

The effect of ambient lighting combined with Emergency Vehicle Approaching warning on driver reaction

Effekten av omgivande belysning i kombination med Emergency Vehicle Approaching-varning på förarens reaktion

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The effect of ambient lighting combined with Emergency Vehicle Approaching warning on driver reaction

Vliv ambientního osvětlení v kombinaci s EVA varováním na reakci řidiče

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- Driving simulator experiment, testing various preemptive warnings
- Gathering relevant data from the experiment
- Analysis of data gathered from the experiment
- Discussion of the results



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Abstract

Emergency vehicles face increased traffic risk because of their exemptions from traffic laws when responding to an emergency site. Some exemptions are the possibility of exceeding the speed limit, running a red light, or generally driving in a way that could be considered reckless. As a result, incidents with emergency vehicles can lead to delays in their response time and further complications. To prevent such situations, a warning message delivered to drivers of mainly passenger cars could change their behaviour, leading to a safer and better reaction. The present thesis aimed to analyse whether the usage of the EVA (Emergency Vehicle Approaching) warning message and the EVA warning message augmented with ambient lighting could have these effects on drivers of passenger cars.

To investigate whether this hypothesis is true, a driving simulator experiment was conducted with a total of $n = 60$ participants using the same scenario with three different Scenario Variations representing different levels of the warning. Apart from the driving simulator experiment, all participants also filled out one questionnaire about their background before and one about their experience in the simulator after the experiment. The scenario was a rural road with music playing through the speakers to make it more difficult to hear and spot the emergency vehicle in advance. The results demonstrated a statistically significant difference in driver behaviour between the group with no warning and the two groups with either the EVA message or the EVA message with the AEL (Augmented Emergency Lighting) by utilising interior ambient lighting. However, no statistically significant difference was found between the two groups who received the warning. Overall, the participants had a positive attitude towards this technology. Although, further research on the effectiveness of ambient lighting is necessary.

Keywords: Ambient lighting, EVA warning message, emergency vehicle, driving simulator experiment, driver behaviour

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List of Abbreviations

3GPP	Third Generation Partnership Project's
ABS	Anti-lock Braking System
AEL	Augmented Emergency Lighting
ANOVA	Analysis Of Variance
DSRC	Dedicated Short Range Communication
EVA	Emergency Vehicle Approaching
EVW	Emergency Vehicle Warning
HMD	Head-Mounted Display
HMI	Human-Machine Interface/Interaction
HSD	Honestly Significant Difference
HUD	Head-Up Display
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transport Systems
LED	Light-Emitting Diode
LTE	Long-Term Evolution
M	Mean
OBU	On-Board Unit
RPM	Revolutions Per Minute
RSU	Road Side Unit
SE	Standard Error
SD	Standard Deviation
SPL	Sound Pressure Level
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VR	Virtual Reality



1 Introduction

Emergency vehicles, as such, are a particular type of road vehicle with the sole purpose of helping in accidents that occur both on and off the road. This group of vehicles can be further classified into, however not only, three main groups on which this thesis is focused – the police, the ambulance, and the fire department. To fulfil their role, emergency vehicles need to get to the accident site safely and in the shortest time possible to provide adequate help. This is achieved by several exemptions from regular traffic rules, such as exceeding the speed limit, using dedicated lanes, or going through an intersection violating a red light. But these exemptions can also lead to an increased level of stress for other drivers on the road, as well as drivers of the emergency vehicles, which can then lead to accidents involving emergency vehicles (Weibull et al., 2023). A warning system is equipped on the emergency vehicles to warn other drivers about their approach to prevent these situations. This system combines audio and visual warnings through sirens and emergency lights. However, even when these systems are in place and used, they can only reduce the chance of an accident, not entirely prevent them (Catchpole et al., 2007). This is because there are still situations when the driver can be distracted by, for example, the radio, passengers in the car, the sound of the sirens can bounce from buildings in the surrounding area, not be heard in time, lights could glare off of other vehicles, windows and further disorient the driver rather than warn him. The latter two options are mostly prevalent in cities, where roads tend to be in the vicinity of buildings and cars are closer to one another (Tippannavar et al., 2023). Apart from these distractions, other situations, like the emergency vehicle driver making an unexpected manoeuvre, can also disorient the driver and make the situation more stressful.

Collisions between emergency vehicles and other traffic users are a common problem around the world (Boldt et al., 2021; NHTSA, 2011). Since emergency vehicles can travel faster than the speed limit in an emergency, the consequences of these collisions tend to be even worse than collisions to which the emergency vehicles are responding. Suppose a collision happens when the emergency vehicle is responding. In that case, another emergency vehicle must be dispatched to the original emergency and probably another emergency vehicle to the accident involving the crashed emergency vehicle. This significantly prolongs the response time and, therefore, can more likely cause a loss of life. According to a study on selected European countries by Boldt et al. (2021), using publicly available data from 2014 to 2019, more than 50% of registered accidents involving ambulances resulted in a fatality of other road users, approximately 30% of these accidents resulted in a fatality of the transported

patient and approximately 13% of these accidents resulted in a fatality of a staff member of the ambulance. The countries providing data for this study were Germany, Austria, and Switzerland, from which there were 597, 62, and 25 accidents, respectively. Another study done by N. S. Council (2023) reported that in the USA, there were 198 fatalities due to a crash with an emergency vehicle in 2021. This number has steadily increased for the last five years, slightly levelling in 2021. A further study done by Watanabe et al. (2019) also discovered that there is an increased probability of risk when an ambulance is operating with sirens and lights activated. The crash rate is 4,6 per 100 000 responses with no sirens and lights and 5,4 per 100 000 responses when both are engaged. A further increase is then visible based on whether the ambulance is transporting a victim. There, the crash rates are 7 per 100 000 responses with a victim and no sirens and lights and 17,1 per 100 000 responses with a victim and both systems engaged.

The number of accidents involving emergency vehicles can be decreased by utilising modern technologies from the field of HMI (Human-machine Interface/Interaction) and ITS (Intelligent Transport Systems) (E. T. S. Council, 1999). These technologies can help drivers better understand when and, in the future, possibly even from where the emergency vehicle is approaching so they can react faster and more safely. Currently, drivers are expected to be vigilant and observant enough to spot the lights and hear the sirens of an approaching emergency vehicle. However, utilising technologies that deliver the warnings via an HMI has an advantage over the current state. Using the HMI, a driver would receive the warning directly in the vehicle's cabin, increasing the likelihood that the driver would register it and respond appropriately. This is because the warning is delivered instantly and prominently, making the driver more aware of the EV's presence. Ideally, this could lead to a situation when the emergency vehicle does not need to slow down since all the drivers were alerted in advance and had time to react accordingly, be it by creating a path for the emergency vehicle or just by stopping on the side of the road. An example of such technology can be a variable message sign or in-vehicle warning system. One example of this system is the use of EVA warning messages, which is being tested on multiple sites across Europe. Tests and evaluations of EVA include how to present the warning to the drivers to get the best response. One possibility of how to improve the warning is if an EVA warning message combined with AEL utilising a car's ambient lighting can further improve the driver reaction compared to only the EVA warning message.

1.1 Aim and Research Questions

This thesis aims to investigate if and how ambient lighting can improve the response of drivers presented with situations when they need to interact with an emergency vehicle. Drivers are used to receiving warnings in the vehicle cabin via various means, for example, by instrument cluster or via an information screen. The ambient lighting in the car was not yet used in such a manner. The ambient lighting is used in the study as a means to "prime" the driver for the situation. This thesis is intended to answer the following research questions:

1. Can ambient lighting, combined with EVA warning, help drivers react faster and safer when an emergency vehicle is approaching?
2. Can the EVA warning with ambient lighting increase the safety of the encounter with the emergency vehicle on the road compared to the current situation with no warnings?
3. How do the drivers feel about augmenting the EVA warning with the LED lights and their subjective reactions?

1.2 Methodology

The data for this thesis were obtained via a driving simulator experiment with experienced drivers (drivers who have had their driver's licence for at least ten years and drive at least 15 000 kilometres per year) and a short questionnaire to understand their background better. This study is conceived as a continuation of previous research by Björn Lidestam, with the difference being the target group (previously, targeting the younger generation with no emphasis on their driving experience or skill). In total, one scenario with three different Scenario Variations was created and then analysed:

- Scenario Variation 0 - Baseline group: no in-vehicle warning at all, only sirens and blue lights from the ambulance
- Scenario Variation 1 - EVA group: the driver gets an early warning about an emergency vehicle approaching via a message in the instrument cluster and a voice-over
- Scenario Variation 2 - EVA + AEL group: the driver gets an additional warning before the EVA message in the form of a blue flashing light; the light is placed where a door ambient lighting strip would be in a real car; this should put the driver into a state of heightened reflexes and thus make them react quicker and safer

Twenty participants ran each Scenario Variation without giving them any prior explanation about what type of study was being done. Each participant was instructed to drive as if in a rush but simultaneously adhere to the traffic laws. Data collected from this experiment were then analysed to fulfil the aim of this thesis:

- Questionnaire before the experiment – the data from the survey provided a better understanding of the drivers in general
- Experiment part – data from the experiment are intended to address the specific differences between the drivers from the three distinct groups
- Questionnaire after the experiment – data from this part were used to assess whether the drivers felt any difference compared to their normal experience with emergency vehicles

The data obtained from the experiment was analysed to answer the stated research questions. For this, various metrics were recorded during the experiment, such as the speed of both the vehicle and the emergency vehicle, their position relative to the centre of the road, and steering angle.

1.3 Delimitations

The thesis focuses primarily on visual warning in the instrument cluster with auditory enhancements and visual warning realised by utilising ambient lighting of a vehicle. Although the current thesis uses only an ambulance as the emergency vehicle in the simulation scenario, this system could be adapted to give warning about any other emergency vehicle. The design of these warnings was not the primary focus of this thesis. In the case of the EVA warning, the same design as in the study done by Lidestam et al. (2020) was used, and the warning utilising the ambient lighting was arbitrarily created using knowledge of pattern recognition a human perception. The study was focused on experienced drivers, defined by the two criteria stated in Chapter 1.2, driving a simulated passenger vehicle. The necessary data were gathered from a driving simulator experiment with one scenario and three different Scenario Variations representing the warning levels. The analysed metrics are drivers'

reaction times, their position relative to the centre of the road, and subjective answers from questionnaires.

The study itself was conceived as a continuation and extension of research done by Lidestam et al. (2020).

1.4 Outline

The present thesis is structured as follows. In Chapter 2, background and theoretical information related to the topic is provided. Chapter 3 details the driving simulator experiment conducted for the present thesis. Chapter 4 deals with the data analysis of the driving simulator experiment. The results and methodology used in the present thesis are discussed in Chapter 5, followed by Chapter 6 concerning the research questions and a final summary of the thesis.



2 Background and Theory

This chapter provides background and theoretical research on the issues elaborated in the thesis. First, a driver's reaction time is outlined with various factors that can affect it, followed by the current state of technologies and processes for emergency vehicles. Also, a description of V2X (Vehicle to Everything) communication needed for EVA and other alerts to work appropriately is presented. Lastly, the area of HMI is described, and the issues of communication and warnings are raised.

2.1 Driver reaction time

Podoprigora et al. (2020) states that a human reaction is a subconscious process that manifests itself in times of distress or due to an external stimulus. Generally, it is measured from when a stimulus is presented until an action is taken. Reaction time as an indicator in connection to traffic is mostly when talking about accidents, for example, handling a breaking manoeuvre (Drożdziel et al., 2020). However, reaction time is also essential when avoiding a dangerous situation or when presented with a problem where a quick reaction is critical, like allowing an emergency vehicle to pass safely. The latter is essential for the present thesis.

Reaction time itself can be affected by several factors. A study done by Makishita et al. (2008) looked into how age and mental workload can affect reaction time and found out that both of these factors play a critical role. The study was conducted on three age groups; the "young" and "middle" performed relatively the same, but the "elderly" group performed significantly worse. Another factor that can contribute to prolonged reactions is alcohol. In contrast to the previous study, in this case, young drivers were the most susceptible to being affected by alcohol. Čulík et al. (2022) attributes this to the fact that younger drivers tend to be more reckless and are prone to alcohol consumption. Yadav et al. (2019) further solidifies this notion in a study where a reaction time to two hazardous events was analysed. Two groups aged 21-25 years and 25-41 years, respectively, were analysed in four different levels of alcohol intoxication (0% BAC, 0.03% BAC, 0.05% BAC and 0.08% BAC). When analysing the results for a scenario with a group of pedestrians crossing a highway at a 5% significance level, a decrease in drivers' reaction times by 2% for every year of driving experience was found to be significant. Furthermore, a 15% reduction in the reaction time was found in the case of the mature drivers compared to the young group.

2.2 Emergency vehicles

Emergency vehicles (i.e., the cars that are designated and authorised to respond to emergencies), by definition, must react quickly but also safely in the place of an emergency. This can bring other traffic users into dangerous situations when there is no preemptive warning of the emergency vehicle approach. A warning system is mandatory for every emergency vehicle to avoid such endangerment. The warning system of emergency vehicles in Sweden consists of two distinct components: lights and sirens (TSFS, 2021). Both components fulfil the crucial role of warning other traffic users about the approach or presence of the emergency vehicle. This can further contribute to the safe passage of the emergency vehicle since the drivers were alerted in advance and should create a path for emergency vehicles. The warning system already mentioned has three separate levels of application (TSFS, 2021):

1. Only blue flashing lights on the car
2. Blue flashing lights and the siren
3. Blue flashing lights and the siren with an additional flashing of high beams (this application may only be used in daylight to avoid dazzling other drivers)

As seen from the list, the sirens can only be used with the blue lights, and the high beam flashing has the most limited use case. Apart from adhering to the Swedish regulations, all warning lights must, among other things, also comply with the United Nations ECE R65 regulations (TSFS, 2021; United Nations, 2011).

The exception to these limitations is the police. Police cars are the only emergency vehicles that can utilise blue lights to make drivers move over and also a red light (SFS, 2007). The example of a police car with the lighting system is shown in Figure 2.1.



Figure 2.1: Swedish Volvo police car with warning lights
(Kevin B., 2023)

The cars are equipped with three types of lights, the dominant being the light bar mounted on the vehicle's roof. Supplementary blue lights are added all around the car, notably in the front grille, behind the front glass, in the front corners, and in the rear bumper. The last type of light is the light bar mounted below the license plate, which is used as the high beam flasher or can be turned on permanently to increase visibility. Note that apart from just the lighting system installed on the car, the car is equipped with highly reflective material on all sides. This additional passive measure helps drivers notice if the vehicle is in low visibility conditions or if the lighting system is not activated.

2.3 V2X communication

Vehicle-to-Everything (V2X) communication is a general form of vehicular communication (Kawser et al., 2019). It is a wireless technology that aims to enable data and information exchange between a vehicle and other traffic actors and its surroundings, see Figure 2.2 (Mannoni et al., 2019). The expected benefit of this technology is to increase road safety and decrease accident numbers and fatalities. To achieve this goal, several dedicated use-case scenarios and warning messages are to be implemented. Such alerts include, among others, Emergency Vehicle Approaching, Road Works Warning, Stationary Vehicle, Traffic Condition Warning or Wrong-Way Driving (Broz et al., 2022). Other use cases of this technology include, but are not limited to, cooperative automated driving or infotainment services (Hasan et al., 2020). To facilitate the information exchange and data delivery, two approaches are being developed simultaneously:

- ITS-G5 - a type of DSRC (Dedicated Short Range Communication) based on an existing IEEE (Institute of Electrical and Electronics Engineers) 802.11p standard, which can be simplified as a modification to Wi-Fi, it refers to a wireless short-range communication between the OBU (On-Board Unit) of the vehicle and an RSU (Road Side Unit) at dedicated locations (ETSI, 2020)
- C-V2X - communication-based on a cellular wireless network such as the LTE (Long-Term Evolution); this technology has been in use for mobile phones, but in later years, development for dedicated vehicular communication standards introduced in the 3GPP (Third Generation Partnership Project's) Release 14 and Release 15 (3GPP, 2017, 2018)

The main difference between these two technologies is that the ITS-G5 is a short-range communication solution, which requires a new infrastructure to be built alongside the existing roads. At the same time, the C-V2X solution can be built without any new infrastructure since it could use an existing cellular infrastructure. Another advantage C-V2X has is a significantly longer range to transmit the messages.

2.3.1 V2I communication

The first significant application of the V2X communication technology is the V2I (Vehicle-to-Infrastructure) communication. This type of communication provides a transfer of information between the infrastructure itself and the vehicle that is using it. The message that needs to be transmitted is generally sent from a back-office, where all types of information are aggregated (Lokaj, 2022). The appropriate message is then stored and sent to the corresponding RSU units, which distribute it to the vehicles in an area where it is relevant. The exception to this type of information distribution is using a mobile RSU, which can be placed anywhere alongside the road and have a predefined message to distribute. This application is helpful in cases of longer road works or in places where it is known that road closure will take longer time (Lokaj, 2022). The utilisation of the back-office is, on the other hand, helpful with quickly changing information such as weather-related events or if there is a car crash. This approach

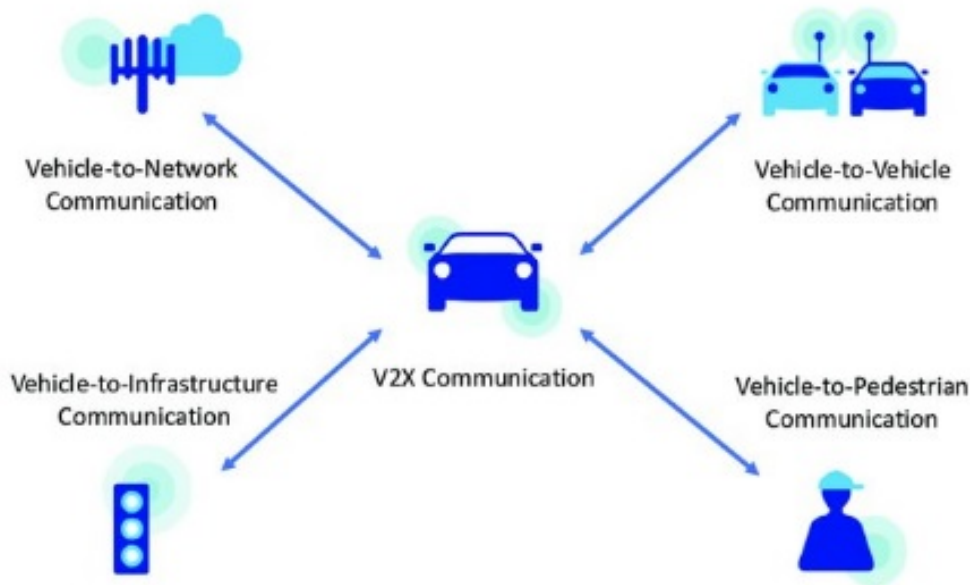


Figure 2.2: Components of V2X communication
(Mahmood et al., 2019)

also helps with the problem present in previous technology, Radio Data System - Traffic Message Channel (RDS-TMC), which used a location table and a list of predefined events (Davies & Klein, 1991). The events were then broadcast to all the road users connected to a specific transmitter alongside a regular FM radio signal.

