Transportation Research Part F: Psychology and Behaviour 109 (2025) 137–146

Contents lists available at ScienceDirect

Transportation Research Part F: Psychology and Behaviour

journal homepage: www.elsevier.com/locate/trf

Driver's gaze behavior when approached by an emergency vehicle – The effects of in-car warnings and system introduction

Kajsa Weibull [a,b,*], Björn Lidestam [a], Erik Prytz [b,c]

[a] Swedish National Road and Transport Research Institute, Linköping, Linköping SE-581 95, Sweden
[b] Department of Computer and Information Science, Linköping University, Linköping, Sweden, Linköping SE-581 83, Sweden
[c] Center for Disaster Medicine and Traumatology, and Department of Biomedical and Clinical Sciences, Linköping University, Linköping, Sweden

ARTICLE INFO

Keywords:
Emergency vehicle
In-car warning
Emergency vehicle approaching
Eye tracking
Driving simulator
Intelligent transport system

ABSTRACT

This study investigates drivers' eye gaze behavior in response to Emergency Vehicle Approaching (EVA) warnings. EVA warnings, delivered through in-car alerts, provide advance notice of approaching EVs, enabling drivers to move over in time. Previous research indicates that EVA warnings influence driver behavior positively, promoting safer interactions. This study expands further by exploring the role of system introduction to make drivers benefit from EVA warnings.

A simulator experiment with 73 participants was conducted. Before driving, half of the participants were introduced to the EVA system. The participants were driving on a highway and were overtaken by EVs twice during a 20-minute drive. During the drive, half of participants received EVA warnings. Gaze distribution was analyzed in three areas of interest (Forward, Mirrors, Dashboards). Analysis of driving simulator data did not reveal any differences in driving behaviors. However, the analysis of drivers' gaze distribution suggests that EVA warnings contribute to increased mirror usage, indicating early scanning for approaching EVs. Furthermore, drivers who were introduced to the EVA system before driving but never received an EVA warning in the simulator looked through the front windshield less than drivers who were introduced and received an EVA warning.

This study contributes to understanding the driver gaze behavior when receiving an in-car warning for emergency vehicles and supports previous findings regarding EVA warnings positive impact of driver behavior.

1. Introduction

Drivers of emergency vehicles (EVs) face risks when interacting with surrounding traffic. The emergency driving task is difficult and collisions between EVs and other road users result in fatalities every year (Burke et al., 2001; Hsiao et al., 2018; Missikpode et al., 2018; Saunders & Gough, 2003). Between the years 2012 and 2023, 553 law enforcement officers were killed in vehicle crashes in the US (National Law Enforcement Officers Memorial Fund, 2023). Besides fatal collisions, interactions with other road users can lead to delays for emergency response organizations which increases the time it takes to provide patients with proper care (Wang & Xu, 2021; Wiwekananda et al., 2020).

One method to support civilian drivers in the EV interaction is to provide them with an Emergency Vehicle Approaching (EVA)

* Corresponding author.
E-mail addresses: kajsa.weibull@vti.se (K. Weibull), bjorn.lidestam@vti.se (B. Lidestam), erik.prytz@liu.se (E. Prytz).

https://doi.org/10.1016/j.trf.2024.12.010
Received 28 March 2024; Received in revised form 25 September 2024; Accepted 6 December 2024
Available online 10 December 2024

warning. An EVA warning is an in-car warning that lets the driver know in advance that an EV is approaching. This allows the civilian driver to notice the EV earlier, compared to when only providing a warning with lights and sirens, which gives the civilian drivers more time to move over safely. Previous studies have found that EVA warnings are associated with drivers maintaining a lower speed and moving over more quickly compared to drivers who do not receive an EVA warning (Lenné et al., 2008; Lidestam et al., 2020; Payre & Diels, 2020; Savolainen et al., 2010).

In previous studies with EVA, measurements such as the speed and lateral position of the participant's vehicle have been used. However, there is a risk that the measurements from the driving simulator do not tell the full story about the driver's intentions and reactions when being provided with an EVA warning. To gain a better understanding of driver intention, eye tracking is believed to be a useful tool. It allows for comparisons in eye gaze distributions between drivers who do and do not receive an EVA warning in an EV interaction. The effectiveness of in-car warnings has previously been supported by eye tracking (Ma et al., 2022; Xu et al., 2023). Previously eye tracking has only been used to study the effects of EVA in Lenné et al. (2008). Their findings indicate that drivers who receive EVA warnings scan their environment more than drivers who do not receive EVA warnings before an EV interaction. However, Lenné et al. (2008) did not examine where the driver's visual scanning took place.

There is a risk of EVA warnings increasing the complexity of the driving task. Previous studies have found that the level of driving complexity affects drivers' monitoring of the road center (Harbluk et al., 2002; Victor et al., 2005). An increased task complexity is associated with a decrease in time spent looking at dashboards or mirrors (De Waard, 1996; Harbluk et al., 2007). Furthermore, an increased level of automation has been shown to decrease the time spent looking at dashboards (Deniel et al., 2024). If a driver's visual scanning of the environment were to decrease when an EVA warning is presented, it may be a sign that the warning is doing more harm than good. The current study used a simulator experiment to further explore the learning effects and eye gaze behavior when drivers interact with the EVA system. It was hypothesized that receiving an EVA warning would lead to a quicker detection the approaching EV compared to the drivers who do not receive an EVA warning.

