals, $p < .001$, 59-m interval, $p < .05$), which represented the 90 m prior to the event. During this period, mean speed was up to 15 kph lower when the AWD was activated.

Mean braking pressure. The Condition × Distance interaction was significant, $F(18, 378) = 5.49$, $p < .05$. Brake pressure was higher in the SW than the AW condition immediately after the EV was sighted (69- to 39-m intervals, $p < .05$; Figure 3).

Visual scanning. The interaction between the two factors was significant, $F(68, 1428) = 1.35$, $p < .05$. Cumulative saccade duration was higher for the SW and AW conditions as compared with

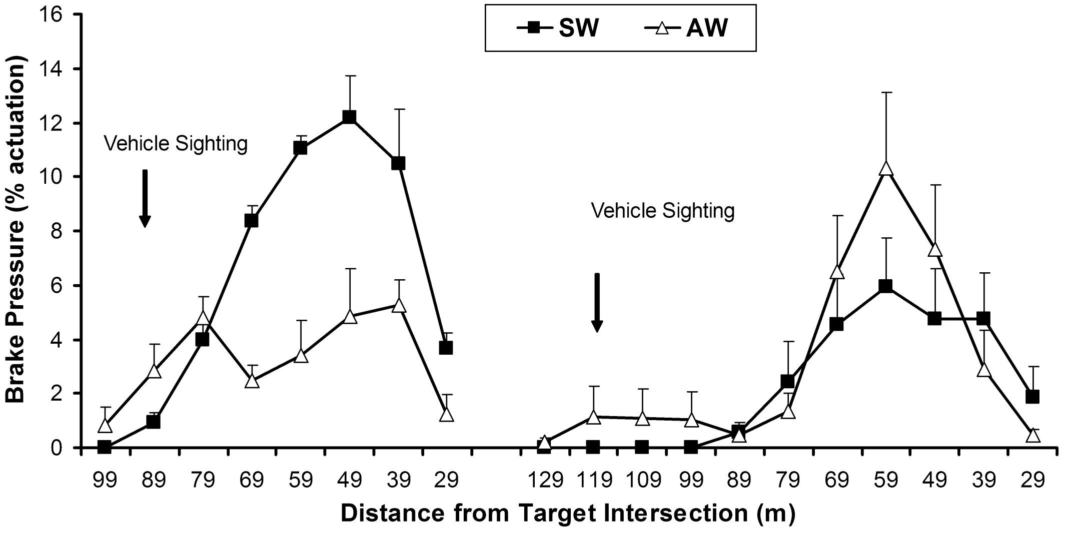

Figure 3. Brake pressure (percentage actuation ± *SE*) for the adjacent-lane (left) and turning-across (right) events on approach to the target intersection for the standard warning (SW) and advance warning (AW) conditions. Each distance on the *x* axis represents a 10-m segment from the stated value.

NW but was over a greater distance for AW (AW, 189- and 199-m intervals, $p < .05$; SW, 209-m interval, $p < .05$; Figure 4). These points occur around the time the EV siren became audible. With AW, as compared with SW (*M*s = 7.2% and 4.6%, $p < .05$), cumulative saccade duration was higher at the 119-m (before the EV was visible) and 69-m intervals (after the EV was visible, *M*s = 13.4% and 11.7%).

Crash Scenario 2: Turning Across

Mean speed. The Condition × Distance interaction was significant, $F(50, 1050) = 13.12$, $p < .001$. Mean speed remained constant in the NW condition and reduced markedly in the SW and AW conditions (Figure 2). In the SW and AW conditions, speed did not drop as compared with the control (NW) condition until after the EV was visible: AW, 89- to 29-m intervals ($p < .05$); SW, 59- to 29-m intervals ($p < .05$). Again, participants did reduce speed earlier with AW than with SW (59- to 39-m intervals, $p < .05$), with speed being almost 10 kph lower during this critical period. Note that in the TA event the points at which the AWD was activated, the EV siren became audible, and the EV was visible were closer to the target intersection than was the case for the AL event because of the faster closing speed in this event.

Mean braking pressure. There was a significant main effect for distance, $F(12, 252) = 9.32$, $p < .05$. As evident in Figure 3, across the SW and AW conditions brake pressure was highest after the EV was visible (69- to 49-m intervals, $p < .05$). The interaction was not significant.

Visual scanning. The Condition × Distance interaction was again significant, $F(50, 1050) = 1.49$, $p < .05$. Cumulative saccade duration was higher in the AW condition than the NW immediately after the EV was visible (99-, 89-, and 49-m intervals, $p < .05$; Figure 4).

