The effect of an LED Strip on Drivers' Situational Awareness in an Automated Vehicle: A Simulator Study

Bachelor's Project Thesis

Dennis Prakken, s2953293, d.t.prakken@student.rug.nl,
Supervisor: Dr. M.B. Schippers
External supervisors: Prof. Dr. D. de Waard & Dr. A. Stuiver

Abstract: Conditionally automated vehicles are the next major step in automation, making it possible for driver's to engage in non-driving related tasks on dedicated roads or lanes on highways. However, this introduces the "out-of-the-loop problem" because drivers are neither in physical control nor monitoring their surroundings, resulting in lower situational awareness. Then, if a scenario occurs in which the vehicle is unable to react accordingly, drivers may suddenly have to take over control of the vehicle, which can lead to dangerous situations. This paper investigates whether it is possible to increase a driver's situational awareness. A driving simulator experiment was designed in which an LED strip was mounted below the screens that gave information about surrounding vehicles. Participants ($n = 6$) conducted two trials: (1) with LED strip, and (2) without LED strip, and during automated driving, they were engaged in a non-driving related task on a tablet placed near the gearshift lever until a take-over request occurred. No significant results were found, however, trends show a higher situational awareness when the LED strip was active.

Keywords: Automated Driving; Levels of Automation; Out of the Loop; Situational Awareness; Driving Simulator

1 Introduction

1.1 Background

More and more major car manufacturers are designing and equipping their cars with automated driving mechanisms (Chan, 2017). In the near future, vehicles could in fact become fully autonomous, but until this is the case, a wide range of problems must first be solved. One such problem is that of the driver's situational awareness during periods of automated driving. This study investigates some of the crucial problems that arise, and the main objective of this study is to determine whether situational awareness can be improved when the driver's focus is not on the road.

As of today, these so-called automated vehicles (AVs) are not yet fully autonomous, and by adopting the Society of Automobile Engineers' (SAE) definition of levels of automation, the most advanced vehicles currently on the road can be classified as SAE level 2 (or below) (On-Road Automated Driving (ORAD) committee, 2021). A distinction can be made between the different levels of automation, where SAE levels 0-2 can be classified as driver support features such as lane centering and adaptive cruise control. SAE level 3 can be classified as conditionally automated driving, meaning that the driver of the vehicle only has to drive the vehicle when the vehicle indicates that this is necessary. SAE levels 4 and 5 can be classified as fully automated driving so with these vehicles it is not required to drive the vehicle by yourself, and such vehicles could even be installed without a steering wheel and pedals for gas and braking.

Numerous car manufacturers are striving to reach the next step in automation, which is SAE level 3, and the vast majority of these manufac-

Table 1.1: List of abbreviations.

Abbreviation	Definition
AV	Automated Vehicle
HUD	Head-Up Display
ITL	In The Loop
NDRT	Non-Driving Related Task
OOTL	Out Of The Loop
OTL	On The Loop
SA	Situational Awareness
SAE	Society of Automobile Engineers
SART	Situational Awareness Rating Technique
TOR	Take-Over Request

turers may have had slightly too high expectations regarding their predictions for the market introduction of (fully) AVs (Chan, 2017). Some expected to be able to introduce fully automated vehicles as early as 2020, however, none of them have reached their goal yet. In an interview study by Kyriakidis et al. (2019), 12 expert researchers in the field of human factors were asked about their expectations. They came to the consensus that it could take a long time before fully AVs would be deployed, because there are many challenges left to be solved, including acceptance, safety and legislation. However, these experts believe it could be possible for AVs up to SAE level 4 to be deployed in specific areas, such as dedicated lanes on highways, hence they believe it is important to devote our resources to the development of a safe and highly automated vehicle.

Thus, based on the current progress of car manufacturers and the perspectives of some experts, it is not feasible to expect fully AVs to be deployed on public roads in the forthcoming years. Therefore, a logical and realistic first step would be to start with an easier to solve problem. Driving on a highway is often much less demanding than driving in busy urban areas, therefore it would be great if you are able to activate automated driving when certain limited conditions are met and then be able to engage in a non-driving related task (NDRT). Depending on agreements/legislation made concerning what can and cannot be done during automated driving, people could be restricted to using the steering wheel to operate and do things on a head-up display (HUD), however, they might also be allowed to use their smartphones and are free to engage in whatever they desire. This way, drivers can experience the freedom of their own vehicle, but still have the luxury of public transportation and thus be able to perform other tasks.

However, the main problem that arises is that these conditionally automated vehicles may encounter a situation that they cannot handle, and then the driver suddenly has to take over control of the vehicle. This is where a take-over request (TOR) comes into play. When a scenario occurs in which the AV is unable to process what to do next, the vehicle signals that the driver has to take over control. This can happen, for example, if there has been an accident or an animal suddenly crosses the road, but it can also be due to the malfunctioning of software or hardware such as cameras or sensors. This in turn introduces yet another big problem, which is better known as the "out-of-the-loop" problem (Merat et al., 2019).

In automated driving research, a distinction can often be made between different levels of vehicle control by combining both physical and visual control of a vehicle. Firstly, when a person is driving the vehicle themselves, they are in physical control over the vehicle, as well as monitoring the environment, and this is known as in the loop (ITL). Secondly, a driver can also be on the loop (OTL), which means they are not in physical control of the vehicle, but they are monitoring the environment. Lastly, when the driver is neither in physical control nor monitoring the environment, they are out of the loop (OOTL). These concepts are closely related to situational awareness (SA), and situational awareness is at its highest when a driver is ITL. OTL and OOTL can be more or less interconnected, depending on the driver's level of monitoring, where the more a driver is OTL, the higher the driver's situational awareness will be.