EVA warnings constitute one example of an increasing number of novel technologies in cars. It is important to consider how to introduce drivers to such new features in their vehicles. Otherwise, drivers might not even be aware of the warning and support systems they have in their vehicles (Harms et al., 2020). An introduction is especially important when the system requires the driver to act, such as for EVA or Forward Collision Warnings. If a driver is unaware of the warning system featured in their vehicle, it is more likely that they do not know how to act the first time the warning is presented. Weibull et al. (2023) found that drivers who received an EVA warning did not move over earlier than drivers who did not receive a warning for their first interaction with an EV. However, in the second and third interactions with EVs, EVA warnings shortened the move-over time. Weibull et al. (2023) suggested that this might be due to an unfamiliarity with the EVA warnings. One purpose of the present study is therefore to examine if an introduction to the EVA system has an impact on the driver's ability to make use of the EVA warning the first time it is presented. It was hypothesized that the drivers who received an EVA warning and had an introduction to the EVA system would be even quicker at detecting the EV than the group who received an EVA warning but without an EVA introduction.

2. Method

This research complied with the American Psychological Association Code of Ethics. Informed consent was provided by each participant.

Fig. 1. The simulator used in the study.

2.1. Participants

A total of 73 participants were included, ranging from 19 to 54 years old ($M = 38.1$, $SD = 10.1$). All of them had a valid driver's license. They received their driver's license 1 to 37 years ago ($M = 18$, $SD = 11$) and drove an estimate of 0 – 100 000 km per year ($M =$ 22 210, $SD =$ 20 286).

One driver chose to end the participation in the study due to simulator sickness. Therefore, the data from 72 participants was analyzed. The participants were recruited through social media and received a gift card of 120 SEK as compensation for their participation.

2.2. Materials

2.2.1. Simulator

A moving base simulator with a passenger car cabin (Volvo XC60) was used (Fig. 1). The simulator provided eight degrees of freedom and a 210-degree forward field of vision. Due to a technical malfunction, the motion platform was inactive for 16 of the 72 participants. These 16 were equally distributed across the experimental groups.

Within the cabin, there were four Smart Eye tracking cameras (Fig. 2). Eye movements were collected at a frequency of 100 Hz. To be able to analyze the eye-gaze behavior, three predefined areas of interest were selected: Forward (front windshield), Mirrors (left rear-view mirror, right rear-view mirror, center rear-view mirror), and Dashboards (infotainment system, speedometer).

The EVA warning was presented through an audio alert with a voice stating: "Varning! Utryckande fordon! Var god ge fri väg." ("Warning! Emergency vehicle approaching! Please move over.").

2.2.2. System Introduction

Two introductions to technical in-car systems were included in the study. The first one described the EVA system and the second one a parking assistance system. The introductions included information about the purpose of the support system and in what cases it would be activated. Both introductions were written to resemble those normally provided by a car manufacturer.

2.3. Design

The study employed a 2 (Introduction: EVA vs. Parking Assistance [Control]) × 2 (Warning: Warning vs. No warning [Control]) × 2 (EV Event: 1st, 2nd) split-plot factorial design. Event was a within-group variable. The between-group variables are presented in Table 1. Half of the participants were given an introduction the EVA system and the other half were introduced the parking assistance system. None of the participants interacted with a parking assistance system in the experiment. The introduction to the parking assistance system served as a control condition in the current study. Half of the participants received an EVA warning when driving in the simulator. The EVA warning was presented to them 20 s before the EV overtook the participant's vehicle.

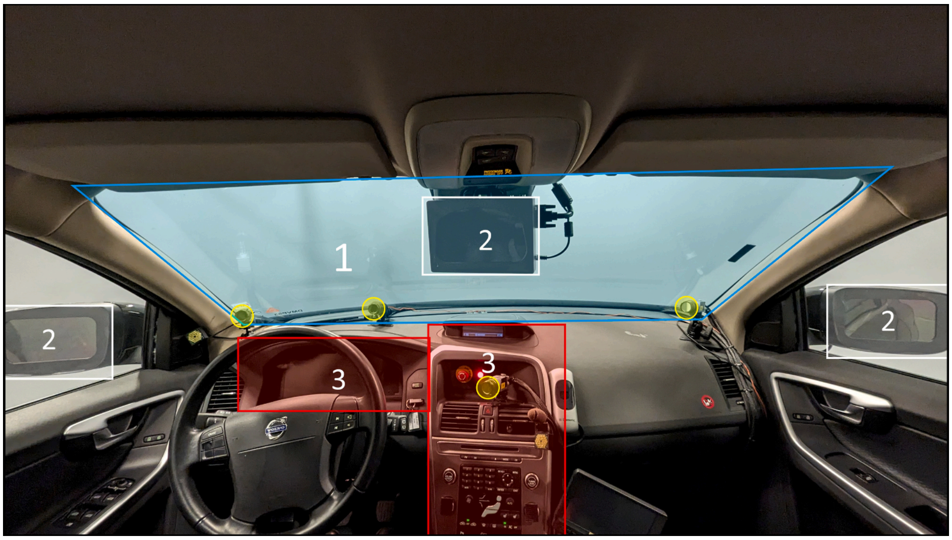

Fig. 2. The inside of the cabin used in the current experiment. The three areas of interest are marked: 1 = Forward, 2 = Mirrors, 3 = Dashboards. The yellow circles mark the eye tracking cameras.

Table 1
Group design.

	EVA Introduction	Parking Introduction
EVA	$n = 18$	$n = 18$
No-EVA	$n = 18$	$n = 18$

2.4. Procedure

All participants were informed that the purpose of the study was to test novel technical solutions in cars. When arriving, they were informed about the procedure, their anonymity, and their right to end their participation in the experiment at any time. After that, they provided informed consent and responded to a pre-experiment questionnaire. They were asked about their driving experience and demographics such as age and gender. The participants were asked if they had any hearing or visual impairments. The participants were excluded if they had visual or hearing impairment that was not corrected by visual or auditory aids. Before sitting down in the simulator, they were asked to read an introduction, either about the parking assistance system or the EVA system. The experimental leader did not answer any questions about the system or their relevance to the experiment.