2.3.2 V2V communication

The second application of the V2X communication technology is the V2V (Vehicle to Vehicle) communication. This type provides a transfer of information between two vehicles that are sufficiently close to establish a connection. This type of communication is mainly used for warnings that are location-based and which can move on their own. Such alerts can be, for example, Slow Vehicle, Traffic Condition Warning, Weather Condition Warning (this message can include, for example, ice on the road) or Emergency Vehicle Approaching (Broz, Srotyr, & Jerabek, 2022). Another application of V2V communication is using vehicles as "temporary RSUs". This means that when a vehicle receives a warning message, it can then send it to other vehicles that are not yet in range of the RSU (Cho et al., 2009). This approach is called multi-hop networking, shown in Figure 2.3.

2.4 Human-Machine Interface/Interaction

Human-machine interaction is defined as an interaction between a human operator and a machine (Orlický, 2021a). This interaction is always carried out via a system medium with which the operator interacts, and this medium is then defined and referred to as human-machine interface (Orlický, 2021a). This field was first described in the 1960s during the first space flight era and combined many technical and non-technical sub-disciplines. (Novotný, 2021). When it comes to vehicle HMI and interaction between the driver and the vehicle, the technical disciplines that are mainly analysed are automotive design and construction of different interior parts, and from the non-technical ones, the driver's response to the interfaces

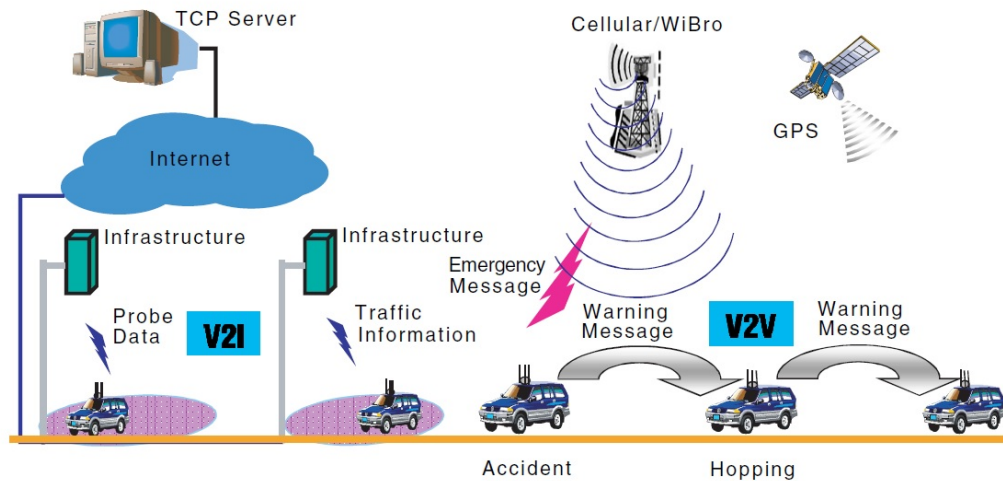


Figure 2.3: Components of V2X communication © 2009 IEEE

(Cho et al., 2009)

and general feeling of the driver in the cabin (Novotný, 2014). The technical disciplines can be easily quantified and analysed compared to the complex nature and responses of human behaviour. Because of this difference, automotive manufacturers and manufacturers of assistance and communication products need extensive studies to achieve results which can move the industry forward.

The goal of automotive HMI is to efficiently convey information between the vehicle and the driver, allowing the driver to operate the car's various functions properly. These interfaces do not have to be only devices the driver directly interacts with, but also multiple feedback from the vehicle, like tire noise (Orlický, 2021a). Below are some examples of HMIs:

- Infotainment system
- Instrument cluster
- Head-Up display
- Central console
- Steering wheel
 - Button controls
 - Paddle shifters in case of a car with automatic transmission
 - Steering feedback from the wheel
- Air conditioning controls
- Sound system
- Outdoor sounds such as road noise or engine noise
- Lighting
- Vibrations from the drivetrain

This section further focuses on various HMIs relevant to this thesis's problem statements.

2.4.1 Types of HMI

This section presents the most widely used HMI systems in cars today. Since the current thesis is focused on drivers and their reactions when presented with an EVA warning, the HMI systems presented here could directly affect the drivers in such situations or be used to alert them further.

Infotainment System

An in-vehicle infotainment system is generally in the middle of the central console (Cazoo editorial team, 2023). Nowadays, the infotainment typically consists of a touchscreen display mounted on the dashboard. Some manufacturers, like Lexus, Genesis, BMW, or Mercedes, implement a secondary set of buttons or a small touchpad in the base of the central console (Cazoo editorial team, 2023). An example of the infotainment with the secondary controls is shown in Figure 2.4.



Figure 2.4: Infotainment screen of Mercedes convertible with a supplementary set of controls in the base of the central console

(Mikes-Photography, 2016)

Today, a vast majority of new cars are equipped with an infotainment system ranging from basic infotainment systems that fulfil the function of navigation, media centre and hands-free to systems that encompass a lot more features like weather forecast, air conditioning settings or setting the drivetrain modes (Atiyeh, 2022; Cazoo editorial team, 2023). In modern high-end cars equipped with ambient lighting, the infotainment system is, in most cases, the only means of setting the lighting. When the automotive manufacturer wants to develop a new infotainment system, several phases of development need to be done to achieve intuitive, easy-to-use and non-distracting infotainment (Luna-Garcia et al., 2018).

The initial design phase is arguably one of the most difficult since it needs to cater to many differently skilled and tech-savvy drivers. This phase also contains a set of partial requirements, like user requirements, structure and placement in the cabin and appearance of the system (Luna-Garcia et al., 2018). After the design phase, an interaction with the system must be solved, preferably reflecting the findings and decisions made in the design phase. This phase focuses on how the driver controls and interacts with the system, e.g., if the screen

is touch-sensitive or placement of any secondary means of controlling the system. An integral part of this phase is also the learnability of the system, which can be promoted, for example, via the usage of widgets as shortcuts (Luna-Garcia et al., 2018). The next phase deals with the security and reliability of the system, not in the sense of security as resistance to external threats, but whether the information provided by the system is conveyed to the driver in a secure and trustworthy environment. This should ensure that the driver experiences minimal distractions and their attention is focused on the road and not on the infotainment (Luna-Garcia et al., 2018). The last phase is the connectivity of the system itself. This problem became more and more prevalent in later years when mobile software developers started to present their solutions for using the phone as an infotainment system. The first step in connectivity was via Bluetooth when the infotainment could double as a hands-free device and media centre, followed by more advanced functions like mobile mirroring (Luna-Garcia et al., 2018). The latest connectivity requirements are regarding internet connectivity.

Automobiles are becoming increasingly aware of their surroundings thanks to the implementation of various sensors and cameras. This information is crucial to the development and progress of autonomous vehicles, hence the emphasis on mobile network connectivity, as all this information could be shared between the vehicles themselves and increase safety (Fallgren et al., 2018).

Instrument Cluster

With a few exceptions, like the Tesla Model 3, every car on today's market is equipped with an instrument cluster directly behind the steering wheel ("Instrument Clusters", 2023). The primary function of an instrument cluster is to keep the driver updated on the car's status using various gauges and indicators ("What Is An Instrument Cluster And Why Is It Important?", 2020). The most crucial information drivers receive is from the speedometer, showing the car's speed, and the tachometer, showing the engine's current RPM (Revolutions Per Minute). Other important information conveyed to the driver via the instrument cluster are, for instance, coolant temperature, fuel level, and engine status. Various indicators are also turned on depending on the situation, for example, ABS (Anti-lock Braking System) or traction indicator ("Dashboard Instrument Cluster Explained", 2023). Recently, more and more car manufacturers have started to phase out analogue instrument clusters in favour of digital ones. These provide a more flexible approach to displaying information to the driver and a certain amount of freedom in configuring what to show. Be it basic engine information when on the track or displaying a map with route directions and audio settings with car information "taking a backseat". Overall, the information density is hugely expanded compared to the old systems, and the response time and information precision have increased as well ("Dashboard Instrument Cluster Explained", 2023).

Head-Up Display

The HUD (Head-Up Display) technology projects information onto a transparent screen in the driver's field of view. This should help the driver better focus on the road ahead and not be distracted by looking at the instrument cluster. The presence of the HUD closer to the focus point on the road can lower the driver's reaction time in certain situations and improve awareness under challenging conditions such as low visibility (Charissis & Naef, 2007). Two primary technologies are used today in terms of the information projection which are:

- Projection onto a dedicated screen - cheaper version and easier to implement (Carwow staff, 2022)
- Direct projection onto the windscreen - more expansive, but also more pleasant to use according to drivers (Carwow staff, 2022)

The technology was first introduced in the military and used in the 1940s in fighter jets (“Understanding ADAS: Automotive Heads-Up Display (HUD)”, 2023). The first automotive usage was by Nissan in 1989, which displayed only basic information on the HUD (“Understanding ADAS: Automotive Heads-Up Display (HUD)”, 2023). Nowadays, HUD shows not only basic information, such as the speed that the vehicle is driving, but also various information from the sat-nav, like the time to final destination and route guidance, or driver assist systems, such as lane-keep assist and speed limit (Carwow staff, 2022). The driver and their settings directly influence the amount of information displayed. This means that every driver can find the right amount of information displayed on the HUD to avoid getting distracted by it. Figure 2.5 shows the example of a windscreen HUD. The HUD is above the steering wheel in the driver’s field of view. Apart from the HUD, a digital instrument cluster and an infotainment touchscreen can be seen in the figure.



Figure 2.5: Cockpit view of Volkswagen Touareg with a Head-up Display (Volkswagen, 2018)

Visual Signals

Another way of warning the driver is by a visual warning in the cockpit. According to Werneke and Vollrath(2011), many accidents are caused by a lack of information. This is most prevalent at intersections, where drivers tend to overlook other traffic. This is caused mainly because the drivers tend to focus on areas from which other vehicles with right of way may come (Werneke & Vollrath, 2011). Two main reasons for this driver error were then identified by Werneke and Vollrath(2011):

- driver failed to see/overlooked the other traffic
- driver failed to look around, did not anticipate traffic in a particular direction

Werneke and Vollrath(2011) suggests that by using an in-vehicle warning signal located in the driver's peripheral vision, the driver's attention can be directed to the areas from where traffic is approaching. Jonides et al. (1988) found four essential properties of peripheral vision in terms of how people perceive the peripheral cues compared to central cues:

- peripheral cues do not utilise processing resources as heavily
- peripheral cues produce attention responses that are more difficult to suppress (even when subjects are instructed to ignore them)
- peripheral cues are more effective in summoning attention (they produce greater costs and benefits)
- peripheral cues are effective even when their onsets are unexpected

The risk associated with this kind of implementation is that the driver could be startled by the warning or have a seizure if they had a medical condition such as epilepsy. An option to fine-tune the alert (change the frequency, pattern or colour) and an alternative to entirely turn it off must be included to avoid these risks. An audio signal could also be included to improve the warning and get the driver's attention early and clearly. A study done by (Zheng et al. 2008) proves that a combination of these two warning signals can have a positive effect on the driver's attention and reaction time and also lower their error rate.

2.4.2 Ambient lighting in cars

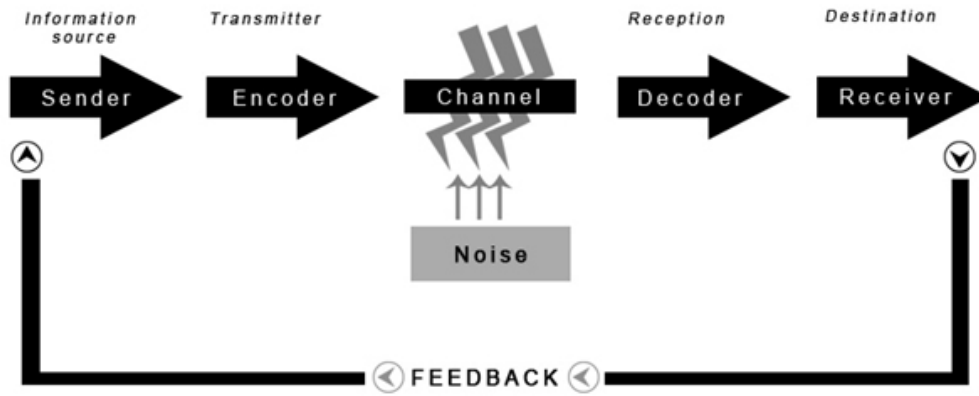
Interior ambient lighting in cars is a fast-spreading novelty (Stylidis et al., 2020). Previously, only a few light sources could be found in the car's interior. These lights were mainly responsible for lighting various controls such as air conditioning or were used to convey multiple messages to the driver (Stylidis et al., 2020). Nowadays, more and more cars are equipped with ambient lighting setups that usually lack practical usage and serve only as decoration. These can help the driver stay awake when driving at night by harmonising the intensity of the vehicle's interior lighting with the external environment (Wördenweber et al., 2007). Significant consideration must be taken into the design to ensure that the ambient lighting is not set up in a way that could dazzle drivers or otherwise impair their vision (Caberletti et al., 2010). This type of ambient lighting can, in most instances, emit multiple colours and, as such, could be utilised to alert drivers about an approaching emergency vehicle.

One of the practical uses seen in new car models is a warning system that uses ambient lights when the car is stationary, and another vehicle or a cyclist is approaching from behind at the same time as the passenger is opening the car door (Man, 2020). Another alternative usage includes flashing the ambient lighting red when the doors are open to warn drivers coming to the vehicle from behind (DeMuro, 2018).

2.5 Communication

Flashing lights of the emergency vehicles and ambient lighting are a form of communication between the emergency vehicle and the driver; in this case, a warning that the emergency vehicle is approaching. The foundation of numerous communication models is the Shannon-Weavers transmission model from 1949, which then referred to telephony and radio (Fiske, 1990). Figure 2.6 shows an updated version of the original model. The only difference between the original and this new one is adding the "Feedback" element, which can more adequately describe communication when a person is involved. However, this element is not necessary to the concept of communication.

Shannon and Weaver's model describes communication as a linear process from sender to receiver. To describe the individual elements of the diagram:



SHANNON-WEAVER'S MODEL OF COMMUNICATION

Figure 2.6: Shannon-Weavers communication model
(Communication Theory, , 2023)

- Information source - the sender of the information or the decision maker who selects which message to send; in this case, the emergency vehicle
- Transmitter - transforms the message into a signal; in this case, a light bulb
- Channel - a medium by which the signal travels to the receiver; in this case, air
- Reception - a decoder for the signal; in this case, an eye
- Destination - a recipient of the signal; in this case, the driver
- Noise - other signals that were not directly sent by the source; in this case, lights of other cars or reflections (Fiske, 1990)

Shannon and Weaver also identified three levels of problems that can occur in communication (Fiske, 1990):

- Level A (Technical Problems) - How accurately can the communication symbols be transmitted?
- Level B (Semantic problems) - How precisely do the transmitted symbols convey the desired meaning?
- Level C (Effectiveness problems) - How effectively does the received meaning affect conduct in the desired way?

In the thesis case, Level A can be described as a problem with the visibility or clarity of the signal. Level B would occur when the driver understands what the signal means and what action to take, for example, whether flashing lights indicate an urge to clear the road or whether there is a police check and the driver should pull over. Level C would then represent how the driver indeed reacts to the signal.

2.5.1 Warnings

A similar approach to communication as Shannon and Weaver's model is the Communication-Human Information Processing (C-HIP) model (Conzola & Wogalter, 2001). This model is based foremost on workplace warning and the communication between the source and the recipient. Conzola et al. (2001) argues that this model can be better used to identify possible bottlenecks in the information flow. Compared to Shannon and Weaver's model, the C-HIP model is not linear, but every information transfer is bidirectional. This signifies the possible bottlenecks. In Figure 2.7, the similarity with Shannon and Weaver's model is shown even more clearly. Elements such as "Transmitter" or "Noise" are not present, but the main difference is that the "Receiver" is more detailed to represent a human even better.

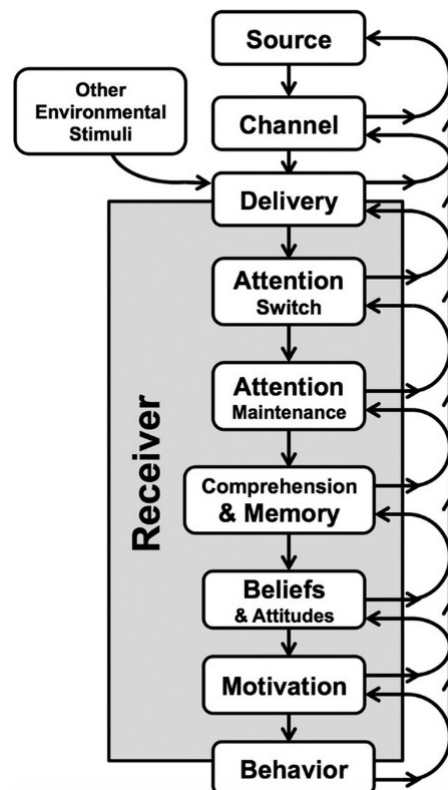


Figure 2.7: Communication-Human Information Processing (C-HIP) model
(Conzola et al., 2001)

In the case of the visual warnings, the channel would be the flashing lights themselves. In the receiver part, the first step is to attract and hold the driver's attention. This is crucial since the environment is full of other visual stimuli. If the attention is maintained, the next step is comprehending the warning. One of the possible bottlenecks in this step is the driver's inexperience or a stressful situation in which the driver cannot react adequately. The next step is beliefs and attitudes, which can be analogised to experience and familiarity with the field/topic or problem. A bottleneck in this step may be that the driver does not deem the situation dangerous or evaluates that no action needs to be taken. The last step is driver motivation. A cost-balancing act takes place, where the driver weighs the benefits of not obeying the warning with the cost of complying with the warning. A bottleneck is, for example, when a driver has to stop the vehicle at an intersection, causing a delay due to a potential red light.

2.5.2 EVA warning use case

EVA, sometimes called EVW (Emergency Vehicle Warning), is an ITS service that alerts drivers about an approaching or stationary emergency vehicle (C-Roads Germany, 2023). This warning aims to alert the drivers that the emergency vehicle is approaching so they can react accordingly, such as forming an emergency lane or lowering their speed and driving to the side of the road. Both of these manoeuvres can decrease the response time.

