Acta Polytechnica CTU Proceedings **51**:36–41, 2024
https://doi.org/10.14311/APP.2024.51.0036

AUGMENTED EMERGENCY LIGHTING AS A SOFT EARLY WARNING: MEASURES ON ROAD USERS WHEN MOVING OVER

Björn Lidestam[a,*], Philip Lindblad[a,b], Petr Ondomiši[a,c], Emilia Sörengård[a,b], Kajsa Weibull[a]

[a] *VTI (The Swedish National Road and Transport Research Institute), SE-581 95 Linköping, Sweden*
[b] *Linköping University, Department of Computer and Information Science, SE-581 83 Linköping, Sweden*
[c] *Linköping University, Department of Science and Technology, SE-601 74 Norrköping, Sweden*
[*] corresponding author: bjorn.lidestam@vti.se

Abstract. A novel interface to provide robust, intuitive, and timely alerts to road users to move over for emergency vehicles (EVs) was tested in a seven-minute driving-simulator experiment. The interface, Augmented Emergency Lighting (AEL), mimics emergency lighting on emergency vehicles (i.e., flashing blue light), by using the cars' interior lighting. AEL was initiated 30 seconds before an EV caught up and increased its brightness proportionally to the distance to the EV. The AEL alert was after 16 seconds accompanied by an Emergency Vehicle Approaching (EVA) alert, presented as a voice command and a text message on the dashboard. Comparisons were made between AEL+EVA alerts, EVA-only alerts, and no alerts, between groups ($N = 61$). Both AEL+EVA alerts and AEL-only alerts were highly successful in getting drivers to move over by slowing down and pulling off to the side as compared to when there were no alerts, but no significant difference between AEL+EVA and EVA-only was found. Questionnaire responses showed that AEL+EVA alerts were generally appreciated and that their timing was good. Further studies on learning effects and usability are discussed.

Keywords: Emergency driving, warning messages, alerts, soft warning messages, simulator study.

1. Introduction

Emergency Vehicle Approaching (EVA) messages are direct messages, presented within vehicles, to alert and instruct the driver to give way. Otherwise, traditionally, when emergency vehicles are on-call, what they have at their disposal to notify others to give way and warn other road users are sirens and flashing lights. This has restraints regarding its reachability [1]. However, the response time and arrival speed of the emergency vehicle play a critical role in determining the chances of survival for individuals in need. For instance, when an ambulance is transporting a person with severe blood loss to the hospital or in case of fire, a quick response is crucial.

One of the main factors contributing to the risk of road traffic accidents is primarily the high speed at which emergency vehicles are travelling when on-call [2]. It was discovered that most road users respond positively to emergency vehicles, but a notable portion struggle to handle the interaction [2]. On-call emergency driving at high speed is associated with a significantly increased accident rate [3].

Giving way to emergency vehicles on call is also of great importance. In a review of data from a paramedic division in Denver on emergency vehicle accidents and collisions [4], the importance of emergency vehicle drivers clearing intersections before entering was highlighted. It was concluded that visual and auditory warning systems should be used to alert other road users, ensuring that they yield for the emergency vehicle to pass without any issues. By giving way to emergency vehicles, it becomes possible for the drivers to reach their destination quickly, potentially saving lives. Moreover, giving way helps reduce the risk of accidents and dangerous situations, as emergency vehicles can move more safely and efficiently when other vehicles are out of the way [4]. Fatal and nonfatal crashes involving civilians and emergency vehicles have also been studied [5], with the conclusion that various factors contribute to crashes with emergency vehicles: *environmental* factors (e.g., sunlight affecting driver visibility) and *roadway* factors (e.g., visual obstructions caused by external objects). The most common violation among road users leading to crashes is the failure to give way. The failure to give way is attributed to road users' inability to visually detect approaching emergency vehicles, resulting in inappropriate driving that increases crashes and accidents [5]. Also, inexperienced drivers may detect approaching emergency vehicles on call but do not know *that* they are obliged to give way and *how* to do so [3].