As defined by Endsley (1988), *"Situational awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and a projection of their status in the near future"*. So, when automated driving is activated, and drivers are free to engage in an NDRT and do so, they will be out of the loop, and consequently will have a lower situational awareness. Research shows that drivers may overestimate the capabilities of currently available

AVs equipped with some simpler driver support features and therefore are often neglecting their supervisory duties, thereby being OOTL, which leads to dangerous situations (Kundinger et al., 2018; Reimer et al., 2016, as cited in Detjen et al., 2021). Moreover, when a TOR occurs at an unexpected time, in a critical situation, people have difficulty regaining control of the vehicle, and the lack of monitoring is also related to lower situational awareness (Merat et al., 2019).

As a result, even as automated driving functions continue to improve, the lack of supervision persists or even increases, which can lead to potentially dangerous situations and an increased risk of accidents during take-over situations. Additionally, several factors may explain the level of situational awareness during periods of automated driving such as the NDRT's positioning. If a person uses the integrated systems of their vehicle, these may have been installed and designed with the intention of keeping SA as high as possible by using a HUD, for example. However, if a person uses their own phone and is looking downwards, they will see little, if anything, of their surroundings, resulting in lower situational awareness. Therefore, it is paramount to improve human-machine interaction (HMI) in AVs, as this can lead to increased safety as well as greater driver comfort.

A study by Radlmayr et al. (2018) shows that it is possible to improve situational awareness and lower reaction time during a TOR when using a HUD as visual NDRT. A semi-transparent balloon game was operated in the HUD and therefore drivers did not have to differentiate from their normal line of sight and thereby were able to peripherally monitor their surroundings. Another study by Lamble et al. (1999) found that the placement of an LED screen inside a vehicle is important and that the detection time of an obstacle is significantly less when the screen is closer to a driver's normal line of sight. Similarly, Dillmann et al. (2021) showed that higher levels of visual exposure as well as manual control exposure can result in faster reaction times and less steering variability. For low visual exposure, a head-down display was used and for high visual exposure, a head-up display was used. To manipulate manual control exposure two different driving conditions were used: (1) intermittent control in which the driver had to take over control during non-critical TORs, and (2) continuous automation. This study also incorporated an illuminated steering wheel that provided warnings about approaching situations. Although it may be possible to increase situational awareness, as shown in these studies, the control groups (with the task of applying their normal driving behavior) continue to outperform the other experimental groups. This is to be expected because these groups are not dealing with the "out-of-the-loop problem" (Merat et al., 2019).

1.2 Research question

Conditionally automated vehicles (SAE level 3) will be the next step in automated driving, and the ultimate goal is for drivers to be able to engage in other activities while being transported in a safe manner. This brings me to my research question:
"How effective is visual exposure to an LED strip representing surrounding vehicles in improving drivers' situational awareness in automated vehicles when their focus is not on the road?"

To answer this, an experiment was designed using a driving simulator, and to increase situational awareness, an LED strip was mounted below the screens of the driving simulator to provide useful information about surrounding vehicles. During the experiment, drivers engaged in an NDRT when automated driving was activated. Then, after some time, a TOR occurred and drivers had to take over control of the vehicle and respond accordingly.

Based on previously cited literature, the hypothesis is that the implementation of an LED strip that provides information about surrounding vehicles can have a positive impact on a participant's situational awareness and thus lead to faster and more adequate control of a vehicle in the event of a TOR. Because this LED strip can be seen in a person's peripheral vision, they will still be able to (subconsciously) gather important information about their surroundings when they are not actively monitoring the road. In the most optimal scenario this would be enough information to help people when they encounter a critical situation. So, the LED strip should help with the perception of elements in the environment and this in turn should help with the comprehension of the current situation. This together can provide a better prediction of what is to come and thus result in greater situational awareness. The Situation Awareness Rating

Technique (SART) (Endsley et al., 1998; Taylor, 2017) was used to gather quantitative results of situational awareness.

2 Methods

2.1 Participants

For this experiment, 6 participants were recruited by word-of-mouth. All of the participants had their driving license and had normal (or corrected to normal) eye-sight. Before the experiment, participants were asked about their age and gender, and were asked for their consent. No participants were excluded from the final data set. The final data set consisted of $n = 6$ participants (*mean age* = 37.5 Years (*SD* = 16.7 Years), 2 Female, *Average annual driving experience* = 9292 km). All participants have completed the two different experimental conditions.

2.2 Experimental Setup

The experiment was conducted in an STSoftware driving simulator, which includes a motion platform and five screens showing the virtual environment (see Figure 2.1). Participants had to sit in a regular car seat and had to operate the steering wheel and pedals for gas and braking, which was similar to a normal car. The gearshift and the pedal for the clutch were not used because automatic transmission was used. When automated driving could be activated, participants had press the button on top of the turn signal lever to activate automation.

Figure 2.1: Driving simulator.

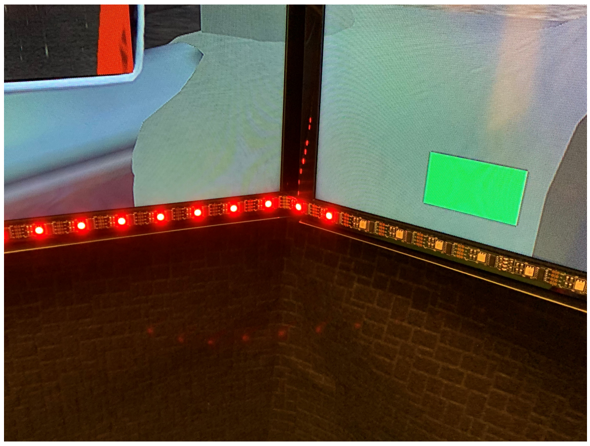

Figure 2.2: LED strip below the screens.