In a previous study done by Lidestam et al. (2020), this type of warning was analysed in a rural environment on inexperienced drivers. Even though the setting had no significant distractions, the EVA message proved valuable and helpful. This was confirmed by the fact that 24 out of 37 drivers not presented by the EVA message did not yield the right of way or were unsure what to do. In another study done by Petrov et al. (2020), the EVA warning was analysed in an urban environment of the Slovak city of Bratislava and a city highway environment of the Slovak city of Žilina. This study focused on the reaction time that the EVA warning message can provide to the drivers. In their conclusion, in both scenarios, the EVA message provided drivers with a theoretical reaction time of more than 30 seconds, which is a significant amount of time for the driver to react.

This service is undergoing pilot trials on multiple sites across Europe. The testing in Sweden is done as a part of the NordicWay 3 project (Jacques, 2023). The project is supposed to run for 2-4 months in 2023, and the data collected are used to evaluate the NordicWay 3 project. Another pilot project on a bigger scale is running in the Czech city of Brno by the Intens company (Intens, 2023). Since this project runs in an urban environment, it implements the EVA message and combines it with an emergency vehicle priority system. This system can prioritise emergency vehicles equipped with the necessary hardware at intersections, thus lowering the response time and increasing safety. Today, 28 intersections are equipped with such hardware and on average, the response time has been reduced by 1-3 minutes (Intens, 2023).

2.6 Prägnanz law and Gestalt principles

Visual warnings can be set up in several ways that influence how humans perceive them. Most notable are the colour and size of the warning and its overall presentation. In the case of a digital warning, such as messages in a car, brightness, placement or frequency (if the warning message uses it in any way) can also play a significant role. Prägnanz law, an overarching law to Gestalt principles, can be considered a set of guidelines for forming a default version of the warning. Prägnanz law is defined as the "tendency to perceive any given visual array in a way that most simply organises the disparate elements into a stable and coherent form" (Sternberg & Stemberg, 2012). In other words, humans tend to interpret shapes in the simplest form, as an example can be the description of the Olympic logo when most people would describe it as five overlapping circles rather than a set of interconnected curves (Fard, 2023). Gestalt principles are defined as follows: "The whole differs from the sum of its individual parts" (Sternberg & Stemberg, 2012). This can be interpreted as people tending to look for patterns rather than individual objects. This is also supported by the fact that "gestalt" can be loosely translated from German as "shape", "pattern", or "form" (Gaskin, 2022). Sternberg and Stemberg (2012) defines Gestalt principles as follows:

- figure-ground – when observing a visual field, some objects tend to be prominent (figure) and others as a background (ground)
- proximity – when observing a group of objects, we tend to perceive them as a group
- similarity – we tend to group objects based on their similarity
- continuity – we tend to perceive smooth lines rather than disrupted or discontinuous

- closure – we tend to perceptually close objects, even if they are not closed
- symmetry – we tend to perceive objects as forming a mirror image around their centre

If the warning is designed according to these principles, the driver's reaction should be faster since understanding the warning should be easier and more natural.

2.7 Driving Simulators

Driving simulators place drivers in an artificial environment, which is supposed to substitute most of the aspects of driving in reality (Chang, 2015). Apart from simulating real-world driving, they also provide a safe means to study numerous aspects of driving without the risk of causing accidents, fatalities and damaging properties. These aspects might be, for example, driving under the influence of either drugs or alcohol, simulating difficult road conditions, or analysing the intuitiveness of interior controls (Chang, 2015; Jiménez, 2018).

Apart from safety, another significant advantage compared to real-life studies is the controlled environment in which investigations are done. This means that every participant in the study has the same experience as everyone else. Another advantage is the reproducible and replicable data from driving simulator experiments and the possibility of repeating measurements. If the study needs to be repeated with specific changes, for instance, more participants or scene modifications, setting up the simulator is much more accessible than setting up an equivalent real-life scenario. Both of these advantages also point to a cost-benefit ratio. The most significant cost is usually the development of the simulator; however, studies tend to be a fraction of the cost compared to real-world studies. Driving simulators can be generally divided into two types:

- Light simulators – usually a part of the car or the seat and driver controls; an example of this simulator is shown in Figure 2.8
- Full-size simulators – usually a whole car cabin to maximise the participant's immersion in the environment; an example of this type of simulator is shown in Figure 2.9



Figure 2.8: An example of a light driving simulator (Ondomiši, 2023)

Another notable difference in the driving simulators is the feedback provided by the simulator, which means how the simulator simulates external forces on the car. This feedback ranges from no feedback like in Figure 2.8, simulating simple vibrations, simulating lateral motion or combining the two latter options in a full motion simulator like in Figure 2.9.



Figure 2.9: A full-size driving simulator (Hejdlösa bilder, 2023)

The last notable distinction in the driving simulators comes from the projection used to simulate the environment around the driver. In this regard, three approaches exist nowadays: display, projector and head-mounted display (HMD). Display projection cannot fully provide image continuity and projection size but offers better portability, lower cost, and reduced space requirements, including better setup of lighting conditions thanks to higher contrast.

On the other hand, the projector offers a more realistic environment projection, image continuity and almost infinite scalability at the expense of space requirements, set-up complexity and the need to get the room as dark as possible to achieve the desired image (Orlický, 2021b). The last means of projection is using virtual and augmented reality in projection-based HMDs. This is the latest technology of scenario projection, which combines the benefits of portability, fast set-up, low surroundings requirement (both from the lighting perspective and space needed), almost infinite scalability, and perfect image continuity. The main disadvantage is the difficulty in setting up interactive and tactile surroundings properly. This means when the scene demands active usage of any physical device from the driver's seat, like interacting with an infotainment screen, adjusting air-conditioning, and interacting with a phone. On the other hand, the usage of VR greatly improved the design stage of car development since there is no need to model the car interior to experience it fully, even if no tactile feedback could be provided as in the case of a real model (Orlický, 2021b). A possible usage of the HMD technology is to create augmented reality, where some parts of the interior are physical, and the surroundings are virtually projected using the HMD.

The danger when using any type of driving simulator is simulator sickness. This is a bodily response that can be triggered during or after an exposure to the simulator. Generally, this is because there is some sort of delay in the simulator from what the participant is expecting to happen based on a real-life experience (Dużmańska et al., 2018). This delay might be caused by low refresh rate of the display, delay in the motion when using a full motion simulator or not properly rendering the environment based on the head position (Dużmańska et al., 2018).

2.8 Statistical Tests

Statistical tests are mathematical tools for analysing quantitative or qualitative data generated in a research study (Bhalerao & Parab, 2010). At its core, statistical tests are used to decide whether there is enough evidence to reject a null hypothesis (H_0) in favour of an alternative hypothesis (H_a). Generally, the null hypothesis states that there is no statistically significant difference in the data sets tested (Ramachandran et al., 2021), for instance, in their means or variance, depending on the statistical test used. The alternative hypothesis then states that there is a statistically significant difference in the tested measures.

When selecting a statistical test for the measured data, there are several factors which need to be taken into account. These are whether the data is normally distributed, whether the data is continuous or discrete and whether the variables are qualitative or quantitative (Bhalerao & Parab, 2010). Each factor affects what test should be selected for the data. In the case of the first two factors, the decision could be up to the researcher, but for the normality of the data, several tests test that. Another deciding factor in choosing what statistical test to use is the number of tested samples since each test is meant for a different number of groups.

The results of statistical tests are usually presented with a so-called p value. This value is defined as: "the lowest level of significance at which the null hypothesis would have been rejected (Ramachandran & Tsokos, 2021)". Primarily, researchers use the alpha value (level of significance) of $\alpha = .05$ or $\alpha = .01$. If the resulting p value is lower than the α , the null hypothesis is rejected in favour of the alternative hypothesis. Generally, this indicates a difference, effect, or relationship in the tested data.



3

Driving Simulator Experiment

This chapter describes the driving simulator experiment that was conducted for this thesis. The methodology for this study is similar to the methodology used in Lidestam et al. (2020), which studied the effect of EVA warning on the driver's response when approached by an emergency vehicle. This time, with a different target group, to further investigate the effect of a preliminary warning on drivers. First, a description of the three Scenario Variations studied is presented, followed by a description of the recruitment process of participants and the design of the experiment. After this, a description of the equipment used to conduct the experiment and its setup is provided. Finally, the experiment procedure is presented.

3.1 Scenario Variations description

This section describes each of the three Scenario Variations that were implemented into the simulator and tested. Compared to Experiment 2 from the study done by Lidestam et al. (2020), an additional level of warning was added and studied as a separate group. This addition was a simulated warning via ambient lighting in the vehicle - AEL. Each test group is referenced by its respective group name in the present thesis, i.e., Baseline group, EVA group and EVA + AEL group.

3.1.1 Scenario Variation 0 - Baseline group

In this variation, the drivers were not given any in-vehicle warning and had to assess the situation of the approaching emergency vehicle themselves. The data measured from the runs of this group were used as a reference benchmark.

3.1.2 Scenario Variation 1 - EVA group

In this variation, the drivers were presented with an audio-visual EVA warning message before the emergency vehicle approached them. This warning was in the form of a warning message displayed in the instrument cluster, and a voice message played simultaneously with the visual alert.

3.1.3 Scenario Variation 2 - EVA + AEL group

In this variation, a visual warning was added in the form of blue flashing lights (AEL) before the EVA message. The LED (Light-Emitting Diode) strips were placed in the driver's peripheral vision and were supposed to simulate ambient lighting in the vehicle that would be present in the vehicle doors.

3.2 Recruitment of Participants

For this study, a minimum of 50 drivers was required to ensure that sufficient data was collected for the validity of the results. There were two main requirements for the drivers to be able to participate in the study:

- Driver has to have a valid driving licence for a passenger car; this meant a category B in Sweden
- Driver has to drive a minimum of 15 000 kilometres per year

These criteria were selected because the purpose of this study was to see how well the EVA warning works for experienced drivers in contrast to the investigation done previously by Lidestam et al. (2020), in which the target group were primarily new and inexperienced drivers. Participants were recruited via email from the VTI database, on the VTI website, and through social media advertising from 27th of April 2023 till 12th of May 2023. Then, they signed up for a suitable time slot via the booking system. Each participant received a movie gift card to rent a movie for free (worth approximately 100 SEK) at SF Anytime as a reward for participating in the study. Data collection ran from the 2nd of May 2023 till the 15th of May 2023.

3.3 Design

Based on the studied Scenario Variations, the participants were divided into three groups of the same number of participants, as best as the final number of participants allowed. A between-group design was implemented for the experiment, meaning each participant drove only one Scenario Variation. This approach was chosen to avoid any priming effect, mainly to avoid any anticipation that could emerge from experiencing any other Scenario Variation.

3.4 Materials and Settings

To replicate the same conditions as in the study by Lidestam et al. (2020) the best, a fixed-base driving simulator located at VTI in Linköping was used. This simulator was equipped with a similar display setup, and upgrades in graphics and slight changes in scenery were performed when recreating the scenario. For the experiment, both visual perceptual cues, i.e., the changing view of the surrounding environment when driving, including an inner rear-view mirror, and auditory perceptual cues, i.e., from the engine, other vehicles, tires and transmission, and air resistance, were given to the participants. A set of three LCD screens was used for the visual cues. The main screen was a 43-inch TV directly in front of the driver from these three. The screen was placed approximately 95 centimetres in front of the participant; the exact distance could not be measured since each participant could set up the seating differently. This screen also simulated the central rear-view mirror. The other two screens were 55-inch TVs set up at a 45° angle and simulated peripheral vision. These screens also displayed door-mounted rear-view mirrors. This setup resulted in approximately 180° horizontal field of view and about 50° vertical. The refresh rate for all these screens was set to 60 Hz. An LED strip, simulating the car's ambient lighting, was mounted under the side screens in the driver's peripheral vision. Apart from these three main screens, a smaller screen was used to simulate

the vehicle's instrument cluster. This screen was behind the steering wheel and displayed standard gauges in a car.

A set of stereo speakers and an additional sub-woofer under the driver's seat were used for the auditory cues. A mix of engine noise, ambient noise and a "Jesus Built My Hotrod" song by Ministry (1991) was used to simulate a distracting environment and to obstruct the sound of the sirens from the emergency vehicle. The combined SPL (Sound Pressure Level) was dialled to be 73 dB from the participants' position; this was done to replicate the same conditions from the previous study. The speakers also played the EVA warning messages. When the message was triggered, the song was tuned down, and a "ping" sound, followed by a voice message: "Utryckningsfordon på ingång! Var uppmärksam!" [Emergency vehicle approaching! Pay attention!] was played. The SPL of the message was about 68 dB, which was enough to be heard audibly over the toned-down background noise. The SPL of the ambulance sirens was set to start at 60 dB when the ambulance spawned in the simulation 500 metres behind the participant's vehicle and gradually increased in volume as it got closer to 84 dB when overtaking the car.

A seat from an older-generation Volvo vehicle and a steering wheel from the same generation were used to simulate the cabin of a real car. For increased realism, the steering wheel included column-mounted stocks and was fully adjustable, the same as the seat, which had a seat belt that the participants were required to use. The full simulator setup can be seen in Figure 3.1.



Figure 3.1: Simulator setup (Ondomiši, 2023)

VTI simulation software was used to model the driving scenario. All Scenario Variations were driven on the same rural road, 3.5 meters wide, with a roadside 0,75 meters wide, marked by roadside markings 10 centimetres wide, 1 meter long, and 2 meters apart. The road centre lines were 10 centimetres wide, 3 meters long, and 9 meters apart. Parking pockets 80 metres long and 3 metres wide were every 1000 metres. The road was also much more hilly and curvy, and there was vegetation as close as 1.75 metres to the edges of the roadsides. Other traffic consisted of cars in the opposite direction, coming, on average, 20 seconds apart. The maximum allowed speed on this road was set to 80 km/h. Other vehicles in the same direction as the participant's car appeared in the scenario at specific points in the simulation. A van and a passenger car behind the driver's car and a passenger car in front of the driver's car appeared at 2 200 meters from the start. At this point, the two cars were 150 and 180 meters behind the driver's car and slowly closed the gap and stayed 25 metres apart. This was used to obstruct the view of the ambulance that closed in from 500 meters behind, at 150% the speed of the participant's vehicle, but not slower than 100 km/h. The car in the back gave way when the ambulance was 50 metres behind it, whilst the delivery van gave way when the ambulance was 40 metres behind it. The ambulance appearance was triggered when the participant crossed a trigger point at 2 655 meters from the start, and the overtake was approximately 4 150 meters from the beginning. During the overtake, the ambulance's target lateral position was in the centre of the opposite lane. The road consisted of hills, curves, vegetation and buildings as close to the road as 1.75 meters. This was implemented to obstruct the view behind the participant's car and make it more difficult to spot the ambulance. In the case of the EVA group, the message was played 14 seconds before the ambulance was estimated to pass the driver. The song's audio was lowered so the message could be heard, and a yellow triangle with the same message was displayed in the instrument cluster, as shown in Figure 3.2. All of these settings were taken from the study by Lidestam et al. (2020).



Figure 3.2: Detail of EVA warning message (Ondomiši, 2023)

For the EVA + AEL group, the ambient lighting started slowly flashing with a blue light 20 seconds before the ambulance was estimated to pass the driver, and the EVA warning message was displayed in the instrument cluster and played to the driver 14 seconds before the ambulance was estimated to pass the driver. The ambient lighting started as a dim blue light flashing in a slow interval of approximately 0.5 Hz and gradually sped up and got brighter. An example is shown in Figure 3.3. The light was then turned off when the ambulance passed the driver. The baseline group did not receive any warning.

The time when the ambulance was estimated to pass the driver was calculated based on the speed of the driver and the speed of the ambulance. Since the speed of the ambulance is directly tied to the speed of the driver.

3.4.1 Data collection

Data from the driving simulator study were collected separately for each participant. Necessary metrics collected for further analysis were timestamp, speed, distance, position on the road, brake pedal position, accelerator pedal position, steering wheel angle, and EVA message states. Furthermore, ambulance metrics such as speed, position on the road, distance and timestamp were also collected.

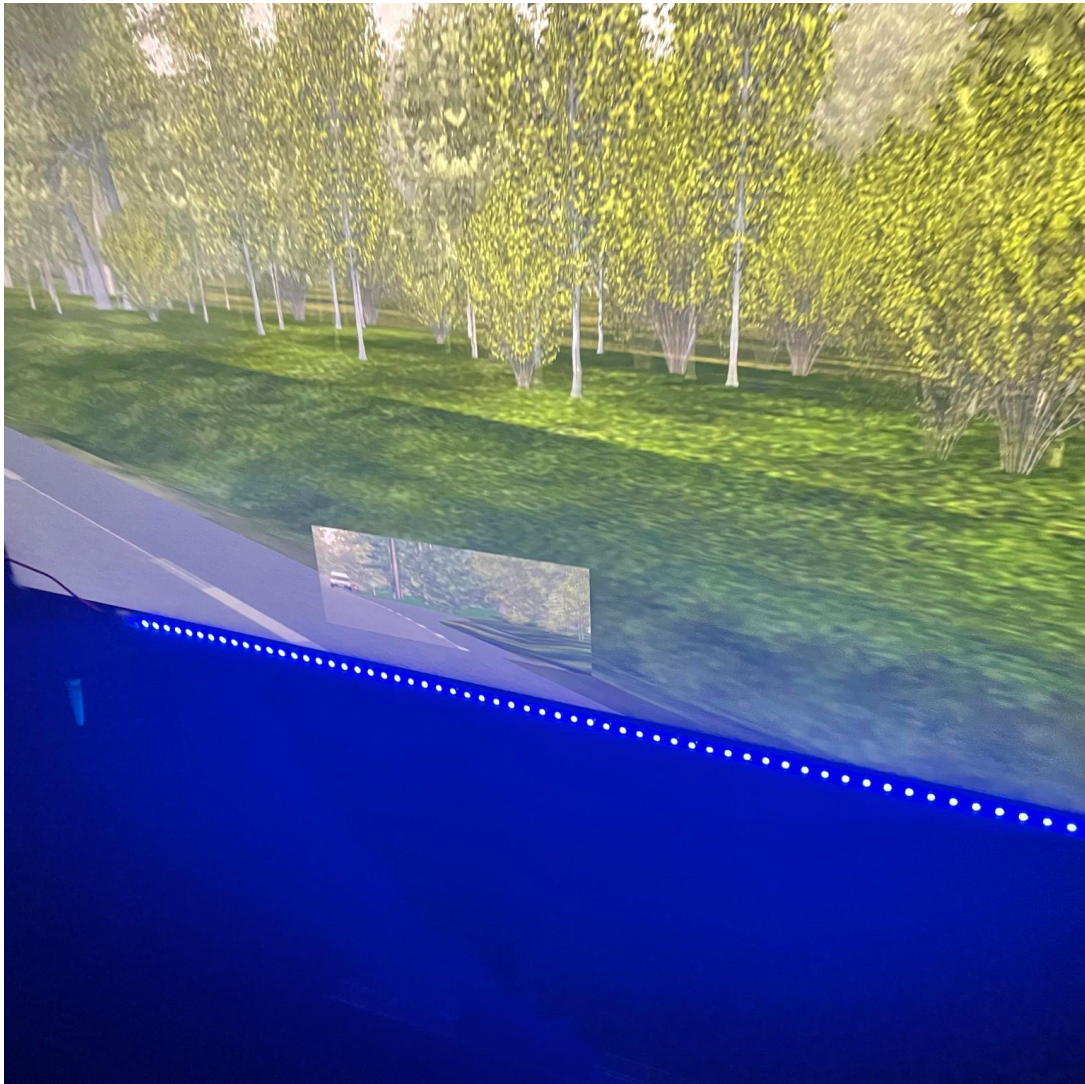


Figure 3.3: LED strips simulating the ambient lighting in the car (Ondomiši, 2023)

3.5 Procedure

The 15-minute time slots were allocated for each participant. Every participant was firstly informed about the study following the ethical guidelines of Vetenskapsrådet (2023) and subsequently received written informed consent that they had to sign. Each participant was assigned an pseudonymization number to ensure anonymity under which the data was collected and further processed. After this, each participant was given a pre-study questionnaire that contained general demographics, such as age and gender, as well as questions regarding their driving experience and whether the participant had any visual impairment. The translated pre-study questionnaire is attached in Appendix A. After the participants filled out the questionnaires, they familiarised themselves with the driving simulator. All the participants were instructed to adjust the seat to their preference and to have the seat belt fastened throughout the experiment. They were also informed about the presence of simulated rear-view mirrors and that even though the car had three pedals, the simulation was set up with an automatic transmission.