In order for warning systems to be effective and efficient, they need to be perceived and used as intended by the design. Compliance with warning systems can sometimes be uncertain. A study on the perception of an alert system among university students and their attitudes toward its importance showed that following the prevention of a crisis at the university, the students' perspective of the warning system underwent a change [6]. The students admitted in retrospect that they had not taken the emergency alert system seriously at first, but after experiencing a campus lockdown, their overall perception of the system became more favourable. This suggests that the experience of an alert system can positively influence both the perception and effectiveness of the system [6].

The optimal, or most efficient, time span for an EVA message to be emitted before the emergency vehicle catches up has not yet been determined. In a previous study on EVA messages, the message was sent out 14 seconds before the ambulance was estimated to pass the participant with instructions regarding slowing down and giving way for an approaching ambulance on call [3]. The message was presented via text on an instrument cluster and with sound where a male voice said "Warning! Emergency vehicle approaching! Please give way!". On the instrument cluster, a yellow triangle was presented as a warning sign with similar text. The EVA alert was crucial in influencing the participants' ability to give way for the ambulance [3, 7]. Additionally, the use of warnings showed the potential to reduce collision risks and minimize the driving time of emergency vehicles [7].

An Augmented Emergency Lighting (AEL) is a warning that is displayed via the interior lighting of a car, mimicking the emergency lighting mounted on emergency vehicles. This technology can be used in combination with an EVA message where the flashing of lights increases, proportionally to the distance, inside the car as the emergency vehicle approaches the road user, making it a "soft" warning. The flashing of lights is, thus, the most intense as the emergency vehicle passes by the road user and when it has passed the flashing of lights stops. This can be used in combination with EVA alerts presented as a voice and a text explaining that an emergency vehicle is approaching and there is a need to slow down and give way. This should then, theoretically, mean that the emergency vehicle on call signals its approach both via robust-and-early signals of what should be the learned-and-intuitive medium of presentation (i.e., seeing approaching flashing blue lights), and also giving direct instructions on how to act. That is, AEL plus EVA alerts should mean that the emergency vehicle on call is first robustly detected and that the driver receives instructions on what to do.

In [3], the warning could be seen as a direct warning since it was given 14 seconds before the ambulance caught up. There is little research on when exactly it is most suitable for a road user to be notified that an emergency vehicle is approaching. However, research over several decades confirms the influence of warning timing on performance [8]. When the time between cue and target presentation is not perfect, it can create a temporal conflict that causes delays in response due to limitations in resource and information processing [9]. On the other hand, if a warning is issued too early and the cause is not perceived, drivers may ignore it, whereas a warning that comes too late will be ineffective [10]. The effects of an advanced warning or a "soft" alert impacts on drivers when interacting with emergency vehicles was studied in [11], where a positive result was observed as the speed reduction was linked to a decrease in injury severity. This highlights the significance of the relationship between impact speed and injury. The cause for this decrease in speed was found to be response priming [11]. The finding could be applicable in other settings where an alert is presented before a perceived threat, as response priming or a soft alert may provide safety benefits.

A soft alert in this context is a warning that is given earlier, for instance about 30 seconds before the emergency vehicle passes by. The AEL increases its intensity as the emergency vehicle approaches, mimicking the increase in intensity proportional to distance.

The aim of the present study was to answer the following two research questions. Firstly, does an early AEL alert for approaching emergency vehicles add benefits when preceding an EVA message? Secondly, how is the AEL experienced by drivers?

2. Materials and methods

2.1. Participants

The study initially had 62 participants, but due to one participant being unable to continue with the simulation, the final sample size was $N = 61$ participants ($n = 44$ men, $n = 17$ women, aged 29–80 years, $M = 58$ years 4 months, $SD = 12$ years 11 months). Participants were randomized to the baseline (control group), EVA, or AEL+EVA groups, respectively. They had had their driver's licenses for 11–62 years ($M = 39$ years 10 months). Regarding driving frequency, 61 % reported driving daily, while 34 % reported driving most days a week. Ten of the participants were professional drivers of buses, trucks, or emergency vehicles as part of their job.

Inclusion criteria were (1) having had their driver's license for ten or more years (category B in Sweden) and (2) having driven more than 15 000 km per year on average. Note: for purposes of another study, the effect of EVA messages on experienced drivers was compared to [3], where most of the participants were new inexperienced drivers.