Below the screens an LED strip is fitted, indicating relevant information about surrounding vehicles on the road, as can be seen in Figure 2.2. The LED strip was positioned directly below the computer screens, which in an actual car would correspond to being directly below the window screens and is readily observable in the driver's (peripheral) vision.

2.2.1 LED strip

A Raspberry Pi 3b+ is used to control the LED strip, and it is receiving data from the driving simulator's computers, which in turn is processed and translated to a vehicle representation on the LED strip. Different LED patterns and colors can be used, but for the representations of relevant information on the LED strip, the implementation of Steffen (2020) has been used. Depending on how close or far away the ego vehicle is from other surrounding vehicles, LEDs turn on or off or the brightness changes, as can been seen in Figure 2.3 (Steffen, 2020). Figure 2.4 shows how this vehicle representation works on the mounted LED strip below the driving simulator's screens.

The color red has been chosen to represent vehicles at a 190 degree angle from the front of the ego vehicle. This allows the outermost LEDs on both sides of the LED strip to be used to represent vehicles behind the ego vehicle, for which the color

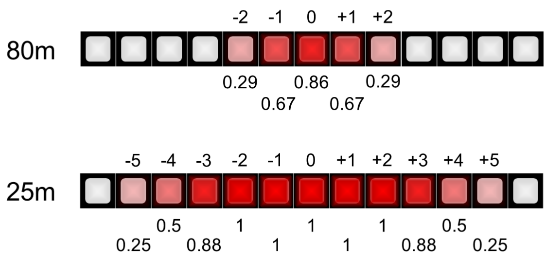

Figure 2.3: ***Note.*** **Two examples of a vehicle representation on the LED strip, one representing a vehicle at 80 meters away, one at 25 meters away. At the top of each strip, the indices relative to the central LED are shown, with the negative indices on the left and the positive indices on the right. Below are the brightness values for each LED. A value of 0 means the LED is off, while a value of 1 means maximum brightness. From "Using a LED Strip in Conditionally Automated Driving to Improve Situational Awareness of Drivers", by S. Steffen, 2020, University of Groningen.**

yellow is used. This way, a person was still able to see some of the yellow LEDs in their peripheral vision, as illustrated in Figure 2.5. These colors were chosen because the vehicles in front and directly next to the ego vehicle can cause immediate danger while the cars behind do not. These colors are already commonly used to indicate potential dangerous/hazardous situations on traffic signs and in car warning lights, and therefore should be intuitively recognizable to most people. Additionally, research has shown that the colors red and yellow were both the best choice in urgent situations (Cobus et al., 2018). The maximum brightness of the LED strip is quite high and to not blind the participants, a brightness of 10% has been chosen for the red LEDs, and a brightness of 20% for the yellow LEDs.

2.2.2 Non-driving related task

For the non-driving related task (NDRT) a tablet was mounted on the center console, to the right of the driver, at a downward viewing angle of approximately 45 degrees. Furthermore, a camera/webcam was used to monitor the participants during the experiment. No video footage was recorded.

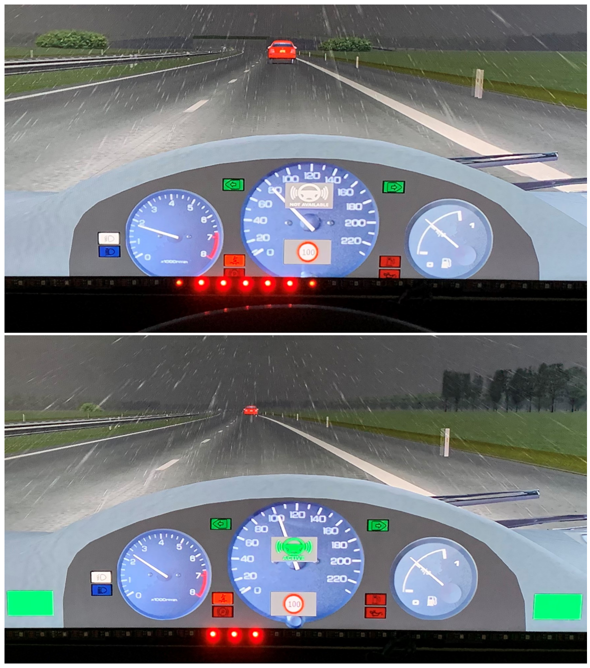

Figure 2.4: Two examples of the vehicle representation on the LED strip. The top figure shows a vehicle that is closer to the ego vehicle and the bottom figure shows a vehicle that is further away.

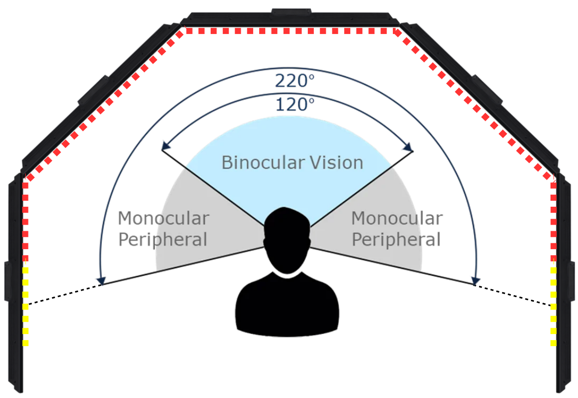

Figure 2.5: Top-down view illustration of a person's field of view inside the driving simulator. The dotted line in front of the screens corresponds to the LED strip mounted below the screens, where the red LEDs were used to represent vehicles at a 190 degree angle from the front of the ego vehicle, and the yellow LEDs were used to represent vehicles behind the ego vehicle.

