Are Eco-Driving Feedback Tools visually distracting the driver?

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Abstract

Electric vehicles gain in popularity due to their low impact of pollution. It becomes more obvious than ever that these cars will be our future. However, it frequently occurs that drivers perceive range anxiety, the fear of running out of battery before reaching their destination, and not much is known about feedback systems of electric vehicles which help the driver in monitoring their battery status. Is it possible that a feedback tool has a distraction potential? This study investigates this question using the speed and steering variances from a driving simulator in a Virtual Reality space. All participants, 23 in total, were between 18 to 29 years old and possessed a driver's license. In the experiment, every participant drove a simulated electric vehicle in four conditions. During two experimental conditions, a feedback gauge was shown, indicating how battery efficient the drive was, during the control condition no feedback gauge was provided, and participants were presented with a low and a high range anxiety condition in each of the two conditions. Results indicated that the eco-feedback gauge has no distraction potential under normal circumstances but while being under range anxiety distraction was suggested in the range anxiety condition. In future research it is recommended to investigate more on a distraction potential of range anxiety.

Keywords: Electric vehicle, driving simulator, efficiency gauge, virtual reality, range anxiety, distracting driving

Are Eco-Driving Feedback Tools visually distracting the driver?

In the last decade the concerns about global warming have risen and European directives have encouraged car manufacturers to improve their conventional engines which are reaching their maximal limits of possible adjustments. In contrast to usual combustion cars, Electric vehicles (EVs) have no emission of CO2 and therefore present a good alternative to lower societal pollution rates. As the sales for EVs have a new peak, a reoccurring problem among owners was noticed. Many experience problems in estimating the vehicle's range capacity, a problem which is known under the term of range anxiety. It means that drivers fear to run out of battery which causes a state of stress and anxiety. In order to counteract range anxiety, information about the driving style are provided to the driver by integrated feedback tools on the EVs dashboards. This should add to the understanding of a battery efficient driving style concerning acceleration, braking and steering. However, new tools in cars can have a negative impact on the drivers' attention. It could enhance the visual distraction potential. Distraction from driving is likely to increase the number of car accidents. Visual distraction is known to cause unsafe driving on the road. The effect of eco-feedback gauges on distraction is not investigated much which is why this study aims to investigate whether these tools are visually distracting the driver. This driving simulator study aims at gaining knowledge about EVs eco-feedback tools' distraction potential based on speed and steering variances.

Background

1.1 Electric Cars

EVs have encountered a growth in popularity in recent years (Kester et al., 2020). Their development is becoming more important and known brands started developing more EVs to add to their product line. One factor leading to this growing interest in EVs is the improvement of changing possibilities for electric vehicles. In the recent years many improvements happened in the charging infrastructure in Europe (Fluchs, 2020). Charging stations and fast charging opportunities become more prevalent which makes the purchase of an electric car more attractive. Another positive reason for the popularity is the beneficial effect on the environment. Due to the rising concerns of global warming, European directives have encouraged car manufacturers to improve their conventional engines to be more eco-friendly, which is reaching its fullest extent, meaning a change is needed (Casals et al., 2016). Therefore, EVs present a good alternative to lower societal pollution since plug-in-vehicles have a null emission tailpipe (Casals et al., 2016). However, some unforeseeable problems have developed which have a huge impact on the driver.

1.2 Range Anxiety

A known reason why people are hesitating to buy an EV is because of its limited battery capacity (Hidrue et al., 2011). Range anxiety is the fear of having an empty battery so that it is not possible to reach one's destination (Birrell et al., 2014, Noel et al., 2019). Since cars with an electric motor works differently than a gasoline motor, drivers seem to have a problem interpreting the adequate range they need per day (Haddadian et al., 2015). Therefore, they meet battery capacity with skepticism even though the battery is capable to last the intended journey. This seems to make EVs unsuitable for longer drives and as such fear prompts range anxiety in the driver even though the battery is often able to last the trip (Rauh et al., 2015). Second, drivers tend to distrust the cars' estimation of distance-to-empty ratio (Franke et al., 2016). Trust is important in order to keep the range anxiety of the driver low. Even though this is not yet fully empirically explored, trust is an important factor in anticipating behaviour and user-experience (Franke et al., 2016).

Accordingly, range anxiety has an impact on the driving style. One change might be to reduce the battery draining by driving slower, but many drivers take up a risky driving style anyway (Kester, 2019). A study of Yuan et al. (2018) showed that people adopt a coping mechanism for their anxiety that might lead to a high chance of car accidents. One risky style can be *grabbing lines*, where the driver is not able to adhere to lane keeping and therefore grab lines or drive on the wrong side of the road (Yuan et al, 2018). However, these researchers also established that drivers feel anxiety relief when having an in-vehicle information system because it gives them a sort of guidance and safety. While every participant experienced range anxiety, in-vehicle information systems (IVIS) helped them to cope better with the stress. Bowen's et al. (2020) study emphasises that stress and anxiety are major factors that lead to dangerous driving. Dangerous driving under anxiety is mostly seen through making more driving errors and unintentionally violating traffic laws (Bowen et al., 2020). In order to reduce these errors, IVISs which provide the driver with feedback about their driving style were implemented into EVs.