Participants were instructed about the simulator and were told that the scenario was as if they were in a hurry since they were already late for work but still adhered to the traffic

laws. The participants were specified that the critical task was to stay as close to the speed limits as possible. Monitoring the instrument cluster for adherence to the determined speed caused the drivers to be more distracted, which in part induced regular driving distractions caused by other traffic, noise, other road users, etc. This ensured the participants would drive as fast as possible and concentrate less on the traffic behind them. No information about emergency vehicles, EVA warnings, and the purpose of this study was given so as not to influence and affect their reactions and the study results. But first, each participant was instructed to drive about 700 meters (roughly one minute) at a lower speed of around 30 - 40 km/h. This ensured the participants were not getting motion sickness and could finish the experiment. After this part, participants were instructed to speed up to the speed limit of 80 km/h, follow the previously given instructions, and adhere to traffic laws. The driving scenario lasted approximately 8 minutes, and an example of the simulation in motion is shown in Figure 3.4. Driver behaviour was examined through reaction to the two different versions of EVA warnings (with and without the AEL), if applied, as well as to the passing of the ambulance vehicle.



Figure 3.4: Simulator in motion driven by one of the supervisors (Ondomiši, 2023)

After the ambulance had passed the driver, they were instructed to continue driving until either a message "Please stop the car" appeared or the study coordinator urged them to stop. After the scenario ended, the participants were given an additional questionnaire about their experience in the simulator based on the Scenario Variation they were driving. The questionnaire consisted of questions regarding participants' subjective feelings towards the presented situation for all the participants. The questionnaire included questions regarding evaluating the EVA warning messages for the participants presented with the EVA warning messages. All the participants were asked to express their stress levels during the Scenario Variations. Apart from that, the participants were also asked about their regular driving behaviour when encountering emergency vehicles to assess the level of driver knowledge on this issue. The questionnaire for the baseline group is attached in Appendix B, for the EVA group in Appendix C and the EVA + AEL group in Appendix D. All questionnaires before and after the experiment were prepared in Swedish for better understanding by the participants and later translated into English. For this thesis, only the English versions are provided.



4 Analysis of Data

In this chapter, the processing and analysis of the data from the driving simulator experiment is presented. First, a brief description of the tests used to analyse the data is provided, followed by general information about all the participants in the study. This includes information such as age, gender, driving experience or whether the participants have any visual impairment. After the general demographics data is analysed and presented, the data from the three Scenario Variations is presented. For each Scenario Variation, the participants' demographic data and the problems observed by the simulator supervisors during the experiment are presented. After that, the simulator data and the data from the questionnaires, which the participants filled out after the study, are analysed. This questionnaire was different based on the Scenario Variation the participant was driving. Finally, combined results from the common part of the questionnaires across all the Scenario Variations are given. The data and graphics used in this chapter were processed using the RStudio software.

4.1 Statistical tests used for the data analysis

- Shapiro-Wilk test - this test is used to determine whether the data follow a normal distribution, which is used as an indicator of whether a parametric or non-parametric test should be used (Ramachandran & Tsokos, 2021)
- ANOVA (Analysis Of Variance) test - this test is a parametric test used to compare several groups of independent observations, with the possibility of a different mean for each group; the tested variable is the mean of the group (Ramachandran & Tsokos, 2021)
- Tukey's HSD (Honestly Significant Difference) test - this is a posthoc test for the ANOVA test to determine between what groups the statistical difference is (Ramachandran & Tsokos, 2021)
- Kruskal-Wallis test - this is a non-parametric equivalent of the ANOVA test (Ramachandran & Tsokos, 2021)
- Dunn's test - this is a posthoc test for the Kruskal-Wallis test to determine between what groups the statistical difference is (Ramachandran & Tsokos, 2021)

- Welch Two Sample t-test - this is a parametric test used to determine whether there is a statistically significant difference between two independent samples; the tested variable is the mean (Ramachandran & Tsokos, 2021)
- Fisher's Exact test - this test is used to compare quantitative data; a contingency table is used to perform this test (Gad & Rousseaux, 2002)
- Wilcoxon rank sum test - this test is a non-parametric equivalent to the Welch Two Sample t-test; the tested variable is the median (Ramachandran & Tsokos, 2021)

4.2 Demographics and general information

Initially, a total of $n = 62$ participants registered for the study, but due to one participant not being able to finish the study because of motion sickness and one participant not fulfilling the criteria of driving at least 15 000 kilometres in the last year, the final number of participants was $n = 60$. The data from both of these participants were not included in the data analysis. The experiment was carried out utilising the between-group design. This means the participants are subjected to only one Scenario Variation to mitigate potential fatigue and practice. Because of this, the participants were randomly assigned to one of the testing groups, aiming to have the same number of participants in each group. Neither gender nor age were considered at the recruitment stage and when splitting the participants into groups. This was because neither was expected to affect the results. The final number of participants was 20 for the Baseline group, 20 for the EVA group and 20 for the EVA + AEL group. Of these participants, 43 were men and 17 were women. The average age of the participants was $M = 58,49$ (Mean) ($SD = 12,95$ (Standard Deviation)), with the oldest being 80 years old and the youngest being 29 years old. Most participants were 66 years old, and the median was 61. The final distribution is shown in Table 4.1.

Table 4.1: Participants distribution

Scenario Variation (group)	Baseline		EVA		EVA + AEL	
	Women	Men	Women	Men	Women	Men
Age/Gender						
28-40	3	3	–	–	1	1
41-50	1	–	1	3	2	1
51-65	2	6	1	6	1	4
65+	2	3	1	8	2	8
Total	8	12	3	17	6	14
Total per group	20		20		20	

The participants were then asked about their driving habits and experience/proficiency. First, participants answered how long they had had their driver's licences. A majority of 29 (48%) participants obtained their driver's licences before 1980; therefore, they have been driving for at least 40 years. Because of that, their affinity for new technologies, such as the EVA warning system, might be skewed since this might be seen as more of a distraction rather than a helpful innovation. The distribution is shown in Figure 4.1.

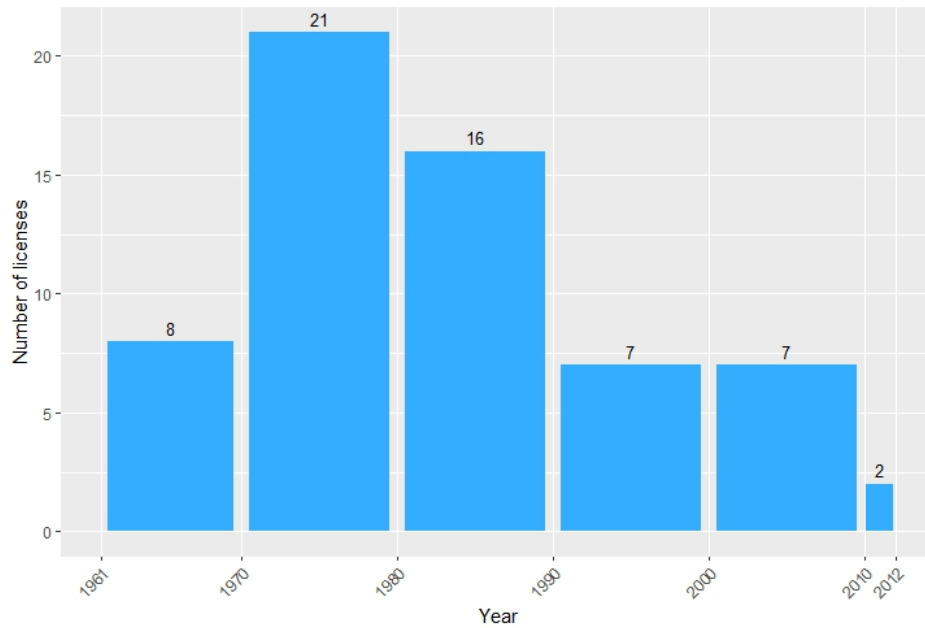


Figure 4.1: Year of driver's licence acquisition

The participants were asked about their driving proficiency and whether they had taken other driving licence classes. Of the 60 participants, 37 (61.67%) stated that they have classes other than B and AM. AM was specified in the question but was not considered an additional class, as it is automatically obtained by completing the necessary exams for class B. The classes' occurrences are shown in Figure 4.2.

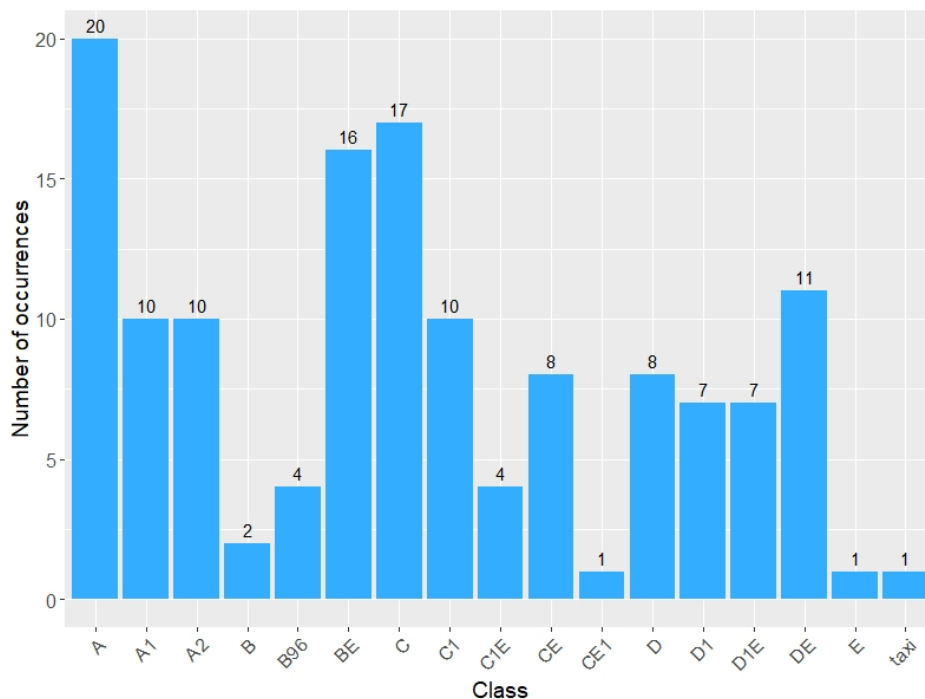


Figure 4.2: Number of other licence class occurrences

In addition to a car licence, 21 participants also have a motorcycle licence (some also filled in the A2 and A1 groups, even though they have a licence for a larger motorcycle). This is proportionally a high number when considering that by the end of 2022, there were only 313 889 motorcycles, excluding mopeds, in Sweden (Analysis, 2023). Another notable class are BE, an extension to the standard passenger car licence entitling the holder to tow trailers of up to 3500 kg, and the C class, entitling the holder to drive heavy vehicles exceeding 3500 kg.

The participants were also asked to specify whether they were professional drivers and, if so, to specify the type of profession. This question was included to be in line with the questionnaire from a previous study conducted by Lidestam et al. (2020) but also to give a better understanding of the participant pool. Of the 60 participants, 10 (16.67%) were professional drivers. Of these 10, most were lorry and ambulance drivers, with four each. Three out of 10 reported being bus drivers, one participant being a fireman, and one being a taxi driver. One participant also stated to be a professional driver in multiple fields.

Of the 60 participants, 44 (73.33%) stated that they have some visual impairment and, therefore, had to wear glasses or contact lenses while driving in the simulator and when they drive in real life. Out of these 44, two were not further analysed since one participant answered "Student" as a visual impairment and one answered "Construction job" as a visual impairment. From the remaining 42 (70% out of the 60 total), 22 (52.38% out of the 42 analysed) reported wearing glasses without specifying what type of impairment, eight (19.04%) were nearsighted, four (9.52%) reported having a combination of nearsightedness and astigmatism. Four (9.52%) participants were farsighted, one (2.38%) participant reported having an immovable eye and wearing glasses, one (2.38%) reported having vitreous detachment in the right eye and wearing glasses, one (2.38%) reported having a window eye retinal detachment and one (2.38%) reported as having a strabismus and an unspecified visual impairment.

The participants were also asked about their driving experience. Specifically on how often they had driven in the last 12 months. All participants indicated that they were driving at least once a week. A majority of 36 (60%) participants answered driving daily, 21 participants (35%) responded driving most days of the week, and only three participants (5%) reported driving a few times a week. The distribution of driving frequency is shown in Figure 4.3.

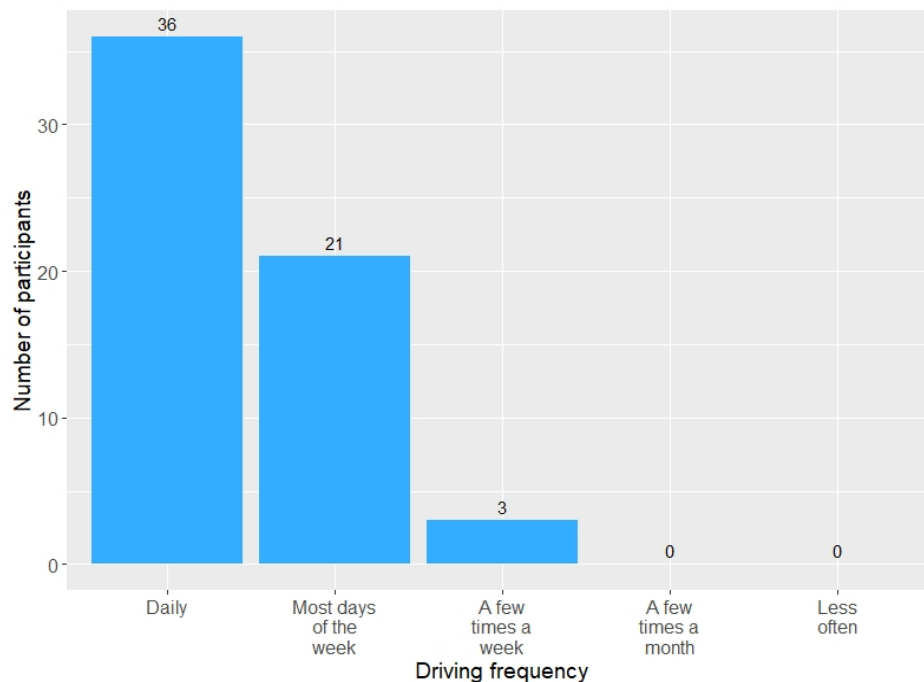


Figure 4.3: Driving frequency of the participants

The last question that the participants were asked in the general demographics questionnaire was about the number of kilometres driven in the previous 12 months. A majority of 22 participants (36.67%) reported driving between 15 000 and 19 999 kilometres in the last 12 months, and 12 participants (20%) reported driving between 20 000 and 24 999 kilometres. The highest amount reported by one participant was 80 000 kilometres in the last 12 months. The answers from all participants are shown in Figure 4.4.

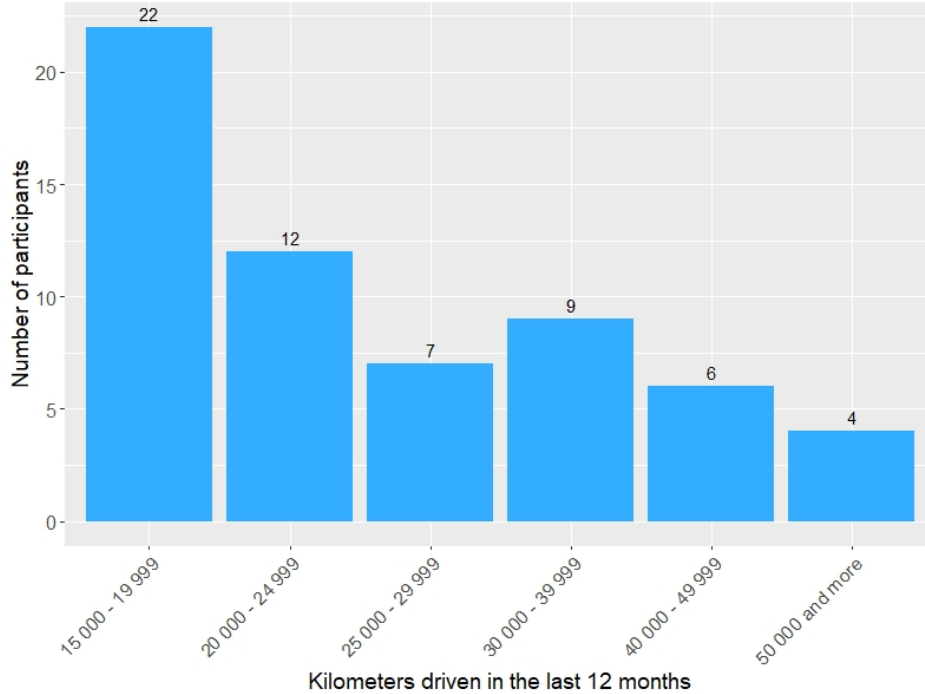


Figure 4.4: Driving experience from the last 12 months

4.3 Results from Driving Simulator Experiment

The following section presents the results of the driving simulator experiment. At first, general information about the participants driving each Scenario Variation is given. Afterwards, an analysis of the data collected from the driving simulator experiment is presented by comparing the Scenario Variations. This provides a better understanding of whether the warnings impact the driver and how significant the impact is. The comparison between the data from the EVA group and the EVA + AEL group then gives us an insight into whether the addition of AEL has any meaningful improvements in the reaction over just the EVA message.