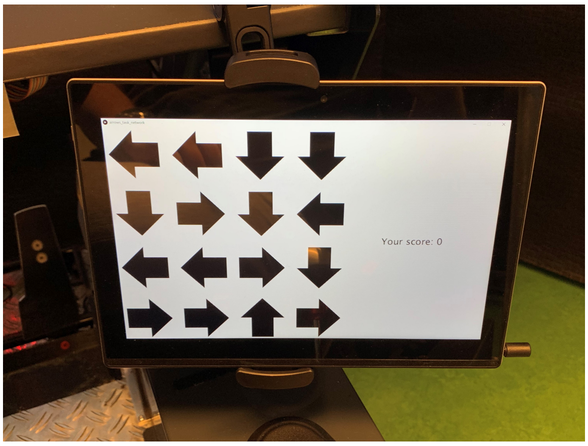

Figure 2.6: Arrow Task on a tablet. Participants had to find and click the upright arrow within a collection of randomly placed arrows pointing in different directions. After each correct guess, a new random collection of arrows was generated.

During the experiment, while automated driving was active, participants were asked to engage in an NDRT. The task chosen for this is the Arrow Task (see Figure 2.6), which was specifically designed to test a driver's visual and cognitive load (Jamson & Merat, 2005). The goal for this task was for participants to find and click the upright arrow within a collection of randomly placed arrows pointing in different directions. After correctly clicking the upright arrow, participants scored 1 point and a new random collection was generated. Participants were instructed to get an as high as possible score so that they were truly immersed in the NDRT.

2.3 Experimental design

The experiment was a two by one factorial within-subjects design. All participants completed the two different experimental conditions. In all conditions, participants started the experiment by manually driving the car until the car indicated that automated driving was available and the participant activated this feature. This automated driving feature was able to overtake slower vehicles and can be classified as SAE level 3 ((On-Road Automated Driving (ORAD) committee, 2021), meaning the vehicle can drive itself until it requests otherwise (e.g., a potentially dangerous situation arises). Also, in all conditions, the driven route consists of a two-way highway with low traffic, and during automated driving the speed of the car is kept at a constant of 100 km/h. This speed limit is chosen because it is the speed limit on (most) Dutch highways, and also because the weather conditions are not optimal. The weather conditions used for this experiment are (heavy) rain and dusk to limit the participants' visibility. The main reason for this was that if the participants accidentally looked up when they were not supposed to, a quick glance at the screens was most likely not enough to scan and process their surroundings.

2.3.1 Independent variable: Visual exposure to LED strip

To manipulate visual exposure to the LED strip, it can either be active or inactive. The purpose of this is to determine whether the LED strip can have a positive effect on the driver's situational awareness during the experimental conditions.

2.3.2 Dependent variable: Non-driving related task

During each session, while automated driving is active, participants were instructed to engage in a non-driving related task and try to get an as high as possible score. The purpose of this is to immerse the participants in the Arrow task so that they are not constantly monitoring the screens, thus reducing the likelihood that they will accidentally see a situation coming up where they would need to take over control of the vehicle, creating a situation with low situational awareness. Furthermore, by using the same NDRT for each participant, the experimental conditions were the same for everyone and could therefore be more easily controlled.

2.3.3 Dependent variable: Take-over requests

During each session, after automated driving has been active for some time, a take-over request (TOR) occurred to which the participants had to react accordingly. Thereafter, participants had to take control of the car and were able to brake/throttle and/or change lanes. Participants were still able to take control of the car at any time, however, they were instructed to only take control when it was requested by the vehicle.

Figure 2.7: Bicycle on highway.

Figure 2.8: Wrong-way driver on highway.

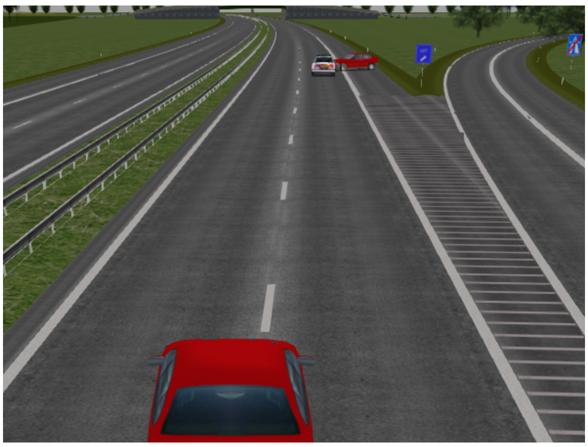

Figure 2.9: Collision on highway.

In each session, three TORs occurred, all of which were critical take-over situations, meaning there was immediate danger and participants had to take over steering and throttle, and had to react quickly and as safely as possible. The order in which these TORs occurred, as well as the order in which the participants took part in the two experimental conditions, was randomized, in order to minimize the practice effect (Donovan & Radosevich, 1999). After the participants completed all three scenarios during a trial, the trial was completed. The three different scenarios that participants encountered were the following:

Bicycle on highway: The first scenario in which participants had to take-over was a bicycle riding at a slow speed in the right lane of the highway (see Figure 2.7). In this scenario, participants had to maneuver around the bicycle.

Wrong-way driver: The second scenario in which participants had to take-over was a wrong-way driver driving at a high speed in the left lane of the highway (see Figure 2.8). In this scenario, participants had to take-over steering and driving but had to stay in the same lane.

Collision on highway: The last scenario in which participants had to take-over was a collision between two cars in the right lane of the highway (see Figure 2.9). In this scenario, participants had to maneuver around the collision.

2.4 Procedure

Participants received an information form and had to sign for their informed consent. Then, they had to fill out a demographic questionnaire. Thereafter, they took place in the car seat and adjusted it to their preferences. The participants' task during the experiments was explained and they were guided through the actions they had to perform, such as braking and changing lanes. Also, the human-machine-interface of the driving simulator was shown, which consisted of sounds, a (virtual) speedometer with icons, and an LED strip below the screens that can both be active or inactive. The purpose of the LED strip was explained as well.