1.3 Eco-Driving Feedback Tool

In order to lower the range anxiety of EVs drivers, eco-driving gauges were developed. These give feedback about how battery efficient the driving style is at any given moment. Accordingly, this feedback should help reduce possible range anxiety for EV owners. Eco-driving assessment tools are located on the dashboard of EVs (see Figure 1) and its design varies from one manufacturer to another (Braumann, 2015). The feedback provided is the same for every gauge, it shows how battery efficient the driving style of the driver is (Braumann, 2015). More in detail, the smart driving tool is used to show whether the battery is charging, in eco mode or being drained (Rouzikhah et al., 2013). In sum, this tool is providing constant feedback to let the driver know their consumption and make planning ahead easier. However, this feedback system is relatively unexplored. With every new display there is a potential for visual distraction (Beloufa et al., 2014). Some known visual distractors are IVIS, and the feedback tool can be included in this category.

Figure 1

Example of an Eco-Efficiency Feedback tool (left side of the dashboard).

1.4 Distraction while driving

Distraction is a well-known problem in the automobile world. According to Regan et al. (2009), distraction is a form of inattention of the driver who is unsuccessful in attending to the driving task, which leads to a decline in cautious driving. Most traffic accidents (70%) are caused by visual distraction meaning that looking at displays in the vehicle can lead to accidents (ITO et al., 2001). Driving is a complex task which uses a lot of the processing resources of the driver. Their visual field needs to be fully focused on the road in order to not impact their driving style. Therefore, shifting focus to something else reduces the resources which would be necessary to ensure safe driving (Liang & Lee, 2010). Some examples of distractors are changing a song on the stereo, looking at the navigation system or user interface displays. This implies that distraction from the road can happen quickly and may have major negative outcomes like causing a car accident (Rouzikhah et al., 2013). However, not much is known about the potential distraction of eco-driving feedback gauges in electric vehicles. Therefore, research about visual distractors is used as a base in order to expect the impact of efficiency gauges on driving behaviour.

Distraction from the primary task can influence driving behaviour in multiple ways. One of the well-known behavioural impact due to distraction is the maintenance of speed (Sodnik et al., 2008; Yusoff et al., 2017). Yusoff et al. (2017) established that when being distracted, drivers tend to decrease their speed. In their study, the researchers wanted to identify common measurements to detect visual distraction. The research team mentioned a few different methods that help with measuring distraction. To investigate visual distraction, the measurement of driving performance (like speed) would be suitable because it is able to detect the effect of distraction. This is in line with the paper by Yusoff et al. (2017), which states that speed is especially useful for detecting visual distraction. Still, it is also possible that drivers exceed the speed limit easily while being distracted since Young et al. (2013) observed that not only are drivers more likely to go slower under distraction but there is a possibility of going faster. Their goal was to establish how the driving errors differ between visually distracted and not distracted participants. Speeding was a prominent error committed by distracted drivers. More so, participants tended to exceed the speed limits more often. Still, speeding errors were made in both groups but the number of errors in total were higher in the distraction group. It seems like it is dependent on the individual case whether speed is lower or higher, but distraction is disturbing the maintenance of constant speed (Yusoff et al., 2017).

Another measurement of distraction is lateral control (Yusoff et al., 2017). This concerns the impairment of the lane-position. While being distracted and having the eyes off the road the steering wheel is not moved much and as soon as one looks up again the car might have left the lane. Therefore, distracted people need to make more adjustments by steering because of errors they made while being distracted (Yusoff et al., 2017). However, Young et al. (2013) suggest that steering measures do not differ significantly between a distracted and normal driver. Still, the study of Liang and Lee (2010) showed that drivers usually make three types of errors which lead to lane departure. The first one is steering neglect, where the distracted driver is failing to look on the road and is not able to see that a change in the vehicle’s position has occurred. Second, drivers under-compensate when adjusting the car back to a normal position meaning they do not steer enough so that the car is in the middle of the lane. Last, they over-compensate which means they steer a bit too aggressively which happens when they look back to the road and see the car drifting away. The outcome of this study was that people who were exposed to visual distraction have steered more than those who had no distraction at all. This makes steering an important measurement for detecting distraction.

Last, it is important to mention that range anxiety also has an impact on distraction. As stated above, range anxiety arises quickly when driving an electric vehicle. Range anxiety can limit cognitive resources to a point where the driver is distracted (Wang et al., 2020). It can change the driving behaviour since the driver is looking for ways to reduce their anxiety (Yuan et al., 2018). These changes might be an increase or reduction in speed. In order to limit their stress, drivers will try to adopt coping styles. One of them could be focusing more on the IVIS since it gives them feedback on their driving style (Wang et al., 2020). The efficiency gauge is an IVIS, and the drivers might use it more when experiencing range anxiety. As mentioned above, especially in EVs range anxiety happens frequently and efficiency tools are not yet researched enough. In order to know whether people look more and longer on the tool due to range anxiety, more insight is needed.