Since this thesis is conceived as a continuation of a study done by Lidestam et al. (2020), the same dependent variables were chosen to be analysed alongside an additional focus on reaction times as well. The analysed variables were the following:

- time between a trigger and a tangible reaction
- time from reaction to the EV overtaking the vehicle
- whether the participants actively used brakes as their reaction
- time from a trigger to giving way to the ambulance (moving at least 3 metres from the centre of the road)

- time from giving way and the ambulance overtaking the vehicle
- distance to the ambulance when giving way
- lateral position when the ambulance was alongside the participant
- speed when the ambulance was alongside the participant
- comparison of mean speed in the area where the ambulance overtook the vehicle

4.3.1 General information about each Scenario Variation's participants

This chapter gives general information about the participants grouped by their respective Scenario Variations. Apart from that, information about any problems and complications with the simulator the experiment supervisors observed is also presented.

Scenario Variation 0 - Baseline group

A total of $n = 20$ participants were part of the Baseline group. The participants were 29 - 75 years old, $M = 53$, $SD = 13.97$. Of these 20 participants, eight were women and 12 were men. The simulator had a bug for two participants when the speakers' volume did not reach the desired volume of 73 dB. For one participant, the simulation did not play the engine sound, but just the ambience like other cars, the ambulance sirens and the music.

Scenario Variation 1 - EVA group

A total of $n = 20$ participants were part of the EVA group. The participants were 44 - 80 years old, $M = 62.2$, $SD = 9.8$. Of these 20 participants, three were women, and 17 were men. The simulator had a bug for two participants when the speakers' volume did not reach the desired volume of 73 dB. For one participant, the simulation did not play the engine sound, but just the ambience like other cars, the ambulance sirens and the music. One participant also experienced difficulty because the steering wheel did not calibrate properly.

Scenario Variation 2 - EVA + AEL group

A total of $n = 20$ participants were part of the EVA + AEL group. The participants were 36 - 80 years old, $M = 60.3$, $SD = 12.9$. Of these 20 participants, six were women and 14 were men. For one participant, the simulator had a bug when the speakers' volume did not reach the desired volume of 73 dB. For one participant, the simulation did not play the engine sound, but just the ambience like other cars, the ambulance sirens and the music.

4.3.2 Simulator Data Analysis

The following section presents the results of the driving simulator experiment. A comparison between all groups is given if applicable. The main objective of the Baseline group was to get a non-influenced and natural reaction and reaction time from the drivers. For the EVA group, the objective was to assess whether the EVA instruction affected the participants. The EVA + AEL group then aimed to determine whether the EVA instruction combined with LED stripes as a primer to the EVA warning affected the participants. This comparison analyses the impact and, if so, how significant they were. The participants from all three groups were instructed to drive as if they were in a hurry while still adhering to the traffic laws. None of them were informed in advance about the purpose of the study, i.e., reaction times analysis, use of warning messages via HMI, and the occurrence of an emergency vehicle in the simulation.

Time difference between the trigger point and a measurable reaction by the driver

The first variable analysed was the time drivers needed to react from the trigger point. For the Baseline group, the distance between the ambulance visible to the driver and the driver's vehicle was 100 metres. This threshold was measured based on several test runs before the experiment started. Given that the participants adhered to the maximum speed limit in the simulation, the 100-meter mark was the first moment the ambulance could be spotted. In the case of the EVA group, the trigger was when the radio lowered the volume, and the EVA message started playing. The trigger point for the EVA + AEL group was when the LED strips began flashing. This variable gives us a better understanding of how long it took for the participants from different groups to take action, thus signifying they were made aware of the ambulance and are actively trying to give way (either by slowing down, driving to the side or both). An overview of the reaction times is presented in Table 4.2 together with the results of the Shapiro-Wilk test of normality to determine if a parametric or non-parametric test should be used for further analysis.

Table 4.2: Overview of the reaction times and results of the Shapiro-Wilk test for each group

Group	$M [s]$	$SD [s]$	W value	p value
Baseline	4.48	1.82	.9	.034
EVA	6.93	2.19	.95	.37
EVA + AEL	13.35	2.56	.88	.019

Figure 4.5 then illustrates the distribution of drivers' response times in each Scenario Variation. Note that each group has outliers, the most notable being in the EVA group, where one participant reacted almost instantly after the radio lowered the volume and the message started playing.

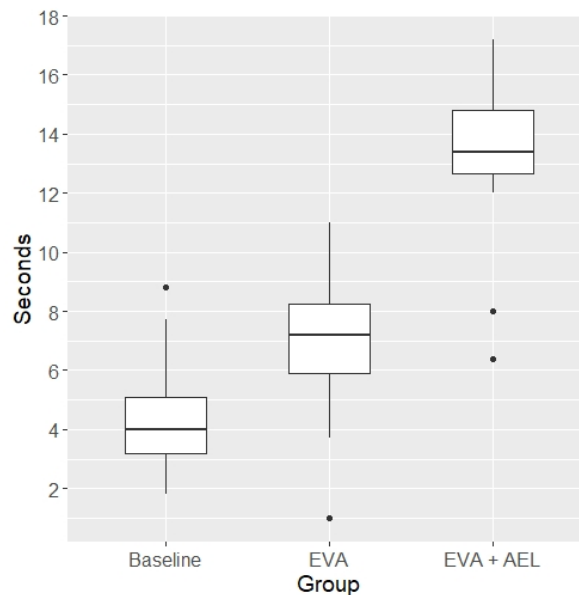


Figure 4.5: Visualisation of the reaction times from the trigger for each group

Since the reaction times from the Baseline group and EVA + AEL group did not pass the normality test ($p < .05$), a non-parametric Kruskal-Wallis Test was selected as the statistical

test to be performed for this variable to test whether or not the warning had any effect on the reaction time of the drivers. The test showed a difference between the three observed groups ($H(2) = 40,8; p < .001; \eta^2 = .68$). To identify between which two groups the difference is, a post-hoc-analysis pairwise comparison using Dunn's test was performed. The results are presented in Table 4.3, which shows statistically significant differences in the reaction times between all three groups. All effect sizes are according to Cohen (1992).

Table 4.3: Dunn's test results for the reaction time

Pair	<i>p</i> value	<i>r</i> value	effect size
Baseline ~ EVA	<.001	.39	medium
Baseline ~ EVA + AEL	<.001	1	large
EVA ~ EVA + AEL	<.001	.61	large

Since the EVA + AEL group also received an EVA warning, a time comparison between the EVA warning and the participants' measurable reaction was made. Only a comparison between the EVA group and the EVA + AEL group could be done. An overview of these reaction times is presented in Table 4.4 together with the Shapiro-Wilk test results.

Table 4.4: Data overview for the time from EVA warning to a measurable reaction

Variable	<i>M</i> [s]	<i>SD</i> [s]	<i>W</i>	<i>p</i>
EVA	6.93	2.19	.95	.37
EVA + AEL	7.58	1.76	.98	.87

Figure 4.6 then illustrates the distribution of drivers' response times in both Scenario Variations. Note that both groups have outliers, the most notable still being the one in the EVA group, where one participant reacted almost instantly after the radio lowered the volume, and the message started playing.

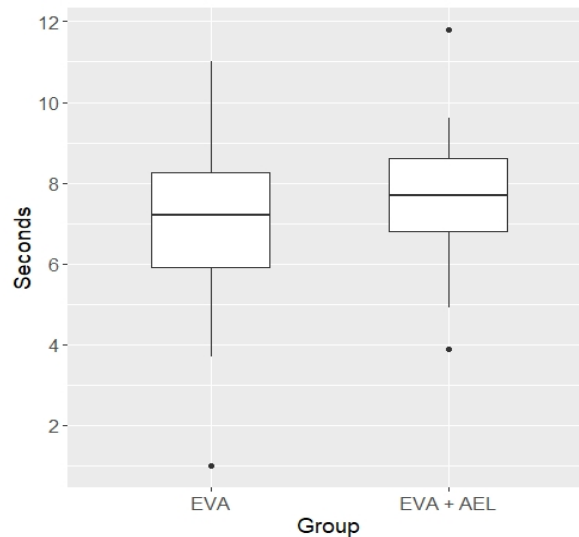


Figure 4.6: The reaction times from EVA warning for EVA and EVA + AEL group

The normality of the data can be assumed for both groups as both groups passed the Shapiro-Wilk test. Based on that, a parametric Welch Two Sample t-test was chosen to be performed to find whether there is a statistical significance between the measured data. Results of the Welch Two Sample t-test are then ($t(22.90) = -0.36, p = .72$). These results signify that there is no statistical significance between the two measurements.

Time difference between the reaction and overtaking by the Emergency vehicle

The second variable analysed was the time difference between the participants' reactions and the moment when the ambulance overtook them. It gives a better understanding of how much time there is between a driver starting to give way and the ambulance overtaking them. Early reaction not only leads to safer overtaking by the ambulance but also allows the ambulance to maintain a higher speed, thus reducing delays. An overview of the response times is presented in Table 4.5 with the results of the Shapiro-Wilk normality test to determine if a parametric or non-parametric test should be performed for further analysis.

Table 4.5: Overview of the response times and results of the Shapiro-Wilk test for each group

Group	$M [s]$	$SD [s]$	W value	p value
Baseline	3.9	1.55	.93	.19
EVA	5.96	2.55	.81	.0017
EVA + AEL	4.74	1.58	.96	.49

Figure 4.7 then illustrates the distribution of drivers' response times in each Scenario Variation. Note that each group has outliers that are in a way mirrored to the previous variable.

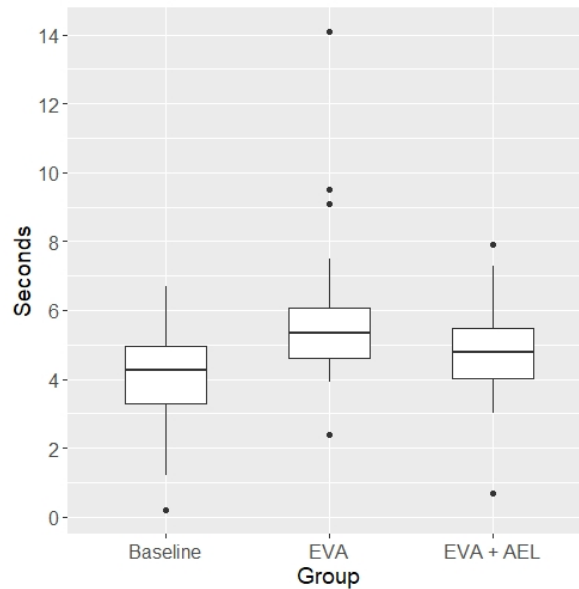


Figure 4.7: Visualisation of the time between reaction and overtaking by the Emergency vehicle

For instance, in the case of the time it took the drivers to react, there was an outlier in the EVA group with almost no response time. The same outlier can be seen with a roughly 14-second delay to the ambulance. Another notable outlier is in the Baseline group, with nearly

zero seconds between them taking action and the ambulance overtaking them. This is the worst possible scenario in this case and signifies that they either did not spot the ambulance or chose to ignore it.

Since, in this case, only the EVA + AEL group passed the normality test ($p < .05$), a non-parametric Kruskal-Wallis Test was again selected as the statistical test to be performed for this variable. This indicates whether the warning affected how far in advance participants reacted. The test showed there is a difference between the three observed groups ($H(2) = 9.11$; $p = .011$; $\eta^2 = .125$). To identify between which two groups the difference is, a post-hoc-analysis pairwise comparison using Dunn's test was performed. The results are presented in Table 4.6, which shows that, in this case, there is a significant difference only between the Baseline group and the EVA group. All effect sizes are according to Cohen (1992).

Table 4.6: Dunn's test results for the time from reaction to overtake

Pair	p value	r value	effect size
Baseline ~ EVA	.0076	.47	medium
Baseline ~ EVA + AEL	.36	1	not significant
EVA ~ EVA + AEL	.46	.61	not significant

Whether the participants actively used brakes in their reaction

The third analysed variable was whether the participants actively used brakes as a part of their reaction. This variable gives us a better understanding of whether the participant actively tried to lower their speed to make the overtaking safer or not. Since, in the scenario, there was a downhill segment before the ambulance was supposed to overtake the vehicle, the vehicle would gain speed before it reached a flat part of the road and would start to decelerate on its own. Because of that, the usage of brakes could have been recognised as a false positive. To avoid this, a braking manoeuvre was only recorded as a positive braking manoeuvre if it lasted until the vehicle was less than 0.5 seconds from overtaking.

This variable was recorded as a "yes/no" (0/1). An overview of the usage of the brakes is presented in Table 4.7.

Table 4.7: Usage of breaks when the ambulance was approaching

Group	used breaks	did not use breaks
Baseline	2	18
EVA	13	7
EVA + AEL	16	4

As this variable was recorded as a binary input, a Fisher's Exact Test was selected as a statistical test to perform for this variable. This told us whether the warning had any effect on the brake usage. The test showed a difference between the three observed groups $p < .001$. To identify between which two groups the difference is, a post-hoc-analysis pairwise comparison using the Proportion test was performed. The results are as follows: Baseline ~ EVA $p = .0033$, Baseline ~ EVA + AEL $p < .001$, EVA ~ EVA + AEL $p = 1$. This signifies that there is a significant difference between the Baseline group and both the EVA and EVA + AEL groups.

Effect of the warning on the driver giving way to the Emergency vehicle (moving at least 3 metres from the centre of the road)

One of the analysed variables was whether the drivers gave way to the ambulance (this was classified as moving at least 3 metres from the road's centre line in a lateral direction). This variable gives us a better understanding of whether the participant actively tried to give way to make the overtaking safer or not. Same as with the analysis from Chapter 4.3.2, to eliminate false positives, it was only recorded if the manoeuvre occurred within the last 1 second before the overtake.

This variable was recorded as a "yes/no" (0/1). An overview of the usage of the brakes is presented in Table 4.8.

Table 4.8: Giving way when the ambulance was approaching

Group	gave way	did not give way
Baseline	0	20
EVA	16	4
EVA + AEL	13	7

Since no one from the Baseline group gave way, a Fisher's Exact Test was performed between the Baseline group and a sum of the EVA and the EVA + AEL group. The results were $p = < .001$. This indicates a strong statistical difference between the groups who did receive the warning and the Baseline group. To further determine if the utilisation of ambient lighting had any effect, a second Fisher's Exact Test was performed between the EVA group and the EVA + AEL group. This test resulted in $p = .48$, which indicates no statistically significant difference between the two groups.

Time difference between the trigger and the driver giving way to the Emergency vehicle (moving at least 3 metres from the centre of the road)

Another analysed variable was the time difference between the trigger and when the participant gave way to the ambulance. This variable gives us a better understanding of whether the drivers gave way and how early. Similarly, as with the braking, giving way to the ambulance leads to safer overtaking by the ambulance but also allows the ambulance to maintain a higher speed, thus reducing delays. No participants from the Baseline group gave way to the ambulance, so they were not part of this analysis. From the EVA group, four participants (20%) did not give way, and from the EVA + AEL group, seven participants (35%) did not give way. All of them were also not part of the further analysis. An overview of the reaction times with the results of the Shapiro-Wilk test of normality is presented in Table 4.9.

Table 4.9: Data overview for the time between the trigger and the driver giving way

Variable	$M [s]$	$SD [s]$	W	p
EVA	10.68	1.18	.96	.73
EVA + AEL	15.84	1.35	.89	.092

Figure 4.8 then illustrates the distribution of the times between the trigger and drivers giving way. There are still outliers in the EVA + AEL group, but they are not as prominent as they were in the case of the previous variables.

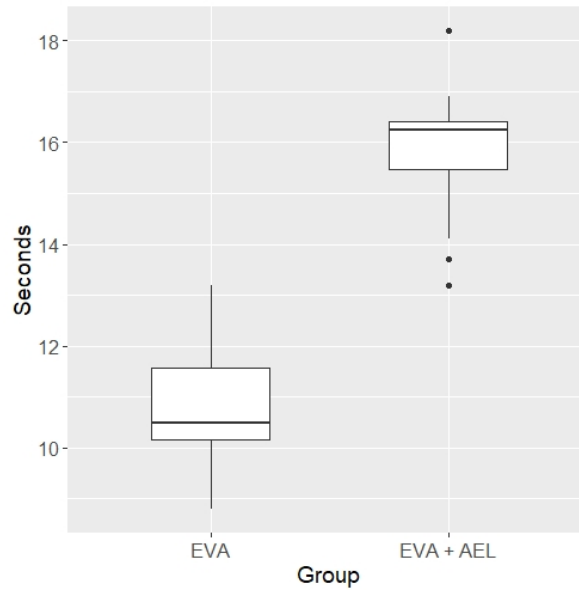


Figure 4.8: Visualisation of the times between the trigger and the driver giving way

Both of the groups passed the Shapiro-Wilk test of normality, and a parametric Welch Two Sample t-test was performed to find if there was any significant difference between the groups. The result of the Welch Two Sample t-test is ($t(26,15) = -11.09, p < .001$), which signifies a statistically significant difference between the two groups.

Time difference between the driver giving way and overtaking by the Emergency vehicle (moving at least 3 metres from the centre of the road)

The following analysed variable was the time difference between the driver giving way and the vehicle being overtaken by the ambulance. This variable gives similar information as the variable from Chapter 4.3.2 but from a different point of view. In Chapter 4.3.2, the observed variable was the time from the reaction to the overtake. The focus in the present chapter is only on the time between giving way and the overtake. This can be seen as an extension to the previous variable since lowering the vehicle's speed has a beneficial effect on the response time and overall safety of the manoeuvre. However, if the driver not only slows down but also pulls over to the side of the road, giving the emergency vehicle more room to overtake, this increases safety even further. Similarly, as with the variable from Chapter 4.3.2, the Base-line group was not part of this analysis, and the EVA group with the EVA + AEL group had their samples reduced by those who did not give way. An overview of the response times with the results of the Shapiro-Wilk normality test is presented in Table 4.10.

Table 4.10: Data overview for the time between the driver giving way and the overtake

Variable	$M [s]$	$SD [s]$	W	p
EVA	2.41	1.19	.96	.66
EVA + AEL	2.61	1.7	.94	.45

Figure 4.9 then illustrates the distribution of the times between them giving way and them being overtaken. Note that this variable does not have any outliers in either of the groups. This suggests that if the participants did give way, they did it in a fairly consistent manner.