2.2. Materials

The same simulator, stimuli, and procedure as in [3] were used, albeit with an upgrade of the graphics [12]. The participants were sitting in a chair resembling a real car, with a 43-inch TV monitor placed 95 cm in front of them and a refresh rate of 60 Hz. In addition to the 43-inch front monitor, two 55-inch monitors were used to extend the field of view. They were placed at a 45° angle from the front monitor at each side, resulting in about 180° field of view horizontally.

After the driving scenario in the simulator, the participants filled out a questionnaire regarding their

Measure	Control			EVA-only			AEL+EVA		
	n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Distance, > 3 m right	–	–	–	16	27.78	13.01	13	36.02	16.08
Speed (kph)	21	80.86	5.43	20	61.74	20.67	20	56.07	22.45
Lateral position (m)	21	1.96	0.40	20	2.94	0.84	20	2.86	0.78

TABLE 1. Descriptive statistics for the control and experimental groups.

experiences of the driving scenario, whether or not they noticed the ambulance before it passed them, experiences and attitudes regarding the alerts (for those in the experimental groups), and how they had learned how to behave when emergency vehicles on call are approaching (see Appendix A).

2.3. Procedure and specifications

The test took about seven minutes to complete. The participants were driving on a narrow road that was 0.75 meters wide, parking pockets appeared about 1 000 meters apart. The road the participant was driving on consisted of hills and vegetation as close as 1.75 meters to the roadside. The purpose of this was so that the ambulance was not easily seen by the participant. Meeting cars appeared every 20 seconds and at 2 200 meters from the start, a car appeared in front of the participant's car. At this point, a car and a van were 180 and 150 meters behind the participant. An ambulance then caught up with the driver at 3 250 meters and the cars behind the participants were supposed to give way when the ambulance was about 40 meters behind them.

Sounds from the environment outside were presented, this included the sounds of driving and the sirens from the approaching ambulance. Music at 80 dB was also played during the scenario and the reason for these distractions was to make it difficult for the participant to detect and hear the ambulance.

The AEL consisted of flashing lights that appeared 30 seconds before the ambulance caught up, with an increase in intensity proportional to distance. Then, an EVA message was presented as a yellow triangle with a blue alert light and a text message stating "Emergency vehicle approaching!" "Pay attention!", 14 seconds before the ambulance caught up. At that point, the radio also changed to a male voice saying "Warning! Emergency vehicle! Please give way!". The AEL was then toned down quickly after the ambulance took over. For the baseline group, there was no alert, but the same scenario played out.

2.4. Design

The design was between groups. Participants were randomized into either of three groups. There was one *Control* group, which received neither AEL nor EVA alert; and two experimental groups, namely the *EVA-only* group, which received an EVA message 14 seconds before the ambulance caught up; and the *AEL+EVA* group, which first received AEL 30 seconds before the ambulance caught up, followed by the EVA message 14 seconds before the ambulance caught up. All groups received a questionnaire after the simulation was completed to evaluate the AEL, the EVA message, and timing aspects.

To determine the effects of AEL and EVA, respectively, three dependent variables were measured. The first one was the distance to the ambulance when giving way by exceeding 3 meters to the right of the road centre line. The second dependent variable was the speed of the participant at the time the ambulance passed by. The third dependent variable was the lateral distance to the ambulance when it passed. The independent variable was group (i.e., Control; EVA-only; AEL+EVA).

3. Results

Mean differences between the three groups were tested by means of ANOVA and t tests to test the effects of EVA-only and AEL+EVA. However, a first and striking result was that *none* of the participants in the Control group (i.e., 0/21, $R = 3.0$) gave way, which resulted in a significantly heterogeneous distribution, χ^2 (1, $N = 61$) = 29.92, $p < .001$, since the majority of participants in the EVA-only and AEL+EVA groups did give way (16/20 and 13/20, respectively).

Regarding longitudinal distance when giving way by moving more than 3 meters to the right of the road centre line, both the EVA-only and the AEL+EVA did so, whereas the Control group (who received no alert) did not, see Table 1. No inferential statistics could therefore be calculated for the longitudinal distance for the Control group. The two experimental groups did not differ with regard to distance, $t(27) = 1.53$, *ns*, see Table 1.