Crash Scenario 3: Car Following

It was anticipated that drivers would move into the left-hand lane to let the EV pass. Hence, the primary measure of interest was the point at which own cab changed lanes to allow this. The following analyses compare the SW and AW conditions.

Participants changed lanes earlier following the onset of AWD than in the SW condition (*M*s = 18.8 and 32.8 s, respectively); $F(1, 21) = 46.35$, $p < .001$. Distance to change lanes was shorter in the AW condition than in the SW condition (*M*s = 240.7 and 524.66 m, respectively); $F(1, 21) = 92.65$, $p < .001$. Mean speed was lower for the AW than for the SW condition (*M*s = 62.5 and 69.1 kph, respectively); $F(1, 21) = 13.25$, $p < .05$.

DISCUSSION

This study evaluated in a driving simulator the

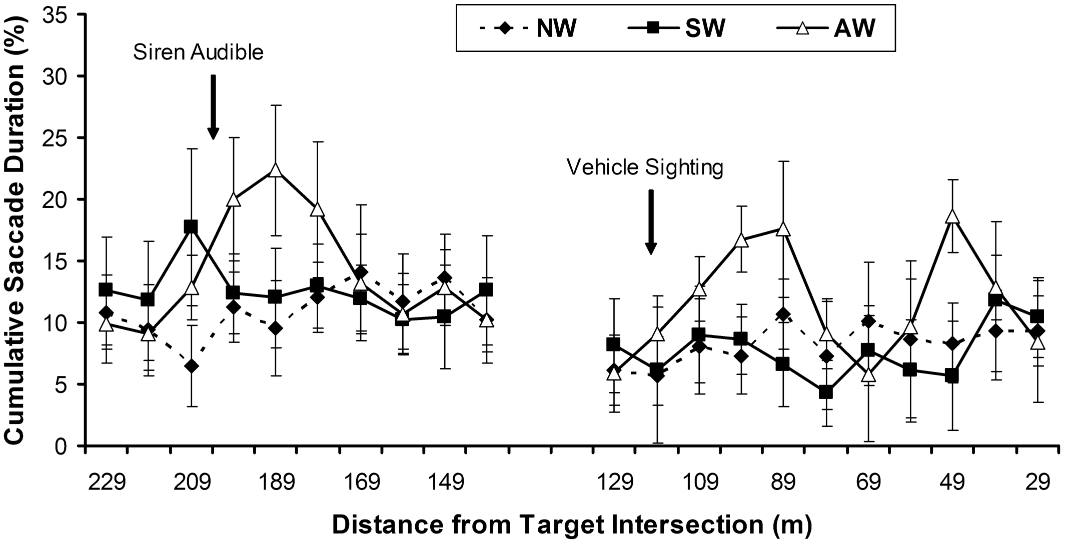

Figure 4. Cumulative saccade duration (percentage per second ± *SE*) for the adjacent-lane (left) and turning-across (right) events on approach to the target intersection for each warning condition (NW = no warning, AW = advance warning, SW = standard warning). Each distance on the *x* axis represents a 10-m segment from the stated value.

influences of advance warning on driver responses to an approaching on-call EV. As the AWD is considered automation that redirects attention, it was expected that the advance warning would alert drivers to the presence of a potential hazard, evident by increased scanning of the environment and earlier reductions in speed. The data for the AL and TA events were as predicted. Scanning activity was higher with AW for a short period after the siren was audible (AL event) and the EV was visible (TA event). This was associated with a greater reduction in mean speed and heavy braking, compared with the SW condition. Importantly, the reductions in speed were evident farther in advance of the intersection when the AWD was activated, although drivers did not actually reduce speed until they had detected the EV.

Driving performance was stable in the control condition, but it was important to collect these baseline data to account for any potential changes. The results for the CF event, as predicted, confirmed the potential positive safety benefits of the AWD. Participants changed lanes earlier with the AWD activated than without it. Mean speed was lower in the AW condition, which again has important safety implications. The driving data for the three events show positive safety benefits associated with the AWD.

Although the application of alerting devices to improving EV safety is novel, experimental research over many decades has shown benefits to task performance through the provision of warning signals and cues and has explored the relationships between warning intervals and performance (Bertelson, 1967; Parasuraman et al., 1997; Posner & Boies, 1971; Posner et al., 1973). As noted earlier, a hypothesized mechanism for these observed benefits is through increased alertness or preparedness, developed rapidly and maintained over a relatively brief interval, which decreases response time (Posner & Boies, 1971; Posner et al., 1973).