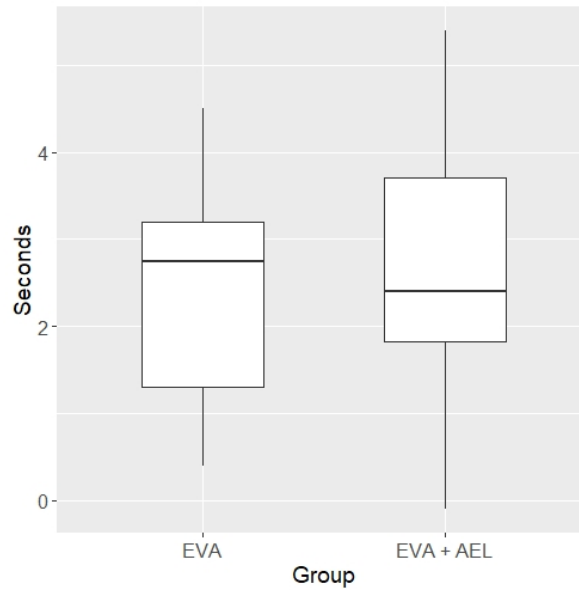


Figure 4.9: Visualisation of the time between the driver giving way and the overtake

As both groups passed the Shapiro-Wilk test of normality, a parametric Welch Two Sample t-test was performed to find if there was any significant difference between the groups. The result of the Welch Two Sample t-test is ($t(22,9) = -0.36, p = .72$), which signifies no statistically significant difference between the two groups.

Distance between the vehicle and Emergency vehicle when giving way (moving at least 3 metres from the centre of the road)

The following analysed variable was the distance between the driver and the ambulance when the driver began giving way. This tells us how far apart the vehicles were from one another and, in a way, the reaction distance of the driver (in terms of giving way, not reaction in general). In practice, the further away from the ambulance the driver reacts, the more distance the ambulance has to spot that the driver is giving way and thus adjust the speed accordingly. Similarly, as with the variable from Chapter 4.3.2, the Baseline group was not part of this analysis, and the EVA group with the EVA + AEL group had their samples reduced by those who did not give way. An overview of the distance with the results of the Shapiro-Wilk normality test is presented in Table 4.11.

Table 4.11: Data overview for the distance between the vehicles when the driver began giving way

Variable	$M [m]$	$SD [m]$	W	p
EVA	27.76	13.02	.93	.22
EVA + AEL	36.03	16.09	.97	.83

Figure 4.10 then illustrates the distribution of the distance between the vehicles when the driver began giving way. Note that this variable also does not have any outliers in either of the groups.

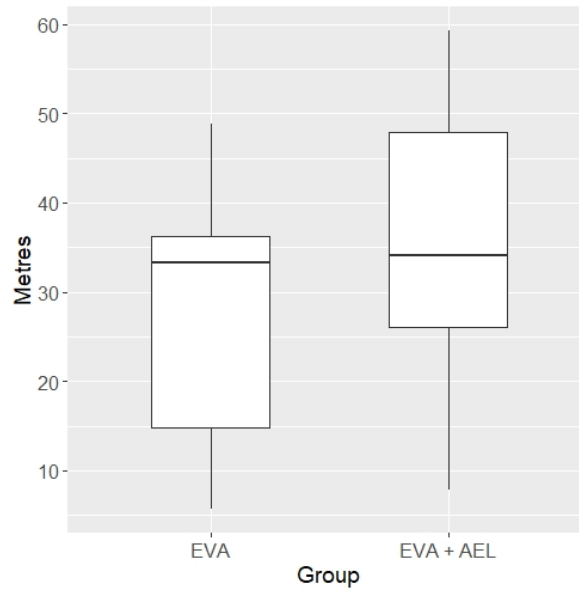


Figure 4.10: Visualisation of the distance between the two vehicles when the driver began giving way

As both groups passed the Shapiro-Wilk test of normality, a parametric Welch Two Sample t-test was performed to find if there was any significant difference between the groups. The result of the Welch Two Sample t-test is ($t(22,96) = -1.50, p = .15$), which signifies no statistically significant difference between the two groups.

Vehicle's lateral position relative to the road centre when being overtaken by the Emergency vehicle

Another analysed variable was the vehicle's lateral position relative to the road centre when they were overtaken by the ambulance. This variable indicates how much space the drivers gave to the ambulance when it was overtaking them. The lateral position is crucial when there might be oncoming traffic or other vehicles on the road in the same direction. An overview of the lateral position is presented in Table 4.12 together with the results of the Shapiro-Wilk normality test to determine if a parametric or non-parametric test should be used for further analysis.

Table 4.12: Overview of the vehicle's lateral position relative to the road centre when being overtaken by the ambulance, and results of the Shapiro-Wilk test for each group

Group	$M [m]$	$SD [m]$	W value	p value
Baseline	1.95	0.4	.93	.14
EVA	2.93	0.83	.91	.063
EVA + AEL	2.87	0.78	.96	.6

Figure 4.11 then illustrates the distribution of the vehicle's lateral position relative to the road centre when being overtaken by the ambulance in each Scenario Variation. Note that each group has outliers, with the most notable for the EVA and the EVA + AEL groups. These were the only two participants who used the available lay-by area located in a place where

the ambulance was expected to overtake, provided that the driver complied with the 80 km/h speed limit.

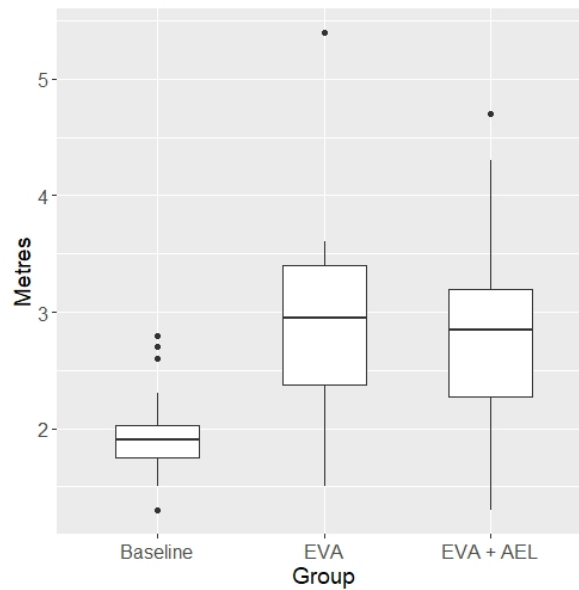


Figure 4.11: Visualisation of the vehicle's lateral position relative to the road centre when being overtaken by the ambulance for each group

As seen in Table 4.12, all three groups passed the Shapiro-Wilk test of normality; thus, a parametric ANOVA Test was selected as the statistical test for this variable. This indicates if there was any difference in the amount of space the participants provided when overtaken by the ambulance. The test showed there is a difference between the three observed groups ($F(2, 57) = 12.3; p < .001 \eta^2 = .3$). To identify between which two groups the difference is, a post-hoc-analysis comparison using Tukey's HSD test was performed. The results are presented in Table 4.13, which shows that, in this case, there is a significant difference between all three groups. All effect sizes are according to Cohen (1992).

Table 4.13: Dunn's test results for the time from reaction to overtake

Pair	<i>p</i> value	Cohen's <i>d</i>	effect size
Baseline ~ EVA	< .001	-1.5	large
Baseline ~ EVA + AEL	< .001	-1.47	large
EVA ~ EVA + AEL	.95	.08	not significant

Vehicle speed, when the Emergency vehicle was overtaking the participant

The last analysed variable was the speed of the participants' vehicles when they were overtaken by the ambulance. This variable better explains how much the participants slowed down in this situation. Since the other cars' speed influences the ambulance's speed, the lower the participant's speed, the safer it is to pass them. An overview of the speeds is presented in Table 4.14 together with the results of the Shapiro-Wilk normality test to determine if a parametric or non-parametric test should be used for further analysis.

Table 4.14: Overview of the vehicle's speed when being overtaken, and results of the Shapiro-Wilk test for each group

Group	<i>M</i> [km/h]	<i>SD</i> [km/h]	<i>W</i> value	<i>p</i> value
Baseline	80.66	5.54	.97	.85
EVA	61.7	20.65	.87	.013
EVA + AEL	56	22.45	.87	.093

Figure 4.12 illustrates the distribution of drivers' response times in each Scenario Variation. Note the outlier in the EVA group, the only participant who stopped the vehicle to make it safe for the ambulance to pass them.

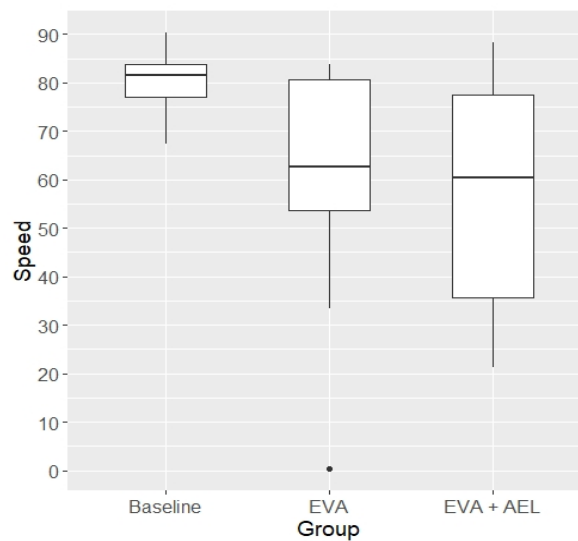


Figure 4.12: Visualisation of the vehicle's speed when being overtaken for each group

Since only the Baseline and EVA + AEL group passed the normality test, a non-parametric Kruskal-Wallis Test was selected for this variable's statistical test. This shows whether the warning affected the participants' speed when being overtaken. The test showed a difference between the three observed groups ($H(2) = 17$; $p < .001$; $\eta^2 = .263$). A post-hoc-analysis pairwise comparison using Dunn's test was performed to identify the difference between the two groups. The results are presented in Table 4.15, which shows a significant difference between the Baseline group and the EVA group, the Baseline group and the EVA + AEL group. All effect sizes are according to Cohen (1992).

Table 4.15: Dunn's test results for the time from reaction to overtake

Pair	<i>p</i> value	<i>r</i> value	effect size
Baseline ~ EVA	.0052	-0.5	medium
Baseline ~ EVA + AEL	< .001	-0.62	large
EVA ~ EVA + AEL	.45	-0.12	not significant

Comparison of mean speeds between the groups

Another measure of the participants' driving performance was a comparison of their mean speeds. By observing Figure 4.13 of the mean speeds with SE (standard error) intervals of the Baseline group, it can be seen virtually no reaction to the trigger regarding slowing down the vehicle; in fact, the opposite reaction. The peak in mean speed at around 4000 metres is due to the downhill section in the simulation. The reason was to make it more difficult to spot the ambulance by accelerating the vehicle to make the driver more focused on maintaining the proper speed. After the peak, a slow flattening of the curve can be observed, with a change at around 4120 metres, which came after the average point of the group's reaction at 4080 metres. The deceleration can then be observed up to the average overtaking point at 4170 metres and partly beyond.

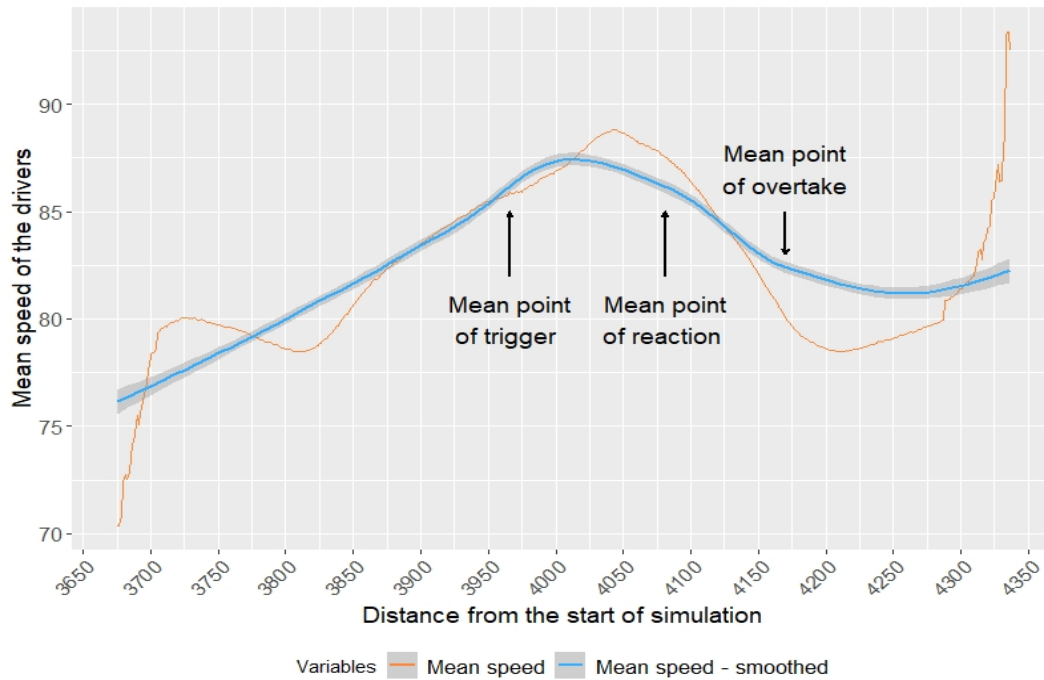


Figure 4.13: Mean speed of the Baseline group

Comparing the Baseline group's mean speed with the EVA group's mean speed in Figure 4.14, it can be seen that the EVA group had a smoother pace. Unlike the base group, the EVA group participants did not reach the same peak average speed on the downhill section, but the peak occurred about 150 metres earlier. The former average reaction point at 4017 metres can also be observed. A more pronounced deceleration than the Baseline group occurred together with achieving a lower mean speed at the average overtaking point at 4140 metres. The drop in the unsmoothed speed curve was caused by the participant coming to a complete stop before the ambulance passed.

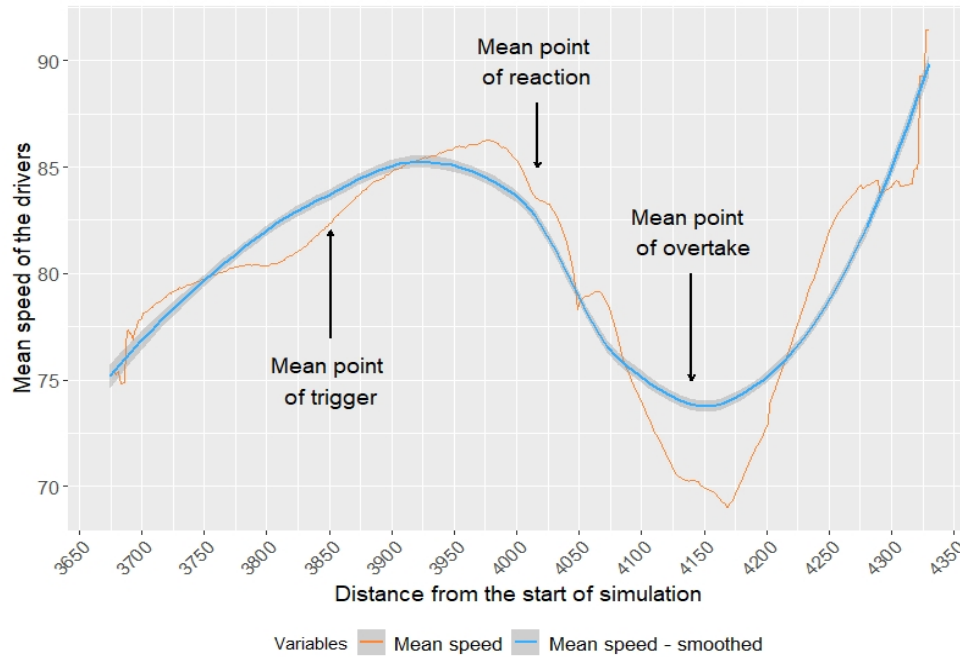


Figure 4.14: Mean speed of the EVA group

Although the mean speed of the EVA + AEL group in Figure 4.15 seems to be the same as for the EVA group, there are some notable differences. The main one is that the EVA + AEL group participants did not reach the same peak average speed as the EVA group, and their acceleration on the downhill section is more linear. However, the average reaction point is at 4050 metres, compared to the 4017 metres of the EVA group. The mean speed is virtually the same as in the EVA group.

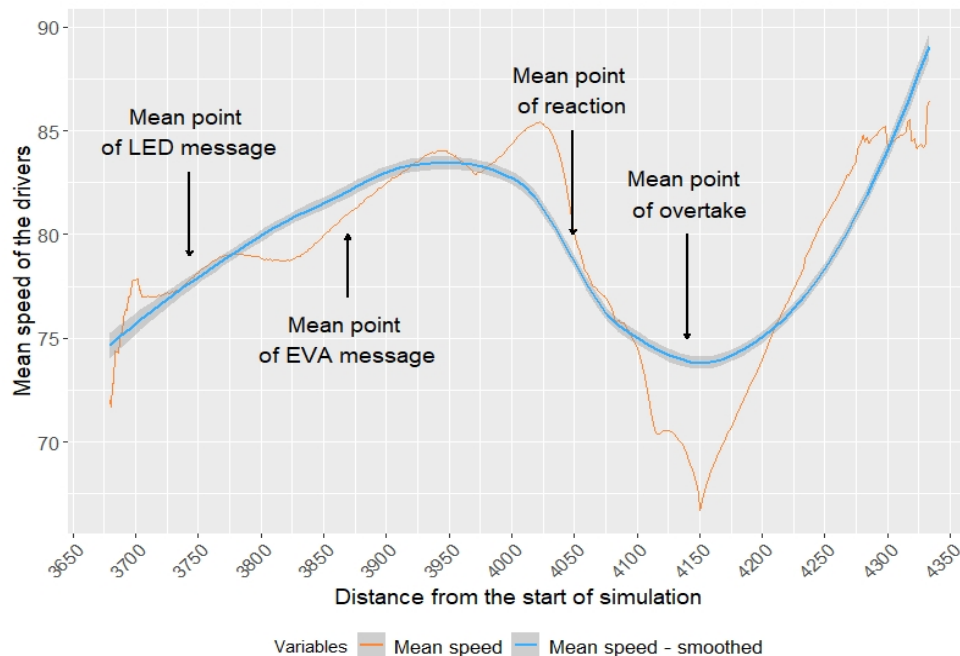


Figure 4.15: Mean speed of the EVA + AEL group

Figure 4.16 then compares all three groups. One of the notable differences is the different peak mean speeds of all groups. Be it when they achieved it or at what speed they achieved it. Another noteworthy difference is the average reaction point between the groups, with the EVA group reacting the soonest, followed by the EVA + AEL group and the Baseline group responding the latest. Figure 4.16 then further confirms the findings of the statistical test from Chapter 4.3.2, that there was no significant difference between the speeds of the vehicles from the EVA and the EVA + AEL group when they were being overtaken by the ambulance. The last notable difference is how the groups reacted after they had been overtaken by the ambulance. While the participants from the EVA and the EVA + AEL groups accelerated at roughly the same pace right after being overtaken, the Baseline group participants further decelerated for another approximately 100 meters before starting to accelerate again.