The eye tracking system was calibrated for every participant before they started driving. All drivers were instructed to drive as they normally would in traffic, with the addition that they should use cruise control. The driving scenario occurred on a three-lane highway with high traffic density in the right and middle lanes. To reduce the risk of simulator sickness and to allow the participants to become familiar with the simulator, the experiment began with a one-minute practice drive at 30 kph. After the practice drive ended, the simulator automatically accelerated to 120 kph and activated cruise control. Approximately nine minutes into driving, half of the participants received an EVA warning. About 20 s later, an ambulance approached the participants' vehicle. The EV was always driving in the left-most lane. Therefore, the participant had to move to another lane if they were driving in the left-most lane. In an attempt to increase the chances of the participant having to change lanes, there was a higher density of traffic in the middle and right-most lanes. Six minutes after the first EV event, there was another approach by a police vehicle. The simulation ended a few minutes after the second EV had passed the participant's vehicle.

Upon completion, participants were asked to complete a post-experiment questionnaire. The survey gathered information about the participants' prior encounters with EVs. If they had received an EVA warning in the experiment, they were asked to share their experience of the warning system used in the experiment.

2.5. Data analyses

A measure of *move-over time* was calculated. The participant's vehicle was considered to have moved over when the participant's vehicle was 2.5 m from the center position of the leftmost lane. This was the smallest lateral difference that allowed the EV to overtake the participant's vehicle. The move-over time was defined as the number of seconds between the point in time when it first was possible for the participant to see the EV and when the participant had moved over. The EV was visible 30 s before overtaking. To examine the driver's behavior when interacting with the EV, a 2 (Warning vs. No warning) $\times$ 2 (Introduction vs. No introduction) $\times$ 2 (Event) split-plot factorial ANOVA, with Warning and Introduction as between groups variables and Event as repeated measures, was conducted. In 46 out of 144 events, the participant was already in the middle or right-most lane before the EV was visible. Therefore, those instances were excluded from the analysis.

Eye tracking data was analyzed in three Areas of Interest (AOI): Forward, Mirror, and Dashboard. *Forward* refers to when the participant was looking through the front windshield. If a participant looked in the left, front, or right rear-view mirror, it was categorized as *Mirror.* If the participant looked at the center console or the speedometer it was labelled as *Dashboard.* The AOIs are displayed in Fig. 2.

The eye tracking data was only analyzed around two periods of interest, which were the times when the EV overtook the participant's vehicle. Namely, 30 s before overtaking, and 30 s after. The time slot was chosen because the EV was only visible during that period. To be able to follow the possible differences in AOIs during the minute when the eye tracking data was analyzed, the minute was divided into six equally long time slots: 30–21, 20–11, and 10–1 s before the EV overtook the participant's vehicle, and 0–9, 10–19, and 20–29 s after the EV overtook the participant's vehicle. In the analysis, the average time spent looking in the different AOIs was compared between the different variables. To examine the eye gaze behavior one 2 (Event) $\times$ 6 (Time) $\times$ 2 (Warning vs. No warning) $\times$ 2 (Introduction vs. No introduction) split plot ANOVA was performed for each AOI. Warning and Introduction were between groups variables, whilst Time and Event were repeated measures.

Greenhouse-Geisser corrections for sphericity were used in the cases where the criteria for sphericity were not met. Data points that were more than three times the interquartile range from a quartile were considered outliers and removed from the analysis. The threshold of statistical significance was set to $\alpha = 0.05$. Post hoc analysis was performed using pairwise comparisons.

3. Results

The results section is divided into two parts. First, the analysis of move-over time is based on driving behavior. Second, the result of the eye tracking analyses is described.

3.1. Driving simulator data

The 2 (Event) × 2 (Warning) × 2 (Introduction) split-plot factorial ANOVA did not indicate a main effect of Event, $F(1, 32) = 0.003$, $p = 0.96$, Warning $F(1, 32) = 0.09$, $p = 0.76$, or Introduction, $F(1, 32) = 0.46$, $p = 0.83$. No significant interaction effect was observed for Event × Warning $F(1, 32) = 0.04$, $p = 0.84$, Event × Introduction $F(1, 32) = 0.03$, $p = 0.85$, Warning × Introduction $F(1, 32) = 0.59$, $p = 0.45$, or Event × Warning × Introduction $F(1, 32) = 3.7$, $p = 0.06$.

3.2. Eye tracking data

All eye tracking data is expressed in the average percentage spent looking at an AOI.

3.2.1. Forward

The 2 (Event) × 6 (Time) × 2 (Warning) × 2 (Introduction) split-plot factorial ANOVA indicated a significant main effect for Event (Table 2), such that the participants spent less time looking forward in the first event ($M = 79.64\%$, $SE = 1.12\%$), compared to the second ($M = 81.66\%$, $SE = 1.08\%$) A significant interaction effect of Event × Warning was indicated, such that drivers who received an EVA warning increased their time looking forward in the second event ($M = 83.53\%$, $SE = 1.51\%$), compared to the first ($M = 79.82\%$, $SE = 1.57\%$).

A main effect of Time was observed. The results are shown in Table 2 and Fig. 3a. A significant interaction effect was seen for Time × Warning (Table 2, Fig. 3b), suggesting that the drivers who received an EVA warning spent more time looking forward 20–29 s after the EV overtaking the participant ($M = 88.76\%$, $SE = 1.57\%$) compared to drivers who did not receive an EVA warning ($M = 82.37\%$, $SE = 1.58\%$). This indicates that drivers who received an EVA warning were quicker at returning to the baseline eye-gaze behavior compared to the drivers who did not receive an EVA warning. A significant interaction effect between Event × Time was observed (Table 2, Fig. 3c), such that the participants spent more time looking forward during the EV overtaking in the second event.

Among the drivers who were introduced to the EVA system, there was a significant difference depending on whether they received the EVA warning or not (Table 2, Fig. 3d). The drivers who were introduced to and received the EVA warning spent more time looking forward ($M = 82.22\%$, $SE = 2.05\%$) than the drivers who were introduced but did not receive the EVA warning ($M = 75.0\%$, $SE = 2.11\%$).