Participants were informed about how to activate automated driving and when automated driving can be activated. When everything was clear, the experimental procedure was explained in some more detail. After that, the experiment started, which consisted of two practice trials and two data collection trials. During the practice trials, the experimenter was available to assist and check if everything was going as intended. Both practice trials took a few minutes to complete.

2.4.1 Practice trial: Familiarization with manual and automated driving and NDRT

Firstly, participants had to do some standard driving to get familiar with the car. This included acceleration, braking, and changing lanes. Then, the car indicated that automated driving could be activated, and participants then had to activate automated driving by pressing the button on top of the turn signal lever. Participants were instructed to use automated driving whenever it was available. With automated driving active, participants were instructed to do the Arrow Task to familiarize themselves with it.

2.4.2 Practice trial: Familiarization with take-over requests

Secondly, participants did another practice trial in which two scenarios with a stranded vehicle occurred. Participants were asked to activate automatic driving and monitor the environment until they had to take over for the first scenario that they encountered. Then, they were asked to reactivate automatic driving and engage in the Arrow Task until the other scenario occurred. Again, participants had to take-over and react accordingly to the situation.

2.4.3 Data collection trials

For all data collection trials, participants were instructed to enable automated driving whenever it was available. Both data collection trials included the same scenarios but in a different order. The order in which participants took the trials was randomized as well. Each experimental condition took approximately 12 minutes per trial. The experimenter was monitoring the experiment from another room and was able to communicate with the participants if necessary. After each trial, their score on the Arrow Task was noted and participants had to fill in a questionnaire to assess their situational awareness. The Situational Awareness Rating Technique (SART) (Endsley et al., 1998; Taylor, 2017) was used for this because it is a quick and non-intrusive way to gather a (subjective) score of situational awareness. Also, it is a widely used method that can be applied in multiple domains such as automated driving.

Without LED strip: Participants started with manually driving the car on the highway until automated driving becomes active. Then, participants will activate automated driving and put their feet on the floor to avoid accidentally disabling automatic driving. Participants will then start with the Arrow Task on the tablet below them. When a TOR occurs, participants will have to respond accordingly.

With LED strip: The procedure for this trial is the same as in the previous condition, with the addition of the LED strip being active.

2.5 Measures

During the experiment, the following data was collected.

2.5.1 Drivers' reaction time

Drivers' reaction time was measured by taking the time that elapsed between when the TOR was presented to the first intervention by the driver, which can either be the movement of the steering wheel or pressing the brake pedal. This is a standard measure that is typically used for reaction times (Mole et al., 2019).

2.5.2 SART score

Situational awareness is a rather broad concept and therefore can be difficult to assess, however, to gather quantitative results of situational awareness, the Situation Awareness Rating Technique (SART) (Endsley et al., 1998; Taylor, 2017) was used. This is a self rating technique consisting of 10 questions grouped into the following 3 dimensions: (1) demands on attentional resources, (2) supply of attentional resources, (3) understanding of the situation. The questionnaire uses a seven-point Likert scale, and the full SART questionnaire and equation to calculate the SART score can be found in Appendix A. This questionnaire was filled out immediately after an experimental condition had been completed, and thus was non-intrusive. Unfortunately, the question about `Information quality` was missing from the original questionnaire and this had been overlooked when designing the questionnaire used for the experiment. Therefore, this question was not used during the experiment.

2.5.3 Statistical Analyses

For all measures, statistical analyses were performed using R-Studio (V 1.2.5019).

For the reaction time (RT), it was first confirmed if no collision has been caused. Then, because the mean RT of all participants for each condition is compared between the groups, a paired t-test was performed, i.e., each participant appears in both groups (trials with LED strip and without LED strip).

For analyzing the SART questionnaire, first the SART score was calculated using the equation in Appendix A. To correct for the missing variable (`Information quality`), the average of the other two variables of the same domain (`Information quality` and `Familiarity`) was added to the equation. Next, a paired t-test was performed because the results of the entire questionnaire can be considered as interval data (as opposed to ordinal data for single Likert scale questions).

3 Results

For this study, a total of 6 participants successfully completed the experiment. A power analyses showed that 24 participants were needed to reach a power of 80% to get a true positive. Therefore, no definitive conclusions can be drawn from these results.

3.1 Drivers' reaction time

Bicycle on highway: In Figure 3.1 the reaction time for when participants encountered the bicycle can be seen. A paired samples t-test was used to find out whether there is a difference in average reaction time (RT) between trials with and without LED strip for all participants (as visualized in Figure 3.4). It was found that the RT for trials without LED strip ($M = 1711$ ms, $SD = 546$ ms) was lower than the RT for trials with LED strip ($M = 1925$ ms, $SD = 477$ ms), $t(5) = 2.6283$, $p = .047$. Cohen's d showed that there was a large effect size for the t-test ($d = 1.07$).

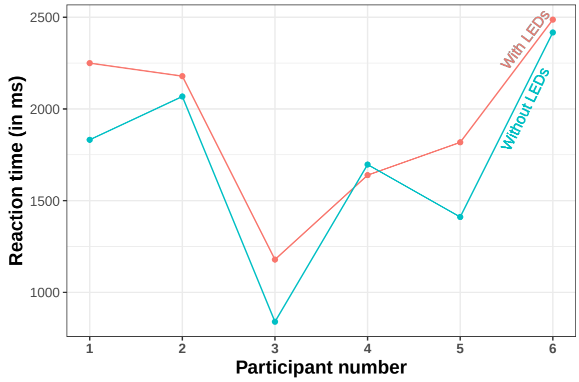

Figure 3.1: Reaction times of each participant for the encounter with a bicycle on highway.