Concerning speed when being taken over by the ambulance, the experimental groups drove slower, $F(2, 58) = 11.04$, MSE = 315.24, $p < .001$, $\eta^2 = 0.28$. Both experimental groups drove slower than the Control group ($p < .01$), but did not differ from each other.

The lateral position was also affected by the alerts, such that drivers who received EVA-only and AEL+EVA alerts moved farther to the right, $F(2, 58) = 12.54$, MSE = 0.48, $p < .001$, $\eta^2 = 0.30$. Both experimental groups moved farther to the right than the Control group ($p < .001$) but did not differ from each other.

In order to further test the effects of the alerts, separate analyses were made on those participants who successfully gave way by moving more than 3 meters

Measure	Control			EVA-only			AEL+EVA		
	n	M	SD	n	M	SD	n	M	SD
Speed (kph)	–	–	–	16	66.96	12.55	13	56.05	22.09
Lateral position (m)	–	–	–	16	3.16	0.75	13	3.15	0.73

TABLE 2. Descriptive statistics for only those participants who gave way by moving more than 3 m from the road center.

to the right of the road center line, see Table 2. Since no participant in the Control group exceeded 3 meters, t tests were used to compare the experimental groups. No significant difference between EVA-only and AEL+EVA was found, however. For longitudinal distance, see above and Table 1. Speed did not differ, $t(18.12) = 1.59$, ns; nor did lateral position, $t(27) = 0.04$, ns, see Table 2.

Regarding how the AEL message with a soft warning was experienced by the AEL+EVA group, the mean rating of the alert, on a scale of 0–100, was $M = 77.5$. With regard to the timing of the alert, 55 percent wanted an earlier alert, 40 percent did not want any change regarding the timing of the alert, whereas only 5 percent wanted a later alert. However, only 25 percent wanted blue LED lights as an alert and 55 percent responded that they wanted the information displayed on the instrument panel.

4. Discussion

Alerts presented as AEL and EVA were successful with regard to prompting drivers to give way – no participant in the Control group managed to give way by exceeding 3 m to the right of the road center line, whereas the majority of the participants in the experimental groups did. This is a very strong result, and also surprising, since the participants were experienced as compared to the majority of participants in [3]. This shows that alerts presented as EVA and AEL have strong effects even though the drivers have driving experience and therefore should be proficient at noticing emergency vehicles on call, and to know how what to do.

The present study as well as [3] shows that in-vehicle alerts greatly improve alertness and driving behaviour to approaching emergency vehicles on call. Giving way is one of the most important aspects for reducing the number of accidents [4]. Road users who find the interaction with approaching emergency vehicles difficult [2] could therefore be helped by AEL and EVA alerts, by being alerted and instructed on giving way.

The present study did *not* show that AEL provides added benefits when preceding an EVA message, however, as there was no statistically significant effect. It is possible that the statistical power was too low to detect a possible relatively small effect size (in the present study the nonsignificant Cohen's $d \approx .57$ for longitudinal distance when giving way), so further studies are encouraged. Furthermore, the effect of AEL alone should be studied, to compare its effect in comparison to no in-vehicle alert, and to EVA messages. It can be assumed that since AEL alone does not provide instruction on what to do, the effect should be stronger for experienced drivers as compared to novice drivers.

Regarding how drivers experience AEL, the majority liked the in-vehicle alerts with AEL included, and 25 percent responded that they wanted AEL in their alerts. Regarding the importance of timing and how it affects performance as described by [8], participants liked the timing of the alert or wanted it earlier. The results thus suggest that an alert at least 14 seconds before the emergency vehicle passes is preferred, but too early warnings may cause some road users to ignore or forget them [10].

Attitudes toward a warning system can change after people have experienced the alert; experiencing the alert can positively change the perception and possibly the efficiency of it [6]. Some participants in the present study reacted more positively to the AEL alert when it was explained, after driving and filling out the questionnaire. It is possible that the efficiency of and positive attitude toward AEL increase once the users have experienced and found out how the AEL works.