3.2.2. Mirror

The 2 (Event) × 6 (Time) × 2 (Warning) × 2 (Introduction) split-plot factorial ANOVA indicated a significant main effect for Warning (Table 3), suggesting that drivers who received an EVA warning had an overall larger proportion of mirror time ($M = 9.75\%$, $SE = 0.74\%$) compared to drivers who did not receive an EVA warning ($M = 7.53\%$, $SE = 0.73\%$).

There was a significant main effect for Time (Table 3, Fig. 4a). Furthermore, Time × Warning resulted in a significant interaction effect (Table 3, Fig. 4b). It was indicated that 30–21 s before the EV overtaking, drivers who received an EVA warning spent more time looking in the mirrors ($M = 9.75\%$, $SE = 0.95\%$), compared to drivers who did not receive an EVA warning ($M = 4.14\%$, $SE = 0.76\%$).

Event × Time yielded a significant interaction, with significant differences between the different time slots in both events (Table 3, Fig. 4c). There was a significant decrease in mirror time from the first to the second event 20–11 s before the EV overtaking (Event 1: $M = 13.46\%$, $SE = 1.1\%$; Event 2: $M = 11.19\%$, $SE = 1.01\%$) and 0–9 s after the EV overtaking (Event 1: $M = 11.7\%$, $SE = 1.04\%$; Event 2:

Table 2
ANOVA eye tracking Forward analysis.

Forward	*df*	*F*	*p*	η_p^2
Within-Subjects Effects				
Event	1	7.14	0.01*	0.11
Event * Warning	1	4.98	0.03*	0.08
Event * Introduction	1	1.51	0.23	
Event * Warning * Introduction	1	0.01	0.94	
Error (Event)	60			
Time	4.26	31.23	< 0.001**	0.34
Time * Warning	4.26	2.38	0.04*	0.04
Time * Introduction	4.26	0.32	0.9	
Time * Warning * Introduction	4.26	1.22	0.3	
Error (Time)	255.4			
Event * Time	4.39	6.63	< 0.001**	0.19
Event * Time * Warning	4.39	1.06	0.38	
Event * Time * Introduction	4.39	0.75	0.57	
Event * Time * Warning * Introduction	4.39	0.25	0.92	
Error (Event * Time)	263.3			
Between-Subjects effects				
Warning	1	1.01	0.32	
Introduction	1	3.96	0.051	
Warning * Introduction	1	6.35	0.01*	0.10
Error	60			

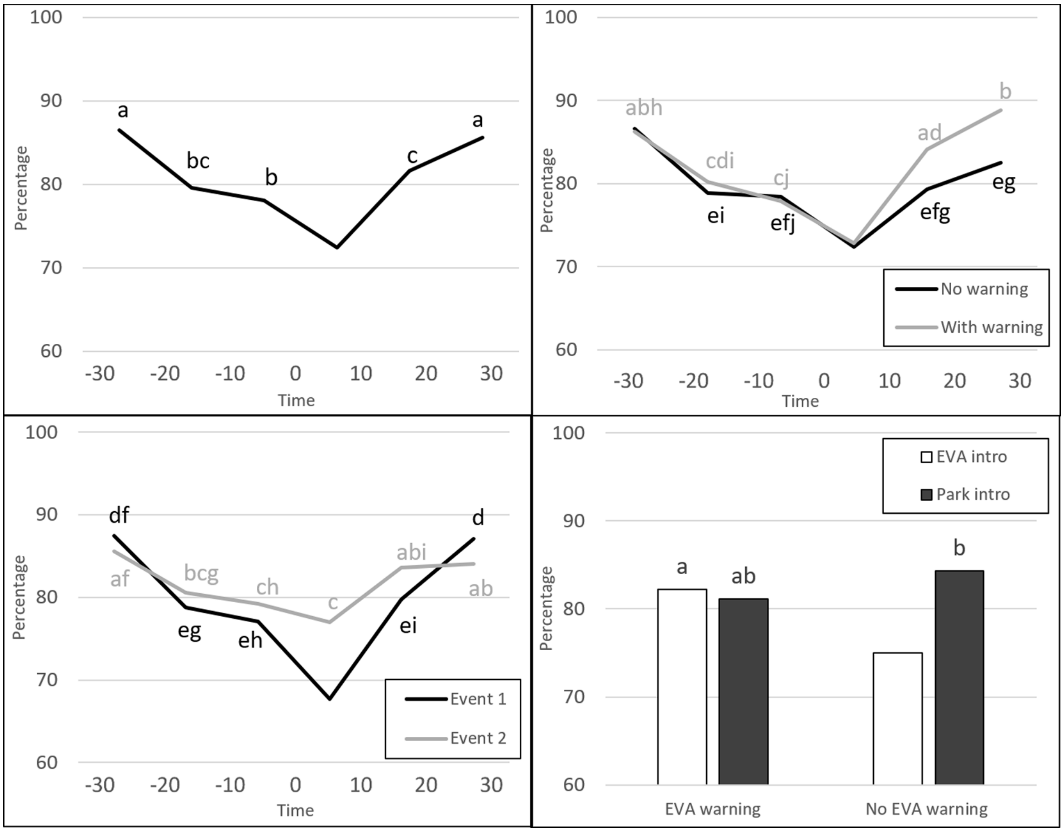

Fig. 3. Data points not sharing a letter are significantly different, whereas those sharing letters are not. Plots of the percentage of time (Y-axis) spent looking at the AOI *Forward.* In Fig. 3a (top left), *3b* (top right), and *3c* (bottom left) the X-axis displays 30 s before to 29 s after the EV overtaking the participant's vehicle. Fig. 3a displays the effect of time. Fig. 3b shows the effect of time and warning. Fig. 3c displays the effect of event and time. Fig. 3d (bottom right) illustrates the effect of introduction and warning.