Wrong-way driver: In Figure 3.2 the reaction time for when participants encountered the wrong-way driver can be seen. A paired samples t-test was used to find out whether there is a difference in average reaction time (RT) between trials with and

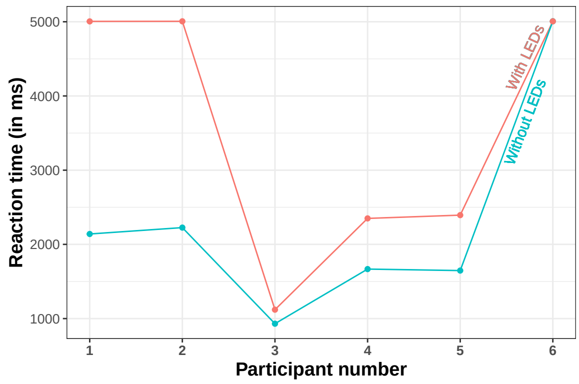

Figure 3.2: Reaction times of each participant for the encounter with a wrong-way driver.

without LED strip for all participants (as visualized in Figure 3.4). It was found that the RT for trials without LED strip ($M = 2270$ ms, $SD = 1418$ ms) was lower than the RT for trials with LED strip ($M = 3480$ ms, $SD = 1733$ ms), $t(5) = 2.3147$, $p = .069$. Cohen's d showed that there was a large effect size for the t-test ($d = 0.94$).

Collision on highway: In Figure 3.3 the reaction time for when participants encountered the collision can be seen. A paired samples t-test was used to find out whether there is a difference in average reaction time (RT) between trials with and without LED strip for all participants (as visualized in Figure 3.4). It was found that the RT for trials without LED strip ($M = 1265$ ms, $SD = 560$ ms) was lower than the RT for trials with LED strip ($M = 1603$ ms, $SD = 406$ ms), $t(5) = 1.9623$, $p = .107$. Cohen's d showed that there was a large effect size for the t-test ($d = 0.80$).

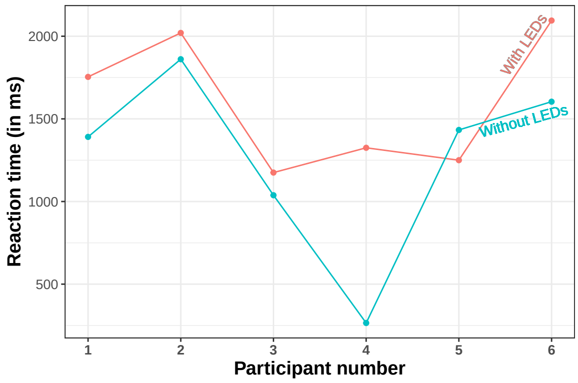

Figure 3.3: Reaction times of each participant for the encounter with a collision on highway.

3.2 SART questionnaire scores

In Figure 3.5 the SART scores for both experimental conditions can be seen. A paired samples t-test was used to find out whether there is a difference in average SART score between trials with and without LED strip for all participants. It was found that the SART score for trials without LED strip ($M = 17.9$, $SD = 7.87$) was lower than the SART score for trials with LED strip ($M = 20.4$, $SD = 6.80$), $t(5) = 0.91085$, $p = .404$. Cohen's d showed that there was a small-to-medium effect size for the t-test ($d = 0.37$).

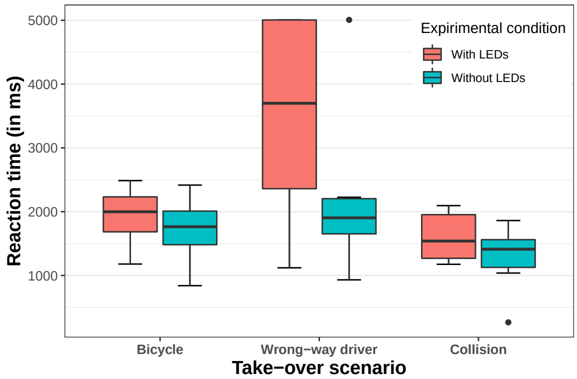

Figure 3.4: Boxplot of reaction times for all scenarios.

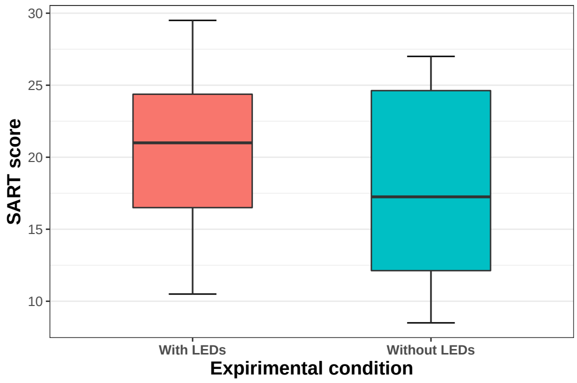

Figure 3.5: Boxplot of SART scores.

4 Discussion

The goal of this study was to find whether visual exposure to an LED strip could improve a driver's situational awareness when automated driving was active and the driver was engaged with an NDRT, so they were neither in physical control nor monitoring the environment. The hypothesis was that the LED strip could give important information about surrounding vehicles and that this could be helpful with perceiving and processing the environment, even if the driver is looking downwards because the LEDs would still be readily visible in the driver's peripheral vision. This might allow drivers to react more quickly and safely to an approaching critical take-over situation.

Results show that there is no significant difference in reaction time for when participants encountered the wrong-way driver and collision ($p > .05$), except for when the participants encountered the bicycle on the highway ($p < .05$). However, because of a rather large effect size, there is a large difference between participants' reaction times, so it is not really possible to draw meaningful conclusion about a driver's reaction time. Although, by examining the trends in reaction times for the three scenarios, it can be seen that, on average, the participants were faster when the LED strip was turned off. In Figure 3.2 it can be seen that there are some extreme outliers of RTs of 5 seconds. This is because when encountering this scenario, a participant does not need to brake and/or steer to avoid something, and thus participants sometimes did nothing until automation was suspended automatically after 5 seconds, so these times can be disregarded in the comparison. It would still be useful to keep this scenario in an experiment as a sort of control scenario, because there is a possibility that a participant decides to (instinctively) turn the steering wheel because they expect something in front of them, which then might cause a collision.