5. Conclusions

Alerts presented as AEL and EVA were highly successful with regard to prompting drivers to give way: an AEL alert combined with an EVA message effectively alerts the road user that an emergency vehicle is approaching and instructs them to give way. The AEL alert preceding the EVA message was also well appreciated. However, there was no significant effect when comparing AEL+EVA to the EVA-only alerts, the stand-alone effect of AEL remains to be studied. Most participants wanted no change in the timing of alerts or wanted it earlier.

References

[1] K. Catchpole, D. Mckeown. A framework for the design of ambulance sirens. *Ergonomics* **50**(8):1287–1301, 2007. https://doi.org/10.1080/00140130701318780

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

[3] B. Lidestam, B. Thorslund, H. Selander, et al. In-car warnings of emergency vehicles approaching: Effects on

car drivers' propensity to give way. *Frontiers in Sustainable Cities* **2**(19), 2020. https://doi.org/10.3389/frsc.2020.00019

[4] C. B. Custalow, C. S. Gravitz. Emergency medical vehicle collisions and potential for preventive intervention. *Prehospital Emergency Care* **8**(2):175–184, 2004. https://doi.org/10.1016/S1090-3127(03)00279-X

[5] C. Drucker, S. G. Gerberich, M. P. Manser, et al. Factors associated with civilian drivers involved in crashes with emergency vehicles. *Accident Analysis & Prevention* **55**:116–123, 2013. https://doi.org/10.1016/j.aap.2013.02.035

[6] D. E. Kopel, V. K. Sims, M. G. Chin. Taking emergency warnings seriously. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* **58**(1):1129–1133, 2014. https://doi.org/10.1177/1541931214581236

[7] T. Kunclová. *Application of geofence for safe interaction with emergency vehicles.* Master's thesis, Linköping University, Department of Science and Technology, 2022. LIU-ITN-TEK-A–22/019–SE, Transport Systems Engineering.

[8] M. I. Posner, R. Klein, J. Summers, S. Buggie. On the selection of signals. *Memory & Cognition* **1**:2–12, 1973. https://doi.org/10.3758/BF03198062

[9] T. J. Triggs. *Capacity sharing and speeded reactions to successive signals.* University of Michigan, Ann Arbor, 1968.

[10] J. D. Lee, D. V. McGehee, T. L. Brown, M. L. Reyes. Collision warning timing, driver distraction, and driver response to imminent rear-end collisions in a high-fidelity driving simulator. *Human Factors* **44**(2):314–334, 2002. https://doi.org/10.1518/0018720024497844

[11] M. G. Lenné, T. J. Triggs, C. M. Mulvihill, et al. Detection of emergency vehicles: Driver responses to advance warning in a driving simulator. *Human Factors* **50**(1):135–144, 2008. https://doi.org/10.1518/001872008X250557

[12] Epic Games. Unreal engine, 2023. [2023-09-16]. https://www.unrealengine.com/en-US

A. Appendix – Post-experiment questionnaire

* Questions that all three groups were presented with
- Questions presented only to the experiment groups (i.e., not Control)

- How did you feel about the warning?

0–100 (did not like at all – liked very much)

- What do you think about the timing of the warning?

☐ I want it earlier
☐ I want it later
☐ no change

- How would you like to receive the warning? (Select all that apply)

☐ message on the dashboard
☐ message on the car's central screen
☐ blue lights in the car
☐ message on a head-up display (windscreen)

* Did you notice the ambulance before it passed?
☐ yes
☐ no

* Did you know what to do when the ambulance approached?
☐ yes
☐ no

* Where did you learn what to do when an emergency vehicle approaches? (choose one)
☐ driving school
☐ observed how others do it
☐ was told by someone
☐ I never got the information
☐ other: ________

- What did you like about the warning? ________

- What did you not like about the warning? ________

* What is your general reaction when an emergency vehicle approaches? (Select all that apply)
☐ I get stressed
☐ I reduce speed
☐ I lower the volume of the radio
☐ I become more aware of my own driving
☐ I adapt to others in the traffic
☐ I wait until the emergency vehicle is very close before I give way
☐ I try to give way immediately regardless of the distance to the emergency vehicle
☐ I try to give way, even if it violates normal traffic rules
☐ I do not know how to act in such a situation