Table 3
ANOVA eye tracking Mirror analysis.

	df	*F*	*p*	η_p^2
Within-Subjects Effects				
Event	1	1.66	0.23	
Event * Warning	1	5.64	0.02*	0.08
Event * Introduction	1	1.65	0.20	
Event * Warning * Introduction	1	0.01	0.94	
Error (Event)	65			
Time	4.2	20.30	< 0.001**	0.24
Time * Warning	4.2	2.96	0.02*	0.04
Time * Introduction	4.2	0.87	0.50	
Time * Warning * Introduction	4.2	0.63	0.67	
Error (Time)	272.9			
Event * Time	4.7	3.19	0.01*	0.05
Event * Time * Warning	4.7	0.60	0.68	
Event * Time * Introduction	4.7	0.91	0.47	
Event * Time * Warning * Introduction	4.7	0.60	0.68	
Error (Event * Time)	290.4			
Between-Subjects Effects				
Warning	1	4.53	0.04*	0.06
Introduction	1	1.92	0.17	
Warning * Introduction	1	0.43	0.51	
Error	65			

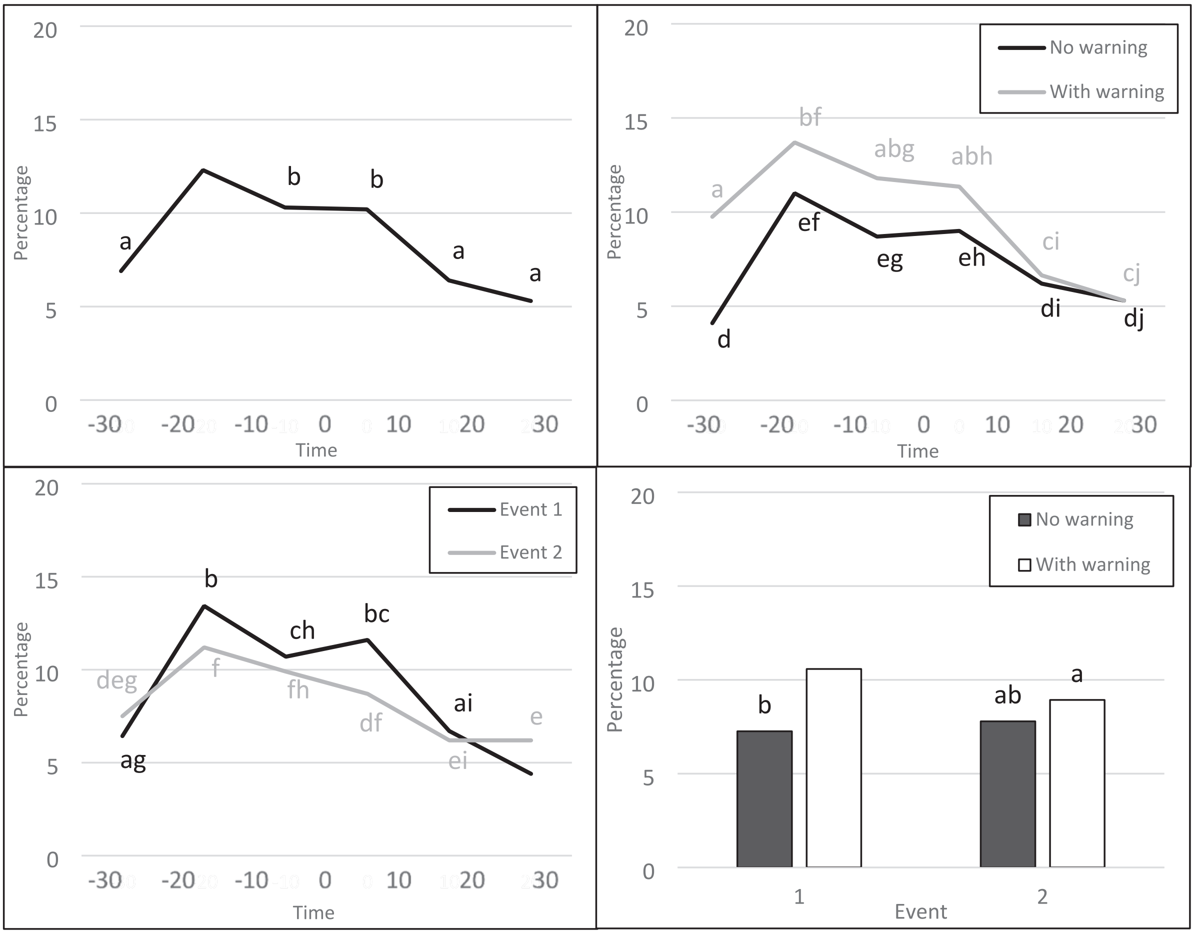

Fig. 4. Data points not sharing a letter are significantly different, whereas those sharing letters are not. Plots of the percentage of time (Y-axis) spent looking at the AOI *Mirror*. The X-axis displays 30 s before to 29 s after the EV overtaking the participant's vehicle. Fig. 4a (top left) displays the effect of time. Fig. 4b (top right) shows the effect of time and warning. Fig. 4c (bottom left) displays the effect of event and time. Fig. 4d (bottom right) displays the effect of event and warning.

$M = 8.95\%$, $SE = 0.95\%$). There was also a significant interaction effect of Event × Warning (Table 3, Fig. 4d), such that in the first event, drivers who received an EVA warning spent significantly more time looking in mirrors ($M = 10.6\%$, $SE = 0.78\%$) compared to drivers who did not receive an EVA warning ($M = 7.26\%$, $SE = 0.77\%$). Furthermore, there was a significant decrease in mirror time between the first ($M = 10.6\%$, $SE = 0.78\%$) and second ($M = 8.93\%$, $SE = 0.85\%$) event for drivers who received the EVA warning.