These observable trends of higher reaction times for the *With LEDs* experimental condition go somewhat against the expectations, because it was expected that participants would react quicker when the LED strip was active because they would be more aware of surrounding vehicles and therefore would need little to no additional time to monitor their surroundings after a TOR had occurred. However, it would be interesting to look at other measures as well to see if a faster reaction time is something desirable, because a faster reaction time does not necessarily mean that a driver reacts more appropriately. It could be that because the driver is unaware of their surroundings and therefore does not know how close a car in front of them is, they react more abruptly, which in turn could mean that they react in a less safe manner. For this reason, an interesting measure to assess could be the driver's steering stability, i.e., the jerkiness of the movements of the steering wheel.

Furthermore, results of the SART questionnaire scores also show no significant results. However, trends do show here that a participant's situational awareness is higher for the *With LEDs* experimental condition, which matches expectations. Unfortunately, because the question about `Information quality` was missing from the questionnaire, the overall SART scores could be slightly skewed. However, an even greater difference between SART scores is expected if this question had been present. This is because it is highly likely that participants give higher ratings for `Information quality` for the *With LEDs* experimental condition, because the amount of knowledge received and understood is probably substantially greater when the LED strip is active. This would mean that the average SART score would become higher for the *With LEDs* experimental condition. Also, the opposite will probably happen for the *Without LEDs* experimental condition, resulting in a lower average SART score.

Moreover, some other observations made during the course of this experiment have more to do with the design of the experiment. A driving simulator tries to mimic real life as closely as possible, but there are some limitations. One of the things that was discovered was that the driving simulator screens are quite far apart from the simulator base, and therefore the LEDs were much further away than if they were installed in the interior of a car. Also, the steering wheel can sometimes obstruct the driver's view, depending on their height, making it difficult to see some of the LEDs in front of them, which can be considered as the most important LEDs. A solution for this could be to use an illuminated steering wheel, such as the one used by Dillmann et al. (2021), which also provides information about vehicles in front of the ego vehicle.

Lastly, as initial research already showed, keeping your hands on the steering wheel and using a head-up display could improve your situational awareness and/or driving performance when encountering a TOR (Dillmann et al., 2021; Lamble et al., 1999; Radlmayr et al., 2018). This was not the purpose of this experiment, because this would mean that specialized equipment such as a head-up display would be necessary, and not many vehicles today are equipped with (sufficient working) HUDs. Perhaps this will be a standard component cars in the (near) future are equipped with or it will be made mandatory in conditionally automated vehicles (SAE level 3) (On-Road Automated Driving (ORAD) committee, 2021).

4.1 Conclusion

An experiment was conducted in a driving simulator to test whether a driver's situational awareness could be improved in conditionally automated vehicles (SAE level 3) when they were engaged with a non-driving related task. An LED strip that gave information about surrounding vehicles was used to increase the driver's situational awareness. No significant results were found and thus no meaningful conclusions can be drawn from these results. However, the trends indicate a higher situational awareness when the LED strip was active, so this is something that should be further investigated in future research.

4.2 Future research

Further research could be conducted to explore if an LED strip could have a significant impact on a driver's situational awareness. Aforementioned changes could be implemented to this experiment to optimize it and find better results. Most importantly, using a larger sample size might yield significant results that show some real effects. In addition, the full SART questionnaire with no missing questions should be used, or the simpler 3D SART could be used. This is a quicker version with three dimensions instead of ten, and it uses a 100-point scale instead.

Gathering more quantitative results could also be useful because then it might be possible to find correlations between SART scores and drivers' performance. Therefore, another measure that might be helpful to examine is drivers' steering stability or drivers' steering adequacy. There are standard measures of driving steering variability that could be used for this (Mole et al., 2019).

Introducing intermittent control (Dillmann et al., 2021) into this experiment to help maintain a certain level of situational awareness by manipulating the manual control exposure could be a great additional independent variable to add to this experiment for further research.

Finally, deviating less from the driver's normal line of sight should increase their situational awareness. This takes away some of the purpose of the LED strip, however, it may be interesting to see if the combination of the LED strip in conjunction with a HUD further improves a person's situational awareness. It may be possible to simulate an NDRT on a HUD above the dashboard on the driving simulator screens. Additionally, buttons on the steering wheel could be used to control the NDRT as well, thereby keeping your hands on the steering wheel. These are matters that can be further explored in future research.

Acknowledgements

Many thanks to Dr. Marleen Schippers for her supervision and assistance throughout the project. Thanks should also go to Prof. Dr. Dick de Waard and Dr. Arjan Stuiver for their expert support during the project. Lastly, special thanks to Sönke Steffen for his preparatory work on the initial design of the experiment.

References

Chan, C.-Y. (2017). Advancements, prospects, and impacts of automated driving systems. *International Journal of Transportation Science and Technology*, *6*(3), 208-216. (Safer Road Infrastructure and Operation Management)

Cobus, V., Meyer, H., Ananthanarayan, S., Boll, S., & Heuten, W. (2018). Towards reducing alarm fatigue: peripheral light pattern design for critical care alarms. In (p. 654-663). doi: 10.1145/3240167.3240218

Detjen, H., Faltaous, S., Pfleging, B., Geisler, S., & Schneegass, S. (2021). How to Increase Automated Vehicles' Acceptance through In-Vehicle Interaction Design: A Review. *International Journal of Human–Computer Interaction*, *37*(4), 308-330.