Our data, however, support response priming theory as the underlying mechanism whereby the appropriate response to the target (EV) was primed by the cue (AWD). In the AL and TA crash scenarios, there was no observable participant response following AWD activation (first-stage warning) until after the EV was audible or visible (second-stage warning). However, whereas participants in AW and SW conditions did not make measurable responses until the presence of the EV had been confirmed, these responses were more rapid with prior exposure to the AWD in the AW condition. This holds true for the increases in scanning activity, reductions in speed, and heavy braking behavior observed.

Whereas previous studies have typically used warning intervals of less than 2 s, appropriate responses were primed using warning intervals of up to 8 s in the present study (interval between AWD activation and EV siren: AL, M = 4.1 s; TA, M = 1.5 s; CF, M = 8.0 s). This is an interesting finding that has theoretical implications generalizable to other settings in which an advisory warning is presented before the threat can be perceived. If prior exposure to the advisory AWD did prime responses, then providing an earlier warning in a given scenario would not provide any additional benefits, given that the points at which the EV siren was audible, and the EV could be seen, would remain the same. Further development of the AWD through the presentation of warning cues in the same location in space as the target may, however, facilitate attentional enhancement of target processing over and above that observed with the current priming paradigm (Ho & Spence, 2005; Ho, Tan, & Spence, 2006).

An EV advisory warning system needs to provide advance warning for different situations, which must be balanced against the potential for false alarms. Although the effects of false alarms were not examined in this study, the benefits of an earlier advisory warning in priming responses to the on-call EV probably outweigh the costs associated with any inappropriate responses to potential nuisance alarms, given that any inappropriate response would be a mild reduction in speed and not an abrupt avoidance maneuver (Lee et al., 2002; Maltz & Shinar, 2004). This requires further examination.

Discussion about safety benefits has focused on speed because speed is a fundamental determinant of crash and injury risk (Aarts & van Schagen, 2006). Even small reductions in travel speed or impact speed will lead to substantial reductions in crash and injury risk (Nilsson, 1984). Nonetheless, these findings should be interpreted in light of some experimental constraints. Driver responses to the AWD may have been different if the driving environment had been more dynamic and complex, involving a greater number of road users and in-vehicle distractions. The simulator laboratory was required to be dark; hence it is possible that the effectiveness of the visual warning provided may change in bright daylight conditions.

Future Research

A number of human factors issues need to be further addressed, including behavioral adaptation and system acceptance and reliability. Research addressing EV warning systems should focus on system effectiveness under different operating conditions, in naturalistic driving environments, and in the context of other in-vehicle systems to ensure that the timing of multiple warnings are coordinated to avoid temporal conflict and to elicit the appropriate urgency of response (Marshall, Lee, and Austria, 2007). Research should also examine whether the changes in behavior associated with the AWD result in a reduction in crashes, near misses, and EV response times. This would require several years of exposure to the AWD in the community before meaningful analyses could be conducted.

Warning signals need to provide reliable information in a salient manner without distracting the driver. Therefore, it is important to incorporate directional cues within this warning system and, ideally, to present the warning in the same spatial location. This would provide more information to the driver and facilitate a more rapid response (Ho et al., 2006; Posner & Boies, 1971; Posner, Snyder, & Davidson, 1980). More precise measures of visual scanning are needed to evaluate the effects of directional cues on target localization. This would provide for a more in-depth assessment of any potential distracting effects associated with the AWD. For a proximity-based system, the incorporation of Global Positioning System technologies may also help to reduce the incidence of some false alarms.

Conclusion

This study evaluated driver responses in a driving simulator to advance warning of an approaching on-call EV. The advance warning condition was associated with a more rapid response once the EV was detected and a lower vehicle speed at the intersection, as compared with the SW condition, which is indicative of improved safety. Priming theory emerged as the likely mechanism underpinning these benefits and is generalizable to other settings in which an advisory warning is presented before the threat is perceived.

To develop this advance warning concept further will require significant technological advancement to allow for the provision of location cues in the visual and/or auditory warnings or to incorporate the presentation of the warning in the same location in space as the target. Although further work optimizing the warning signals should improve these safety benefits and provide further evidence supporting the role of priming in this context, it is likely that the combined use of in-vehicle and out-of-vehicle technologies (e.g., temporary modifications to traffic signals, as used in other settings; Lenné, Corben & Stephan, 2007), offers the greatest potential to reduce casualty crashes involving EVs and to improve response times.