3.2.3. *Dashboard*

The 2 (Event) × 6 (Time) × 2 (Warning) × 2 (Introduction) split-plot factorial ANOVA indicated a significant main effect for Event (Table 4). The drivers spent more time looking at the dashboard in the first event than the second (Event 1: $M = 3.93\%$, $SE = 0.33\%$; Event 2: $M = 2.84\%$, $SE = 0.28\%$). There was a significant main effect of Time (Table 4, Fig. 5a), suggesting that the time participants spent looking at the dashboards varied during the events. There was an increase in dashboard time around the time of the EV overtaking (Fig. 5a). Furthermore, there was a significant interaction between Time × Warning which indicated a larger proportion of dashboard time for drivers who received an EVA warning, compared to drivers who did not 10–1 s before the EV overtaking (EVA: $M = 5.24\%$, $SE = 0.7\%$; No EVA: $M = 3.01\%$, $SE = 0.68\%$) and 0–9 s after the EV overtaking (EVA: $M = 8.43\%$, $SE = 0.98\%$; No EVA: $M = 5.5\%$, $SE = 0.95\%$) (Table 4, Fig. 5b). When further examining the possible effects of Event × Time, it was shown that there was a significant decrease in dashboard time from the first to the second event 0–9 s after the EV overtaking (Event 1: $M = 9.48\%$, $SE = 1.17\%$; Event 2: $M = 4.54\%$, $SE = 0.65\%$) and 10–19 s after the EV overtaking (Event 1: $M = 4.54\%$, $SE = 0.58\%$; Event 2: $M = 2.44\%$, $SE = 0.46\%$) (Table 4, Fig. 5c).

4. Discussion

The present study aimed to examine eye gaze behavior when drivers receive information about EVA warnings, either through being

Table 4
ANOVA eye tracking Dashboard analysis.

	df	*F*	*p*	η_p^2
Within-Subjects Effects				
Event	1	10.25	0.001*	0.13
Event * Warning	1	0.002	0.96	
Event * Introduction	1	3.17	0.08	
Event * Warning * Introduction	1	1.35	0.25	
Error (Event)	66			
Time	3.03	26.96	< 0.001**	0.29
Time * Warning	3.03	3.20	0.02*	0.05
Time * Introduction	3.03	2.06	0.11	
Time * Warning * Introduction	3.03	2.30	0.08	
Error (Time)	199.8			
Event * Time	3.17	6.28	< 0.001**	0.09
Event * Time * Warning	3.17	2.21	0.08	
Event * Time * Introduction	3.17	0.57	0.65	
Event * Time * Warning * Introduction	3.17	1.22	0.30	
Error (Event * Time)	208.9			
Between-Subjects Effects				
Warning	1	3.04	0.09	
Introduction	1	0.42	0.52	
Warning * Introduction	1	0.39	0.54	
Error	66			

introduced to the warning system or by being given a warning without having any prior experience with EVA warnings.

In Lenné et al. (2008), it was found that drivers who received EVA warnings scanned their environment more. However, it was not specified in what areas the drivers scanned their environment. In this study, EVA warnings affected the drivers' eye gaze behavior, such that they looked earlier and more in mirrors which supports the hypothesis of the current study, suggesting that the EVA warning helped them discover the EV earlier than the drivers who did not receive an EVA warning. The results support this study's hypothesis that receiving an EVA warning would lead to quicker detection of the approaching EV. The increased scanning of mirrors if given an EVA warning is not aligned with previous research regarding increased task complexity and gaze behavior. However, previous studies that have found that tasks decrease scanning of mirrors and dashboards have included tasks that are secondary to the driving task such as solving math problems (Harbluk et al., 2007), remembering numbers, or detecting arrows pointing in the wrong direction (Victor et al., 2005). In this study, drivers had an increase in task complexity by receiving an EVA warning, which caused them to scan mirrors, and dashboards more. This effect could be because the EVA warning was primary to the driving task. Receiving an EVA warning and moving over might therefore not be considered a separate task in the same way as in Victor et al., (2005) or Harbluk et al., (2007), but rather a circumstance that requires a higher level of attention to the actual driving task.

Deniel et al. (2024) found that an increase in the level of automation decreased drivers scanning of dashboards. In this study, the participants drove with cruise control that would deactivate if they braked. They rarely altered their speed except if they needed to during the move-over maneuver. During the move over-maneuver they would disengage the cruise control and increase the proportion of time spent looking at the dashboards. This result is aligned with those in Deniel et al. (2024). The drivers who received an EVA warning spent a larger proportion of time scanning dashboards around the time of EV overtaking. One explanation could be that the EVA group was looking for visual information to match the audio-based EVA warning. However, in Ma et al. (2022), an opposite effect was seen. A decrease in dashboard scanning was observed when an audio-based warning for oncoming trains was distributed. The difference may be that the drivers in Ma et al. (2022) did not have to adjust their lateral position when reacting to the warning.

In this study, the drivers were approached by EVs two times. There were interaction effects of event and time for all AOIs. The drivers looked less forward and more into mirrors and dashboards in the first event. In addition, similar to the findings in Weibull et al. (2023), there was a change between EV events among the drivers who received EVA warnings. The drivers looked less in the mirrors and more forward between the first and second events, suggesting a familiarization effect. The eye gaze behavior of drivers without an EVA warning did not significantly change between the first and second events.

It was hypothesized that drivers who got an introduction to the EVA system and received an EVA warning would detect the EV earlier than drivers who received an EVA warning but did not get an EVA introduction. No such effect was seen in the eye gaze behavior. However, the drivers who were introduced to the EVA system looked through the windshield less, but only if they did not receive an EVA warning. It appears that the mismatch between the expectation and lack of EVA warning caused the participants to look at other places than the windshield. It was indicated in Harms et al. (2020), that drivers are not aware of the support systems they have in their vehicles, and this might lead to drivers not making use of the safety systems in their cars. However, this study suggests that there could be a negative impact on forward visual attention if a driver has false expectations of a warning system they do not have.