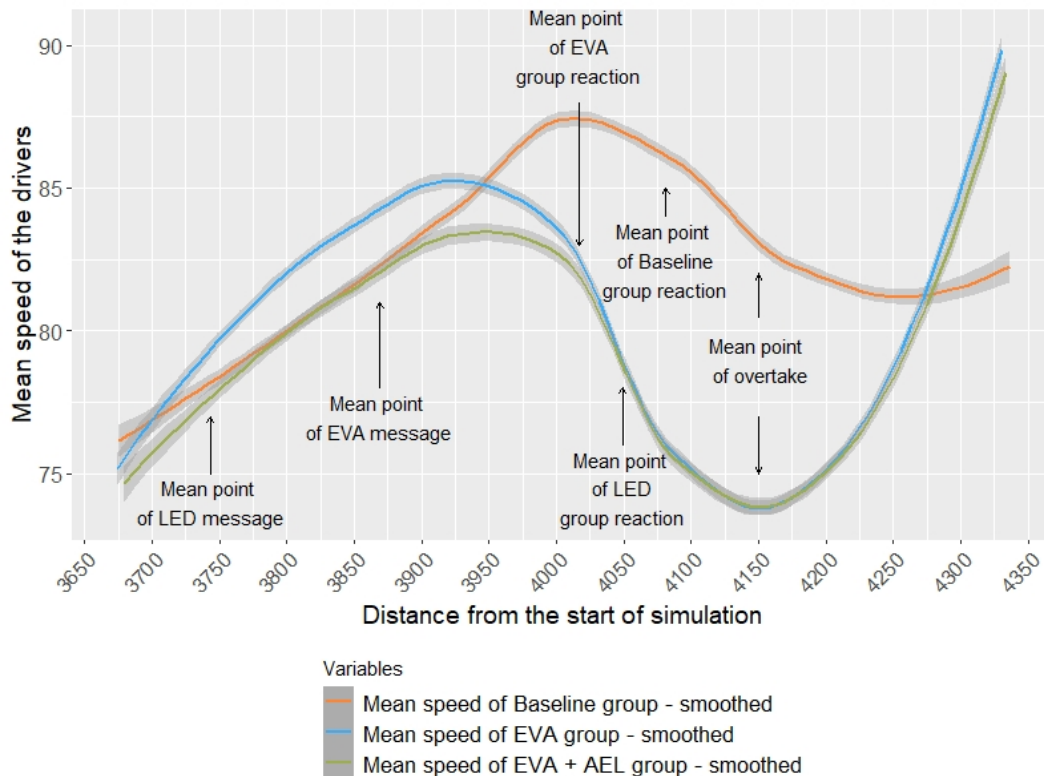


Figure 4.16: Mean speeds of all three groups

4.4 Results of Post-survey Questionnaire

After the driving simulator experiment, participants were given a second questionnaire that they had to fill out. Firstly, the questions that are the same across all the Scenario Variations are analysed, and then the specific set of questions regarding each Scenario Variation is presented.

4.4.1 Post-survey Analysis - Common part

The following sections present the results of the common part of the post-survey questionnaire. The common questions were aimed at the participants' knowledge of how to behave in this situation. Participants were also asked whether they had spotted the ambulance before it had passed them.

Scenario Variation 0 - Baseline group

After the driving simulator experiment, participants were given a second questionnaire that they had to fill out. Of the 20 participants, eight (40%) reported that they had spotted the ambulance before it passed them, and 12 (60%) said they had not spotted it in advance. The next question was whether the participants had a general knowledge of how to behave when an ambulance is overtaking them. There, 19 (95%) participants answered that they knew what to do in the situation and one (5%) participant responded that they did not know what to do. Lastly, the participants were asked where they learned what to do in such a situation and generally when an emergency vehicle is approaching them from any direction. There, 15 (75%) participants answered that they had learned about this during their driving licence training, and one (5%) participant reported that they had learned by observing others in a similar situation. The four remaining answered that they have learned by other means, one (5%) participant responded that they do not recollect how they received this information, one (5%) participant answered that they learned from experience, and two (10%) participants responded that they have learned during their experience when they have been driving in an emergency vehicle.

Scenario Variation 1 - EVA group

Of the 20 participants, 16 (80%) reported that they had spotted the ambulance before passing them, and four (20%) said they had not spotted it in advance. The next question was whether the participants knew how to act when the ambulance was overtaking them. All 20 (100%) participants answered that they knew what to do in the situation. Lastly, the participants were asked where they had learned about what to do in such a situation and generally when an emergency vehicle was approaching them from any direction. There, nine (45%) participants answered that they had learned about this during their driving licence training, and one (5%) participant reported that they had learned by observing others in a similar situation. The ten remaining answered that they knew by other means, four (20%) participants responded that they learned from experience, three (15%) participants answered that they were told by emergency vehicle drivers, two (10%) participants responded that they have learned during their experience when they have been driving in an emergency vehicle, and one (5%) participant answered that they do not recollect how they received this information, and if not, then by common sense.

Scenario Variation 2 - EVA + AEL group

Out of the 20 participants, 16 (80%) reported that they had spotted the ambulance prior to its passing, and four (20%) said they had not spotted it in advance. The next question was whether the participants knew how to act when the ambulance was overtaking them. There, 19 (95%) participants answered that they knew what to do in the situation and one (5%) participant responded that they did not know what to do. Lastly, the participants were asked where they learned what to do in such a situation or generally when an emergency vehicle is approaching them from any direction. There, 13 (65%) participants answered that they had learned about this during their driving licence training, two (10%) participants reported that they had learned by observing others in a similar situation, and two (10%) participants said that they have never received such information. The three remaining have answered that they have learned by other means, one (5%) participant responded that they learned from common sense, one (5%) participant answered that they have learned during their experience when they have been driving in an emergency vehicle, and one (5%) participant responded that they have received the information from private lessons and by observing others in a similar situation.

Results across all the common parts

In total, 40 (66.7%) participants spotted the ambulance before it passed them, and 20 (33.3%) participants did not spot the ambulance in advance. Regarding the knowledge about what to do in such a situation, 59 (98.3%) participants reported that they knew what to do in that situation, and one (1.7%) participant did not know how to react in such a situation. Lastly, regarding where the participants learned what to do in this situation, a majority, 37 (61.7%), reported that they had learned what to do during their lessons when they were in driving school, four (6.7%) participants said that they had learned it by observing other drivers and two (3.3%) reported, that they never received such information. The remaining 17 (28.3%) participants reported learning by other means. There, the prevailing answers were by experience and being an emergency driver.

4.4.2 Post-survey Analysis - Specific part

Scenario Variation 1 - EVA group

The following section presents ratings and subjective comments from the EVA group participants about the warnings they received.

The participants were asked to evaluate various aspects of the warning and provide their subjective feedback. When asked to "grade" the warning on a scale of 0 - 100 (with 0 being "I did not like it at all" and 100 being "I liked it very much"), participants were generally supportive of the warning with the average rating of $M = 78.05$, $SD = 25.88$. Furthermore, participants were asked about the timing of the warning, where 12 (60%) participants were satisfied with the timing and would not change it, seven (35%) participants would have liked the warning earlier, and one (5%) participant would have liked it later.

The participants were then asked how they would prefer to receive the warning if they had a choice. There, multiple options could be selected. The most preferred way, by 14 (70%) participants, would be to receive this sort of warning message in a Heads-Up display if the car would be equipped with this technology. After the Heads-Up display, the second most preferred way, by 11 (55%) participants, for the warning message to be displayed would be the same as they received it in this Scenario Variation, via the instrument cluster. Five (25%) participants would prefer to have the message received by the cars' central screen (infotainment display), and three (15%) participants would like to utilise the ambient lighting.

Lastly, the participants were asked to give feedback about the EVA warning message. A majority of the participants were satisfied with the warning. The main positives were that the warning helped them spot the ambulance sooner than they would have otherwise and that the voice-over reinforced the message. Regarding the negatives, they were primarily aimed at the fact that the participants would have liked to have the warning earlier and that the message made the situation more stressful.

Scenario Variation 2 - EVA + AEL group

The following section presents ratings and subjective comments from the EVA + AEL group participants about the warnings they received.

Participants were asked to evaluate the warning and provide feedback subjectively. When asked to "grade" the warning on a scale of 0 - 100 (with 0 being "I did not like it at all" and 100 being "I liked it very much"), participants were generally supportive of the warning with the average rating of $M = 77.55$, $SD = 19.83$. Furthermore, participants were asked about the timing of the warning, where 11 (55%) participants were satisfied with the timing and would not change it, eight (40%) participants would have liked the warning earlier, and one (5%) participant would have liked it later.

The participants were also asked how they would prefer to receive the warning if they had a choice. There, multiple options could be selected. By 11 (55%) participants, the most

preferred way would be to receive this warning message in an instrument cluster. The following frequent answer was to receive the warning via a HUD if the car would be equipped with that technology. This option would prefer nine (45%) participants. Six (30%) participants would like the message received on the cars' central screen (infotainment display), and five (25%) participants would like to utilise the ambient lighting, same as in their Scenario Variation.

Lastly, the participants were asked to give feedback about the EVA + AEL warning message. As with the EVA group, most participants were satisfied with the warning. The main positives were that the warning made them more vigilant and helped them spot the ambulance sooner than they would have otherwise and that the voice-over reinforced the message. Regarding the negatives, they were also primarily aimed at the fact that the participants would have liked to have the warning earlier and that the message made the situation slightly more stressful.

Comparison of participants' ratings

Since the EVA and the EVA + AEL group participants rated their respective experiences with the warning messages, a statistical test was performed to compare their attitudes towards this technology. Firstly, a Shapiro-Wilk normality test was performed, and its results and the rating overview are shown in Table 4.16.

Table 4.16: Overview of the ratings of each warning message with results of the Shapiro-Wilk test for each group

Group	<i>M</i>	<i>SD</i>	<i>W</i> value	<i>p</i> value
EVA	78.05	25.88	.78	< .001
EVA + AEL	77.55	19.83	.86	.007

Figure 4.17 further illustrates the rating distribution. Both groups have notable outliers, with one EVA group participant rating the whole experience 2/100, the worst rating given.

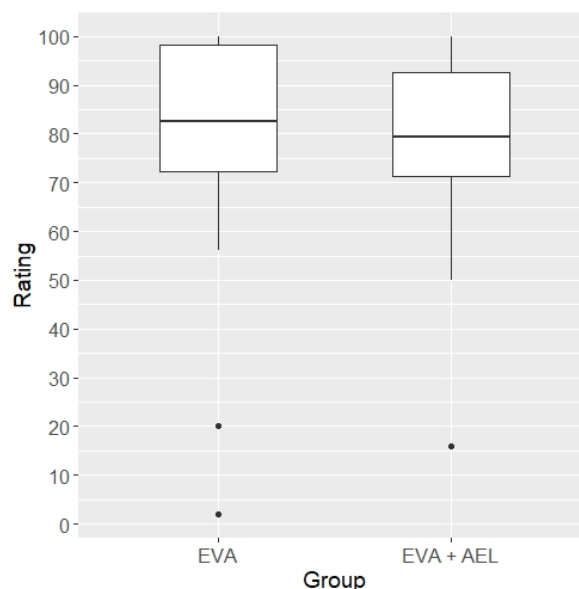


Figure 4.17: Participants' experience rating

Since neither group passed the Shapiro-Wilk normality test, a non-parametric Wilcoxon rank sum test was selected as the statistical test to be performed on the data. This tells us whether one means of delivering the warning is preferred over the other (based on the participant's subjective ratings). The test result was $p = .55$, which signifies no statistical difference between the two groups.

4.4.3 Participants' reactions when the Emergency vehicle was approaching them

The following section analyses the question: "What is your general reaction when an emergency vehicle approaches?". This question was only part of the post-survey questionnaires for the EVA and the EVA + AEL groups. Because of technical problems with the questionnaire, only 16 answers were saved from the EVA + AEL group. Each participant could choose multiple answers to this question. The answers were subsequently divided into two sub-categories.

Participants' feeling when an emergency vehicle is approaching them

This section focuses on how the participants feel in this situation rather than their physical reactions, which can help to understand how aware the participants are and if the situation puts them in distress. Figure 4.18 indicates that nearly half of the participants become more aware of their driving in the cases of the EVA group and the EVA + AEL group.

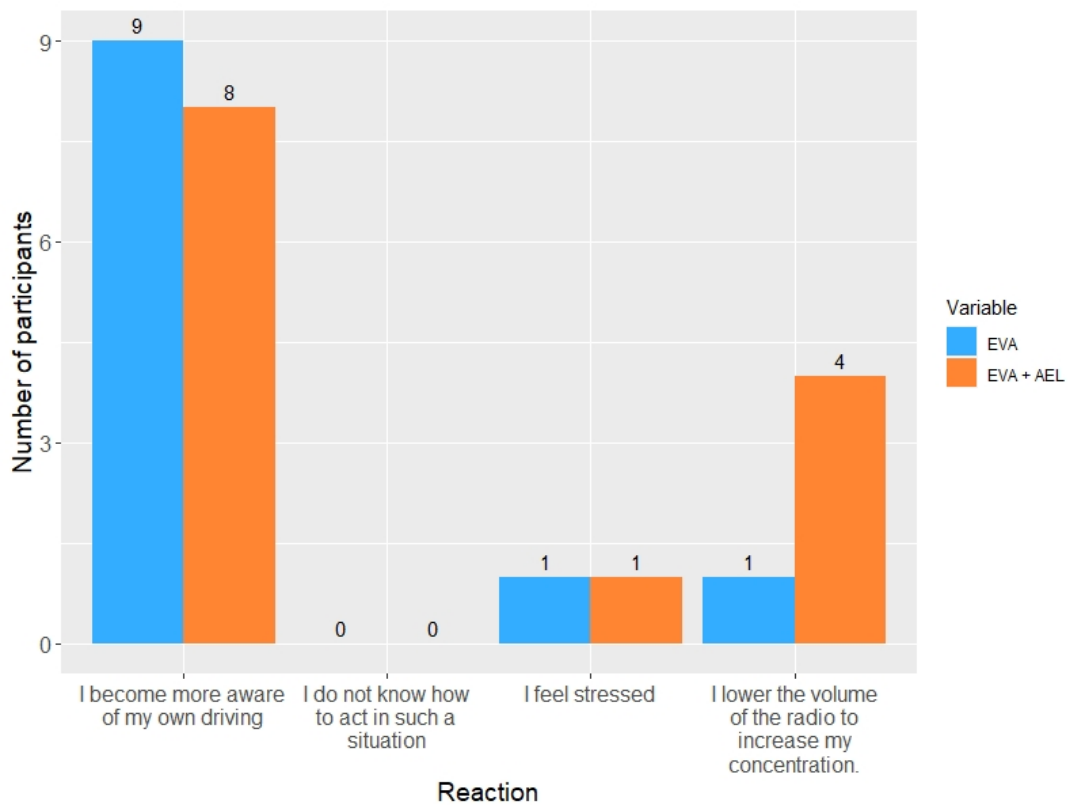


Figure 4.18: Participants' feeling when an emergency vehicle is approaching

A small fraction of drivers, one from the EVA group and four from the EVA + AEL group, responded that they lower the radio volume to increase their concentration on driving. Although this reaction is rare, it highlights one of the steps drivers take to raise their awareness

and stay attentive. Feeling stressed was a rare reaction from the participants. Only one participant from the EVA group and one from the EVA + AEL group responded that they felt this way. This suggests that an emergency vehicle does not induce anxiety in the participants; thus, they can react more quickly and safely. As shown in Figure 4.18, none of the participants responded: "I do not know how to act in such a situation". This suggests that all participants have a certain level of knowledge and confidence to react accordingly in the situation when an emergency vehicle is approaching them.

Participants' response when an emergency vehicle is approaching them

This section focuses on the specific driving reactions of the participants when an emergency vehicle is approaching them, which can help to understand how they react in such a situation. As shown in Figure 4.19, the most widespread reaction among the participants was to give immediate clearance to the emergency vehicle. This behaviour was reported by 16 participants from the EVA group and 13 from the EVA + AEL group. This reaction proves that the drivers are aware of their surroundings and understand the situation's urgency.

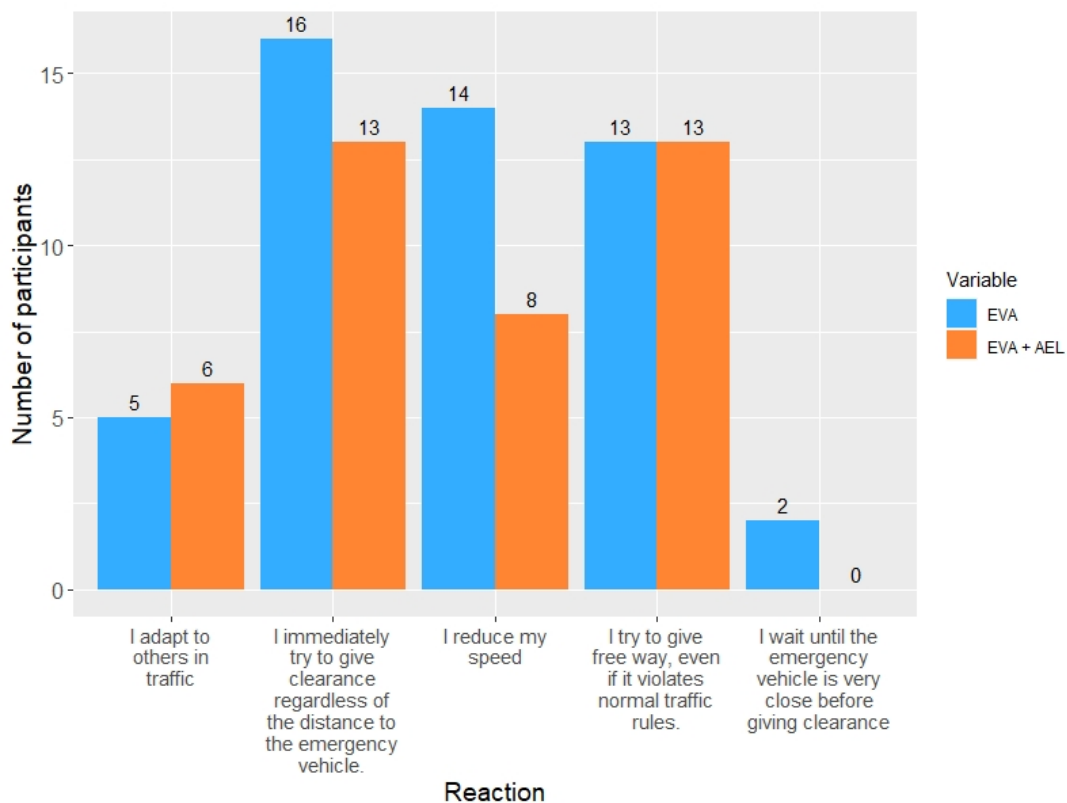


Figure 4.19: Participants' reaction to emergency vehicle

A significant number of participants, 14 from the EVA group and eight from the EVA + AEL group, reported that one of their reactions is reducing speed. This reaction is one of the most common among drivers when presented with any unexpected situation on the road (Schaap, 2012). By slowing down, the driver does not need to focus that much on the road ahead and has more mental capacity to assess the situation and react accordingly. Likewise, a significant number of the participants, 13 from both groups, reported trying to give clearance to the emergency vehicle even if it violates traffic laws. This indicates that drivers are strongly willing to prioritise emergency vehicles' needs over traffic laws.