Dillmann, J., Den Hartigh, R., Kurpiers, C., Raisch, F., De Waard, D., & Cox, R. (2021). Keeping the driver in the loop in conditionally automated driving: A perception-action theory approach. *Transportation Research Part F: Traffic Psychology and Behaviour*, *79*, 49-62.

Donovan, J., & Radosevich, D. (1999). A Meta-Analytic Review of the Distribution of Practice Effect: Now You See It, Now You Don't. *Journal of Applied Psychology*, *84*, 795-805. doi: 10.1037/0021-9010.84.5.795

Endsley, M. R. (1988). Design and Evaluation for Situation Awareness Enhancement. In (Vol. 32). doi: 10.1177/154193128803200221

Endsley, M. R., Selcon, S. J., Hardiman, T. D., & Croft, D. G. (1998). A Comparative Analysis of SAGAT and SART for Evaluations of Situation Awareness. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *42*(1), 82–86.

Jamson, A., & Merat, N. (2005). Surrogate in-vehicle information systems and driver behaviour: Effects of visual and cognitive load in simulated rural driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, *8*, 79-96. doi: 10.1016/j.trf.2005.04.002

Kundinger, T., Riener, A., Sofra, N., & Weigl, K. (2018). Drowsiness Detection and Warning in Manual and Automated Driving: Results from Subjective Evaluation. In *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (p. 229–236). Association for Computing Machinery.

Kyriakidis, M., De Winter, J. C. F., Stanton, N., Bellet, T., Van Arem, B., Brookhuis, K., ... Happee, R. (2019). A human factors perspective on automated driving. *Theoretical Issues in Ergonomics Science*, *20*(3), 223-249.

Lamble, D., Laakso, M., & Summala, H. (1999). Detection thresholds in car following situations and peripheral vision: implications for positioning of visually demanding in-car displays. *Ergonomics*, *42*(6), 807-815. doi: 10.1080/001401399185306

Merat, N., Seppelt, B., Louw, T., Engström, J., Lee, J. D., Johansson, E., ... Keinath, A. (2019). The "Out-of-the-Loop" concept in automated driving: Proposed definition, measures and implications. *Cognition, Technology & Work*, *21*(1), 87–98.

Mole, C. D., Lappi, O., Giles, O., Markkula, G., Mars, F., & Wilkie, R. M. (2019). Getting Back Into the Loop: The Perceptual-Motor Determinants of Successful Transitions out of Automated Driving. *Human Factors*, *61*(7), 1037-1065. doi: 10.1177/0018720819829594

On-Road Automated Driving (ORAD) committee. (2021). Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles [Computer software manual].

Radlmayr, J., Brüch, K., Schmidt, K., Solbeck, C., & Wehner, T. (2018). Peripheral Monitoring of Traffic in Conditionally Automated Driving. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *62*, 1828-1832.

Reimer, B., Pettinato, A., Fridman, L., Lee, J., Mehler, B., Seppelt, B., ... Iagnemma, K. (2016). Behavioral Impact of Drivers' Roles in

Automated Driving. In *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (p. 217–224). Association for Computing Machinery.

Steffen, S. (2020). *Using a LED Strip in Conditionally Automated Driving to Improve Situational Awareness of Drivers.* (Unpublished master's thesis). University of Groningen.

Taylor, R. (2017). Situational Awareness Rating Technique (Sart): The Development of a Tool for Aircrew Systems Design. In (p. 111-128). doi: 10.4324/9781315087924-8

A Appendix

A.1 SART questionnaire

SITUATION AWARENESS RATING TECHNIQUE (SART; Taylor, 1990)

Instability of Situation
How changeable is the situation? Is the situation highly unstable and likely to change suddenly (High) or is it very stable and straightforward (Low)?

1 2 3 4 5 6 7

Complexity of Situation
How complicated is the situation? Is it complex with many interrelated components (High) or is it simple and straightforward (Low)?

1 2 3 4 5 6 7

Variability of Situation
How many variables are changing within the situation? Are there a large number of factors varying (High) or are there very few variables changing (Low)?

1 2 3 4 5 6 7

Arousal
How aroused are you in the situation? Are you alert and ready for activity (High) or do you have a low degree of alertness (Low)?

1 2 3 4 5 6 7

Concentration of Attention
How much are you concentrating on the situation? Are you concentrating on many aspects of the situation (High) or focussed on only one (Low)?

1 2 3 4 5 6 7

Division of Attention
How much is your attention divided in the situation? Are you concentrating on many aspects of the situation (High) or focussed on only one (Low)?

1 2 3 4 5 6 7

Spare Mental Capacity
How much mental capacity do you have to spare in the situation? Do you have sufficient to attend to many variables (High) or nothing to spare at all (Low)?

1 2 3 4 5 6 7

Information Quantity
How much information have you gained about the situation? Have you received and understood a great deal of knowledge (High) or very little (Low)?

1 2 3 4 5 6 7

Familiarity with Situation
How familiar are you with the situation? Do you have a great deal of relevant experience (High) or is it a new situation (Low)?

1 2 3 4 5 6 7

Disclaimer: The question about `Information quality` is missing from this questionnaire.

A.2 Equation to calculate SART score

$$D_1 = Instability\, of\, situation \quad S_1 = Arousal \quad U_1 = Information\, quantity$$
$$D_2 = Variability\, of\, situation \quad S_2 = Spare\, mental\, capacity \quad U_2 = Information\, quality$$
$$D_3 = Complexity\, of\, situation \quad S_3 = Concentration \quad U_3 = Familiarity$$
$$Demand = D_1 + D_2 + D_3 \quad S_4 = Division\, of\, attention \quad Understanding = U_1 + U_2 + U_3$$
$$Supply = S_1 + S_2 + S_3 + S_4$$

$$Situational\, awareness = Understanding - (Demand - Supply)$$