Previous studies have shown that EVA affects driver behavior (Lenné et al., 2008; Lidestam et al., 2020; Payre & Diels, 2020; Savolainen et al., 2010; Weibull et al., 2023). In the current study, there were no effects of warning, event, or introduction on the participant's move-over behavior. One reason might be due to the 46 out of 144 events that were removed from the analysis due to the participant not driving in the left-most lane when the EV was visible. This generated a loss in statistical power and is a limitation of this study. Future studies should examine the correlation between driving and eye gaze behavior in interactions with EVs.

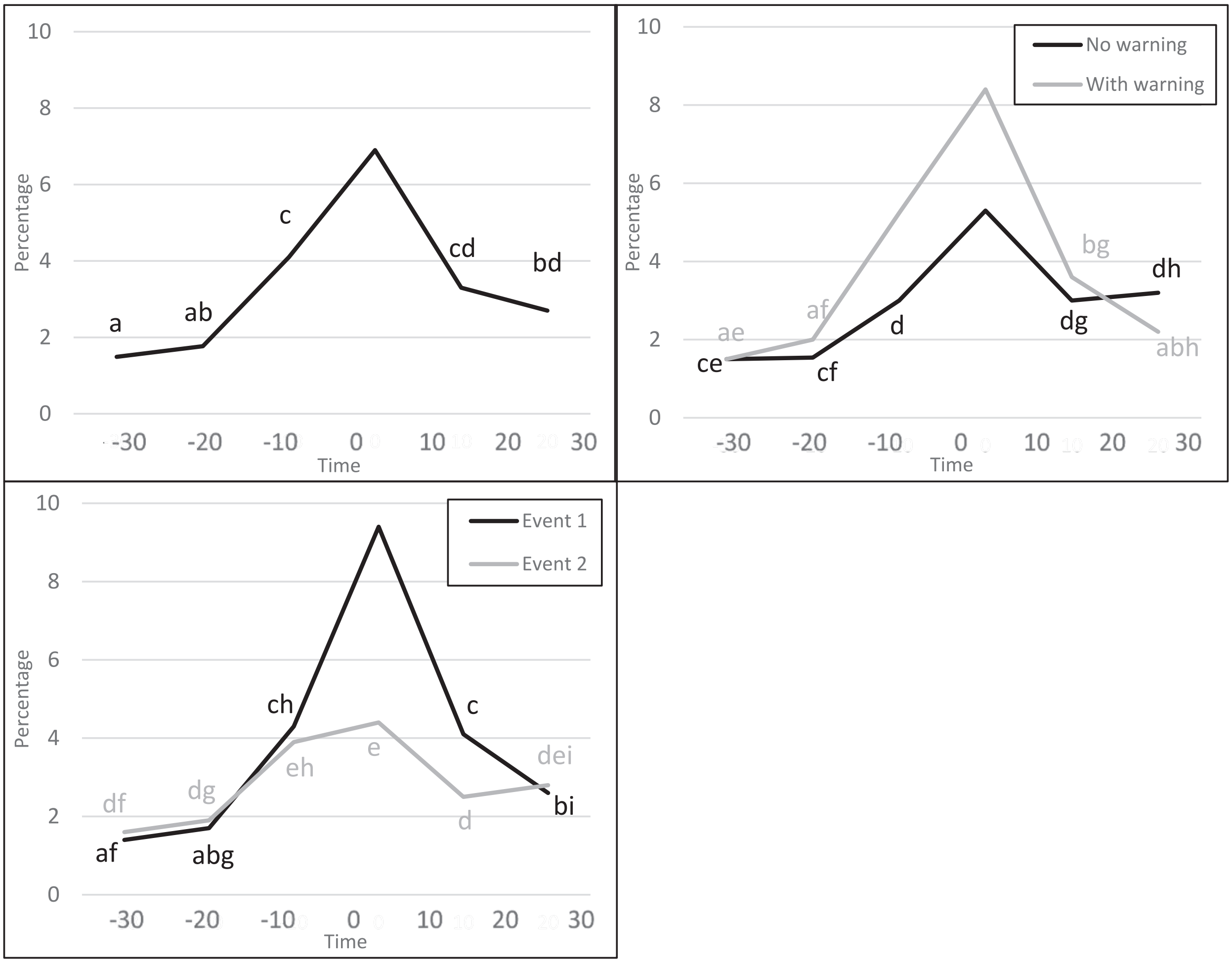

Fig. 5. Data points not sharing a letter are significantly different, whereas those sharing letters are not. Plots of the percentage of time (Y-axis) spent looking at the AOI *Dashboard.* The X-axis displays 30 s before to 29 s after the EV overtaking the participant's vehicle. Fig. 5a (top left) displays the effect of time. Fig. 5b (top right) shows the effect of time and warning. Fig. 5c (bottom left) displays the effect of event and time.

One constraint of the present study is the technical malfunction that led to 16 participants having to drive without the simulator's motion system activated. However, the participants who drove without motion were equally distributed over the four groups. Therefore, it should not affect the interpretation of the results of this study.

Another limitation of the current study is the use of the AOIs and eye gaze metrics. The method was chosen due to it being well-suited to answer the research questions of the current study. Furthermore, it has been used in previous relevant studies (Deniel et al., 2024; Ma et al., 2022). One limitation of using AOIs is the areas are predefined and hence constraints what data that can be extracted. However, the AOIs were considered satisfactory to fulfil the purpose of the current study.

The interaction between drivers of EVs and surrounding road users results in fatal collisions every year. This study further supports that EVA warnings can promote safer EV interactions for drivers. In addition, by noticing the EV earlier drivers can move over in time and decrease the risk for EV delays. Future studies should consider naturalistic data collection and alternative forms of driver introduction.