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REFERENCES

Aarts, L., & van Schagen, I. (2006). Driving speed and the risk of road crashes: A review. *Accident Analysis and Prevention, 38,* 215–224.

Bertelson, P. (1967). The time course of preparation. *Quarterly Journal of Experimental Psychology, 19,* 272–279.

Caelli, T., & Porter, D. (1980). On difficulties in localizing ambulance sirens. *Human Factors, 22,* 719–724.

Custalow, C. B., & Gravitz, C. S. (2004). Emergency medical vehicle collisions and potential for preventative intervention. *Prehospital Emergency Care, 8,* 175–184.

Emergency Medical Response Task Force. (1994). Use of warning lights and siren in emergency medical vehicle response and patient transport. *Prehospital and Disaster Medicine, 9,* 133–136.

Ho, C., & Spence, C. (2005). Assessing the effectiveness of various auditory cues in capturing a driver's visual attention. *Journal of Experimental Psychology: Applied, 11,* 157–174.

Ho, C., Tan, H. Z., & Spence, C. (2006). The differential effect of vibrotactile and auditory cues on visual spatial attention. *Ergonomics, 49,* 724–738.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3,* 203–220.

Keppel, G. (1991). *Design and analysis: A researcher's handbook* (3rd ed.). Englewood Cliffs, NJ: Prentice Hall.

Lee, J. D., & Kantowitz, B. H. (1998). Perceptual and cognitive aspects of intelligent transportation systems. In W. Barfield & T. A. Dingus (Eds.), *Human factors in intelligent transportation systems* (pp. 31–54). Mahwah, NJ: Erlbaum.

Lee, J. D., McGehee, D. V., Brown, T. L., & Reyes, M. L. (2002). Collision warning timing, driver distraction, and driver response to imminent rear-end collisions in a high-fidelity driving simulator. *Human Factors, 44,* 314–334.

Lenné, M. G., Corben, B. F., & Stephan, K. (2007). Traffic signal modification to improve safety for intoxicated pedestrians. *Accident Analysis and Prevention, 39,* 751–756.

Llaneras, R. E., Green, C. A., Kiefer, R. J., Chundrlik, W. J., Jr., Altan, O. D., & Singer, J. P. (2005). Design and evaluation of a prototype rear obstacle detection and driver warning system. *Human Factors, 47,* 199–215.

Maltz, M., & Shinar, D. (2004). Imperfect in-vehicle collision avoidance warning systems can aid drivers. *Human Factors, 46,* 357–366.

Marshall, D. C., Lee, J. D., & Austria, P. A. (2007). Alerts for in-vehicle information systems: Annoyance, urgency, and appropriateness. *Human Factors, 49,* 145–157.

Nilsson, G. (1984). *Hastigheter, olycksrisker och personskadekonsekvenser i olika vagmiljoer [Speed, accident rates and personal injury consequences for different road types]* (VTI Rapport 277). Linköping, Sweden: Swedish National Road and Transport Research Institute (VTI). (In Swedish with summary in English.)

Parasuraman, R., Hancock, P. A., & Olofinboba, O. (1997). Alarm effectiveness in driver-centered collision-warning systems. *Ergonomics, 40,* 390–399.

Posner, M. I., & Boies, S. J. (1971). Components of attention. *Psychological Review, 78,* 391–408.

Posner, M. I., Klein, R., Summers, J., & Buggie, S. (1973). On the selection of signals. *Memory and Cognition, 1,* 2–12.

Posner, M. I., Snyder, C. R. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General, 109,* 160–174.

Triggs, T. J. (1968). *Capacity sharing and speeded reactions to successive signals* (Human Performance Center Tech. Rep. No. 08733-23-T). Ann Arbor: University of Michigan.

Wheeler, W. A., Campbell, J. L., & Kinghorn, R. A. (1998). Commercial vehicle-specific aspects of intelligent transport systems. In W. Barfield & T. A. Dingus (Eds.), *Human factors in intelligent transport systems* (pp. 95–129). Mahwah, NJ: Erlbaum.

Wickens, C. D. (1992). *Engineering psychology and human performance* (2nd ed.). New York: HarperCollins.

Wiese, E. E., & Lee, J. D. (2004). Auditory alerts for in-vehicle information systems: The effects of temporal conflict and sound parameters on driver attitudes and performance. *Ergonomics, 47,* 965–986.

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