Five participants from the EVA group and six from the EVA + AEL group responded that they adapt their driving to others in the traffic. This suggests that the drivers might experience collective behaviour to some extent. The least common reaction was waiting until the emergency vehicle is close before giving it way. Of all the participants, only two from the EVA group answered that this is one of their reactions. This further signifies that this reaction is fairly uncommon and ineffective since waiting until the emergency vehicle is close to the driver's car gives the driver less time to make the desired manoeuvre, which may lead to an abrupt, more obstructive than helpful reaction.



5 Discussion

This thesis aimed to investigate if and how ambient lighting can improve the response of drivers presented with situations when they need to interact with an emergency vehicle. Ambient lighting is a technology slowly trickling down to economy cars or cars in even cheaper segments. Today, ambient lighting is used solely to set the ambience in the vehicle cabin, with very few examples of utilising the technology practically. The ambient lighting was used to "prime" the driver for the situation in the driving simulator experiment, and the results were compared to a Scenario Variation where either no warning was present, or just an EVA message was delivered to the driver. The following chapter provides a discussion of the findings from the data analysis and answers to the following research questions:

1. Can ambient lighting, combined with EVA warning, help drivers react faster and safer when an emergency vehicle is approaching?
2. Can the EVA warning with ambient lighting increase the safety of the encounter with the emergency vehicle on the road compared to the current situation with no warnings??
3. How do the drivers feel about augmenting the EVA warning with the LED lights and their subjective reactions?

5.1 Results of Driving Simulator Study

Three distinct Scenario Variations were used to analyse the effects of utilising ambient lighting in an encounter with an emergency vehicle (in this experiment, an ambulance). Of these three, two were Scenario Variations with a warning message and one without any message. This Scenario Variation was used in the analysis as a baseline reaction of drivers when encountering an ambulance. A between-group design was used to mitigate any potential priming effect. Therefore, each participant drove only one Scenario Variation, and no one had prior knowledge about the study. This study was intended as an extension of research done by Lidestam et al. (2020). The previous research targeted inexperienced drivers, while the current study targets experienced drivers. This was defined by the following criteria, which needed to be met by every participant:

- Driver has to have a valid driving licence for a passenger car; this meant a category B in Sweden
- Driver has to drive a minimum of 15 000 kilometres per year

5.1.1 Pre-survey

A total of $n = 62$ participants registered for the study, but one participant did not finish the experiment because of motion sickness from the simulator, and one did not meet the "15 000 kilometres driven in last year" criteria. With these two removed from the participant pool, a total of $n = 60$ participants were part of the study. Each Scenario Variation had 20 participants to ensure equal data pools for the analysis. The average age of the participants was $M = 58.49$, with a third of the participants obtaining their driver's license between 1970 and 1980. This leaves a considerable number of participants who might not know about ambient lighting in cars. Since this technology was almost nonexistent until the early 2000s' and even nowadays is not as widely used in cars as other technologies, the unfamiliarity with the technology could have been a factor.

5.1.2 Simulator data

All Scenario Variations had the same simulator scenario, which was a recreated version from a study done by Lidestam et al. (2020), containing a rural road located mainly in a forest environment. Both oncoming traffic and traffic in front and behind the participant were present in the simulation. The participants were told to drive as if in a hurry but still adhere to the maximum allowed speed of 80 km/h. There was a planned encounter with an ambulance at a specific point in all Scenario Variations, and the participants' reactions were analysed. To make the ambulance harder to spot, two vehicles obstructed the rear view of the participants, and a downhill section of the road was present right before the encounter. Additionally, a radio was played at 73 dB volume throughout the runs to make it more difficult to hear the sirens and approximate the real-world situation until participants received the EVA warning message. The radio volume was automatically lowered so the message could be heard.

The experiment results indicated a statistically significant difference between the driving habits of the participants based on the warning message they received. Even though the participants who got the EVA warning message reacted later to it as a trigger and the participants from the EVA + AEL group even later, compared to the Baseline group (this was expected since the warnings came earlier before the ambulance could be physically spotted). Their driving behaviour and reactions were much more appropriate to the given situation. An example might be the usage of brakes as an active part of the reaction instead of letting the vehicle slow down on its own via engine braking. In this case, there was a statistically significant difference between the Baseline group and the EVA group, and the Baseline group and the EVA + AEL group with $p = .0033$ and $p = < .001$, respectively. Another notable difference was that zero drivers from the Baseline group, who did not receive any warning, gave way to the ambulance. On the other hand, using ambient lighting to the EVA warning message did not yield any statistically significant results $p = .48$.

Regarding the reaction, the warning had a statistically significant effect on the lateral position of the participant's vehicle and their speed when overtaken. In the case of the lateral position of the car, there was a statistically significant difference between the Baseline group and the EVA group, and the Baseline group and the EVA + AEL group with $p < .001$ and $p = < .001$, respectively. Since no participant from the Baseline group gave way, it could also be argued that the warning was necessary for the drivers to give way. In the case of the speed of the vehicle, there was also a statistically significant difference between the Baseline group and the EVA group, and the Baseline group and the EVA + AEL group with $p < .0052$ and $p = < .001$, respectively. However, in this case, the effect of the warning was not as strong for the EVA group as in the case of the lateral position.

When analysing the mean speed of each group, it was noted that the EVA group and EVA + AEL group started to accelerate after the ambulance had passed them much sooner and faster compared to the Baseline group. This may indicate that the participants, when they received the warning, were not expecting any further encounters or the accident the ambulance might be responding to once the warning message had stopped. This might be a potential negative side effect of the system, where the drivers could put full trust into the system and not rely on their own judgement and vigilance as much.

5.1.3 Post-survey

Common part

Most participants, 59 out of the 60 total, reported that they knew what to do in the presented situation. This further solidifies that the participants were experienced drivers. However, this answer is not supported to the same extent by the result of the analysed variables from the simulator. Especially when considering the results from Chapter 4.3.2 and Chapter 4.3.2, where the respective groups had a statistically significant difference in the speeds and lateral positions. Out of the 20 participants in the Baseline group, only eight of them were able to spot the ambulance in advance. It could be argued that if all the participants from the Baseline group had been able to spot the ambulance in advance, they would have reacted in a way that showed their intention to give way to the ambulance. For example, by moving over to the side, reducing their speed by actively breaking or not reaching that high of a speed before they started slowing down.

Specific part

The results of this question make sense from the participants' perspective since the majority chose to receive the message by the means that would be mainly within the driver's field of view. On the other hand, the low number of participants choosing the ambient lighting was also expected since that technology is relatively new and hard to imagine.

The need for earlier warning might be justified since, in this case, on rural roads, the speed limits are relatively high, and emergency vehicles travel even faster on most occasions. This might have a psychological effect when the drivers feel they lack time or space to react adequately. On the contrary, the timing would not need to change in the case of highways since the viewing conditions are much better, which could allow the driver to feel more prepared. Similarly, in an urban setting, the speed limits are lower, which might have an effect where the reaction would not need to be that drastic from the drivers' point of view. Further research would be required to adequately set the timing of the warning and decide whether the timing should change based on the setting or whether a uniform time delay should be used.

Some participants displayed a degree of scepticism about the reality of this system.

How participants feel when an emergency vehicle is approaching them

The answers in Chapter 4.4.3 and Figure 4.18 imply that the participants become more self-aware when encountering an emergency vehicle. This might be because they do not want to make any unpredictable manoeuvres, which could delay the emergency vehicle or, since other drivers in their vicinity might be stressed, an accident. Overall, the fact that drivers become more aware of their driving behaviour has a positive effect on their reaction and possibly even their driving habits for a while after the emergency vehicles have passed them.

In summary, almost half of the participants showed increased awareness and vigilance when faced with an approaching emergency vehicle. This indicates they seemed aware of the situation and ready to act accordingly.

How participants react when an emergency vehicle is approaching them

By analysing the participant's responses from Chapter 4.4.3 and Figure 4.19, it can be argued that the lower number of responses from the EVA + AEL group points to a possible information overload leading to a stressful situation and, thus, loss of focus. Especially when looking at the "I reduce my speed" option, where the number of responses is nearly doubled from the EVA group.

In summary, the data from Figure 4.19 shows that the participants are proactive and considerate regarding emergency vehicles. While many opted to react in an arguably cautious but also right way, a significant part is ready to prioritise the emergency vehicle's passage, even if that means not adhering to the traffic laws.

Participant's overall ratings of the warning

The EVA group participants and the EVA + AEL group were asked to rate their experience on a scale of 0 - 100, where 0 represented "I did not like it at all" and 100 "I liked it very much". A statistical test was performed on the data, which yielded no statistically significant difference $p = .55$. This indicates that the EVA + AEL group participants were not more satisfied with the warning than those from the EVA group. The results might have been different if a within-group design had been used, which would give the participants a point of reference. Even though there is no statistically significant difference, at least the addition of the ambient lighting did not hinder the warning's performance and intention.

5.1.4 Comparison of the results with the results from the study carried out by Lidestam et al. (2020)

The findings of the present thesis are in line with the findings from a study by Lidestam et al. (2020) in terms of driver responses and actions. Same as in the previous study, the EVA and EVA + AEL warning messages had a positive effect in regards to giving way, where a significant number of participants gave way compared to the Baseline group, where none gave way. The same results can be seen in regards to the participants spotting the ambulance in advance, where only eight participants out of the 20 from the Baseline group had spotted the ambulance prior to it overtaking them compared to twice the amount of participants from both EVA and EVA + AEL groups.

Comparing the measured results, the experienced participants tend to react in a more relaxed way than the inexperienced drivers analysed previously. All three comparable variables, "Distance between the vehicles to giving way", "Speed when overtaken", and "Lateral position when overtaken", had worse results when it came to experience. The experienced participants, if they gave way, did it when the ambulance was much closer to their vehicle compared to the inexperienced drivers. Their speed was higher when they were being overtaken, and their lateral position was closer to the centre line, which signifies that they gave less space to the ambulance for the overtaking manoeuvre. These results might be associated with deteriorating perceptions as the drivers get older or their overconfidence based on their experience. However, without future research, no concrete conclusions as to why this behaviour was observed can be drawn.

5.2 Discussion of Methodology

This section discusses the limitations of the methods and the validity of the conducted research.

The driving simulator provided a controlled environment for running all the Scenario Variations on the same basis, which helped to compare the effects. However, the study's results can not be generalised across different driving conditions.

For this experiment, a fix-based driving simulator was used. This was done primarily to best recreate the conditions from the previous study by Lidestam et al. (2020). Although the usage of a full motion simulator might be argued, it was deemed not beneficial for the purpose of this study since the movement of the vehicle was not the focus of the study. The usage of a full-motion driving simulator might have also introduced another variable causing simulator sickness.

During the experiment, the absence of significant landmarks along the road suggests that the participants were not influenced to slow down more than they would have in a real-life situation, such as coming across an intersection. It can be argued, however, that they may have reacted more abruptly than in real life when they received the EVA warning. Also, the feedback from the simulator was not the same as from a real car, which could further affect their behaviour.

A limitation of the post-survey questionnaire was the between-group design experiments, as it was possible to ask only a limited number of questions for all participants. If, for example, a within-group design was used, all participants could have answered all the questions and further commented on what they liked or disliked about each Scenario Variation. But that would, in turn, affect the data recorded from the simulator since they would have known what is being tested. Also, some questions could have been formulated differently to make them more understandable for the participants.

5.3 Suggestions for Future Research

The results of this study suggest a positive impact of the EVA warning message on driver reaction when encountering an emergency vehicle. Both the speeds and lateral position of the drivers significantly improved when the drivers obtained either of the two presented EVA warnings.

However, the effect of utilising ambient lighting in the vehicle interior was not statistically significant compared to only the EVA warning message. Because of this, future research should focus on analysing this warning alone to determine its usefulness. Another area of focus should be different driving conditions. This study focused only on rural roads and purposefully made it difficult to spot the ambulance. Additional research to better measure the accurate reaction time by utilising eye tracking, for instance, could also be helpful to validate the usefulness of this technology further.

The timing of the warning should also be further analysed and determined since several drivers who obtained one of the warnings reported that they were not fully satisfied with its timing. As was discussed previously, this could be directly tied to the different driving conditions since, in rural areas, an earlier warning might be beneficial compared to a highway environment, where viewing conditions are generally much more favoured towards spotting the emergency vehicle well in advance.

It should also be analysed whether the warnings have the same effect when presented to drivers in different types of vehicles than passenger cars since that could impact the message's timing, delivery and contents. And also how the warnings affect the driver's vigilance itself since the presence of the warning might create a false feeling of safety, and the drivers might put full trust in it.

Another area for further study should be different age groups or gender groups. Since, as was stated previously in the thesis, older drivers might not be as open to this type of warning message. Also, do different genders perceive the warnings in the same way or if there should be different variations?

The last area to focus on is improving the warning messages themselves. As one participant stated, the situation was even more stressful and confusing because the warning did not indicate from which direction the ambulance was approaching them. This information is

especially critical in urban environments where only specific lanes of traffic should yield at intersections, while others should be prevented from entering the intersection altogether.

Last but not least, the infrastructure to enable this technology needs to be built, and the necessary equipment needs to be installed in the vehicles to implement it fully.



6 Conclusion

The present thesis aimed to analyse the effects of ambient lighting as an addition to the EVA warning message on drivers' responses. A driving simulator study was performed to gather the necessary data to answer the research questions stated at the beginning of this thesis. The scenario was reconstructed to be the same as in a study done by Lidestam et al. (2020). This was done because this thesis was conceived as a continuation of said study with a different target demographic and an additional Scenario Variation. A between-group design was used to mitigate a potential priming of the participants. Data gathered during the experiment and the data from two sets of questionnaires were analysed using both descriptive and inferential statistics. All necessary calculations and data formatting were done using Microsoft Excel and RStudio software.

RQ1: Can ambient lighting, combined with EVA warning, help drivers react faster and safer when an emergency vehicle is approaching?

Both groups that received just the EVA warning or the EVA warning with ambient lighting performed better than the group with no warning in place. The data analysis showed a statistically significant difference in the reaction time between the groups who were presented with just the EVA warning and the EVA warning and ambient lighting. This difference is, however, negative since it took the drivers longer to react from the trigger point. However, no statistically significant difference was found in whether the addition of ambient lighting affected how safe the drivers reacted. There, the speed of the vehicle when overtaken by the ambulance, together with its lateral position, and whether the drivers actively braked were considered.

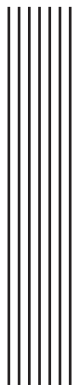
RQ2: Can the EVA warning with ambient lighting increase the safety of the encounter with the emergency vehicle on the road compared to the current situation with no warnings??

There was a statistically significant difference in the lateral position and the speed of the vehicles when overtaken by the ambulance when compared to the situation with no warning in place. This would help any emergency vehicle to increase its safety on the roads and overall safety of the manoeuvre. Furthermore, the actions carried out by the drivers who were presented with the warning messages could also lead to a decrease in the response time

of the emergency vehicle since the whole encounter would be perceived as safer from the emergency vehicle's point of view.

RQ3: How do the drivers feel about augmenting the EVA warning with the LED lights and their subjective reactions?

The results of the post-survey questionnaire show a positive attitude towards this technology. Some participants would like the ability to tweak the timing of the warning, but overall, their stance is supportive. However, compared to the EVA warning, there was no statistically significant difference in how each group liked the warning delivery.



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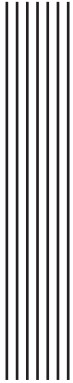
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Appendix

Appendix A

1. Demographics

Research person ID

Age: (number of years)

Sex:

What year did you get your driver's license?

Write your answer here...

Do you have any other driving license qualifications (in addition to B and AM)?

No

Yes (name all)

Are you a professional driver?

No

Yes (specify which one)

Do you have any visual impairment?

No

Yes (mention which one/which ones)

How often have you driven in the last twelve months?

Daily

Most days of the week

A few times a week

A few times a month

Less often

Approximately how far have you driven on average per year in the last five years (in km)?

Write your answer here...

Appendix B

1. Control

Research person ID

Write your answer here...

Did you spot 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? (Pick one)

Driving school

Observed how others do

Someone told me that

I never received the information

Other

Appendix C

1. EVA

Research person ID

What do you think about the timing of the warning? (Pick one)

I would have liked an earlier warning

I would have liked a later warning

I do not wish to change the warning

Did you spot the ambulance before it passed?

Yes

No

What did you like about the warning?

Write your answer here...

What didn't you like about the warning?

Write your answer here...

How did you experience the warning?

I didn't like it at all = 0. I liked it very much = 100.

my

-

max



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

Message on the instrument panel

Message on the car's central screen

Blue light in the car

Message on heads up display (windscreen)

Did you know what to do near the ambulance approach?

Yes

No

Where did you learn what to do when an emergency vehicle approaches? (Pick one)

Driving school

Observed how others do

Someone told me that

I never received the information

Other

What is your general reaction when an emergency vehicle approaches? (Choose all that apply)

I feel stressed

I slow down

I lower the volume on the radio to increase my concentration

I become more aware of my own driving

I adapt to others in traffic

I wait until the emergency vehicle is very close before giving way

I immediately try to give way regardless of the distance to the emergency vehicle

I try to give way, even if it violates normal traffic rules

I don't know how to act in such a situation

Appendix D

1. AEL

Research person ID

How did you experience the warning?
I didn't like it at all = 0. I liked it very much = 100.

my max

What do you think about the timing of the warning? (Pick one)

I would have liked an earlier warning

I would have liked a later warning

I do not wish to change the warning

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

Message on the instrument panel

Message on the car's central screen

Blue light in the car

Message on heads up display (windscreen)

Did you spot the ambulance before it passed?

Yes

No

Did you know what to do near the ambulance approach?

Yes

No

Where did you learn what to do when an emergency vehicle approaches? (Pick one)

Driving school

Observed how others do

Someone told me that

I never received the information

Other

What did you like about the warning?

Write your answer here...

What didn't you like about the warning?

Write your answer here...

What is your general reaction when an emergency vehicle approaches? (Choose all that apply)

- I feel stressed
- I slow down
- I lower the volume on the radio to increase my concentration
- I become more aware of my own driving
- I adapt to others in traffic
- I wait until the emergency vehicle is very close before giving way
- I immediately try to give way regardless of the distance to the emergency vehicle
- I try to give way, even if it violates normal traffic rules
- I don't know how to act in such a situation