5. Conclusions

The results indicate that EVA warning promotes an earlier detection of EVs and that EVA does not impair drivers' scanning of their surroundings, but rather increases it. Half of the participants were introduced to the EVA system before driving in the simulator. The introduced drivers looked through the windshield less, but only if they did not receive an EVA warning. It appears that false expectation of a warning system affects drivers' gaze behavior.

No difference in move-over behavior was observed. This could however be due to many of the events being removed from the analysis due to not meeting the inclusion criteria of being in the left-most lane when the EV became visible.

CRediT authorship contribution statement

Kajsa Weibull: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Björn Lidestam:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Erik Prytz:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This research was supported by the Swedish Transport Administration (TRV 2020/25755), Nordic Way 3 (2018- EU-TM-0026-S) and SAFER (FP18). The funding sources did not affect the design, methodology, or analysis of data in the present study.

Data availability

Data will be made available on request.

References

Burke, C. S., Salas, E., & Peter Kincaid, J. (2001). Emergency vehicles that become accident statistics: Understanding and limiting accidents involving emergency vehicles. In *Proceedings of the Human Factors and Ergonomics Society* (pp. 508–512). https://doi.org/10.1177/154193120104500451

Deniel, J., Schnebelen, D., Reynaud, E., Ouimet, M. C., & Navarro, J. (2024). Driver 's gaze behaviour before, during and after take-over manoeuvres: Influence of agentivity associated with different automation solutions. Transportation Research Part F: Psychology and Behaviour, 100(December 2023), 181–196. DOI: 10.1016/j.trf.2023.11.019.

Harbluk, J. L., & Noy, Y. I. (2002). The impact of cognitive distraction on driver visual behaviour and vehicle control. In *Seventh International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design* (pp. 78–84).

Harbluk, J. L., Noy, Y. I., Trbovich, P. L., & Eizenman, M. (2007). An on-road assessment of cognitive distraction: Impacts on drivers' visual behavior and braking performance. *Accident Analysis and Prevention, 39*(2), 372–379. https://doi.org/10.1016/j.aap.2006.08.013

Harms, I. M., Bingen, L., & Steffens, J. (2020). Addressing the awareness gap: A combined survey and vehicle registration analysis to assess car owners' usage of ADAS in fleets. Transportation Research Part A: Policy and Practice, 134(December 2019), 65–77. DOI: 10.1016/j.tra.2020.01.018.

Hsiao, H., Chang, J., & Simeonov, P. (2018). Preventing emergency vehicle crashes: Status and challenges of human factors issues. *Human Factors, 60*(7), 1048–1072. https://doi.org/10.1177/0018720818786132

Lenné, M. G., Triggs, T. J., Mulvihill, C. M., Regan, M. A., & Corben, B. F. (2008). Detection of emergency vehicles: Driver responses to advance warning in a driving simulator. *Human Factors, 50*(1), 135–144. https://doi.org/10.1518/001872008X250557

Lidestam, B., Thorslund, B., Selander, H., Näsman, D., & Dahlman, J. (2020). In-car warnings of emergency vehicles approaching: effects on car drivers' propensity to give way. *Frontiers in Sustainable Cities, 2*(May), 1–9. https://doi.org/10.3389/frsc.2020.00019

Ma, S., Yan, X., Yang, J., & Liu, R. (2022). Influence of in-vehicle audio warning on drivers' eye-movement and behavior at flashing light-controlled grade crossings. *Human Factors*. https://doi.org/10.1177/00187208221115497

Missikpode, C., Peek-asa, C., Young, T., & Hamann, C. (2018). Does crash risk increase when emergency vehicles are driving with lights and sirens? *Accident Analysis and Prevention, 113*, 257–262. https://doi.org/10.1016/j.aap.2018.02.002

Payre, W., & Diels, C. (2020). I want to brake free : The e ff ect of connected vehicle features on driver behaviour , usability and acceptance. Applied Ergonomics, 82 (August 2019), 102932. DOI: 10.1016/j.apergo.2019.102932.

Saunders, G., & Gough, A. (2003). Emergency ambulances on the public highway linked with inconvenience and potential danger to road users. *Emergency Medicine Journal, 20*(3), 277–280. https://doi.org/10.1136/emj.20.3.277

Savolainen, P. T., Datta, T. K., Ghosh, I., & Gates, T. J. (2010). Effects of dynamically activated emergency vehicle warning sign on driver behavior at Urban intersections. *Transportation Research Record, 2149*, 77–83. https://doi.org/10.3141/2149-09

Victor, T. W., Harbluk, J. L., & Engström, J. A. (2005). Sensitivity of eye-movement measures to in-vehicle task difficulty. *Transportation Research Part F: Traffic Psychology and Behaviour, 8*(2 SPEC. ISS.), 167–190. https://doi.org/10.1016/j.trf.2005.04.014

Wang, X., & Xu, L. (2021). The factors underlying drivers' unwillingness to give way to ambulances: An application of an extended theory of planned behavior. *Journal of Transport and Health, 20*(January), Article 101000. https://doi.org/10.1016/j.jth.2020.101000

Weibull, K., Lidestam, B., & Prytz, E. (2023). False Alarm Effects in Early Warnings for Emergency Vehicles : Exploring. *Human Factors*, 1–10. https://doi.org/10.1177/00187208231216835

Wiwekananda, K. S. S., Hamukti, R. P., Yogananda, K. S. S., Calisto, K. E., & Utomo, P. S. (2020). Understanding factors of ambulance delay and crash to enhance ambulance efficiency: An integrative literature review. *Journal of Community Empowerment for Health, 3*(3), 213. https://doi.org/10.22146/jcoemph.57338

Xu, Q., Fu, R., Wu, F., Wang, B., & Chen, T. (2023). A speed limit advisory system provided by in-vehicle HMI considering auditory perception characteristics for connected environment. Transportation Research Part F: Traffic Psychology and Behaviour, 92(October 2022), 353–368. DOI: 10.1016/j.trf.2022.12.004.