1.5 Present Study

This study is part of a larger project, with the purpose of empirically exploring eco-driving tools within EVs. With this paper, we want to investigate whether eco-feedback tools distract EV drivers. First, we want to investigate whether the driver is more distracted when they have an eco-feedback tool implemented in their dashboard. Therefore, distraction is compared in a situation in which a feedback gauge is provided to one without. The comparison between the two conditions was done by using the measurements speed and steering of the driver. Drivers tend to vary more in speed while being visually distracted. Steering will be also used as a measurement, since driver's inattention leads to more steering. Based on these findings we expect the speed to vary more and steering to be higher in the eco-feedback condition than in the no feedback condition. Second, we intend to estimate whether range anxiety increases the potential for distraction. In order to answer this, the two conditions from above need to have both a low range anxiety and a high range anxiety condition. Therefore, the condition with efficiency gauge in low- and high range anxiety category will be compared to no efficiency gauge and low- high range anxiety. Here, speed and steering ratio are measured as well. We expect that the participants will look more on the feedback gauge in order to reduce their range anxiety and as a result be distracted.

2. Methods

2.1 Participants

In total 23 students participated in this study. Twenty of them were recruited via the SONA-system of the University of Twente (UT) using opportunity sampling and three were recruited by the researchers using a convenience sampling method. Requirements for the participation in this study were to own a drivers' license, be at least 18 years of age and not to be potentially pregnant. Since this study involves a Virtual Reality (VR) headset, the participants should not have any kind of visual impairments (e.g., wear glasses) or were asked to wear contact lenses during the study. Finally, the participants should not have a history of getting motion sick easily. From the overall sample, 14 identified as female (60.9%), 8 as male (34.8%) and one as non-binary (4.4%). The age range of the sample was from 18 to 29 (M=21.4, SD=2.4). The participants' nationalities were German (17), Dutch (4), Luxembourgish (1) and Romanian (1).

2.2 Materials & Apparatus

Software

The driving simulator was developed in Unity (version 2019.2.21f1), a cross-platform game-engine software used to develop video games. This project was run by students and it necessarily utilised necessary pre-existing plugins. The plugins were used to develop the city (Fantastic City Generator), the traffic system like traffic lights and other cars that the participants encountered during their drive (iTS) and for the user input to be recorded, Logitech SDK was implemented. As for the unity environment, the city in which the participants were driving was a typical US-like city (See Figure 2). It had a lot of skyscrapers and small shops. There were functioning traffic lights but no traffic signs, and other vehicles without any pedestrians. Most of the other vehicles adhered to traffic rules except for the technical problem that they sometimes positioned themselves on the left lane but proceeded with a right turn. The car itself (Sedan) also had a plugin called "NWH Vehicle Physics" which enabled the simulation of a real car and its interior design. It did not have functioning mirrors which were therefore covered by a black box. This simulator could only mimic a combustion car, accordingly the dashboard needed adjustments to be in line with that of an EVs. Thus, the sound was turned off and an efficiency gauge was added.

Next to Unity, the softwares SteamVR and Varjo were installed to ensure a connection between the VR headset and Unity. The view of the participants through the glasses can be seen in Figure 2.

Figure 2

The view of the participants while being in the driving environment

Hardware

The experiment was executed on a computer with multiple external hardware connected to it. The computer set-up consisted of an Alienware computer, a “Next Level Racing” chair with steering wheel and pedals from Logitech G920 Driving Force (Figure 3) and the Varjo VR-2 headset.

Figure 3

The set-up of this experiment with the racing chair and the Varjo VR headset.

2.3 Design

In this study a 2x2 within-participant design was used. This experiment is composed of four conditions. Every participant drove in every condition, meaning they had to drive four rounds. On the dashboard of the car a speedometer and a battery were displayed throughout the whole experiment. During the first condition, the Feedback condition, participants had an efficiency gauge displayed on the dashboard and the battery was nearly fully loaded (80%). For the second condition, called Feedback Low Battery, the display was set-up like in Feedback, but this time the battery was nearly empty (20%). In the third condition named No Feedback, no efficiency gauge was displayed and the battery was loaded 80%. For the last condition, No Feedback Low Battery, the participants had the same dashboard set-up as in No Feedback and a nearly empty battery (20%). Feedback Low Battery and No Feedback Low Battery were used to potentially evoke range anxiety because the car might run empty during the drive. These conditions were used as variables to identify potential range anxiety and distraction. Feedback and Feedback Low Battery were compared to No Feedback and No Feedback Low Battery in order to measure whether the efficiency gauge might be a source of distraction.

2.4 Routes

Each route covered a different part of the city and was approximately the same length. Before each condition the researchers chose randomly one of the four prepared routes (See Appendix B). In each of the four conditions the routes were alternated, meaning that by the end of the experiment every participant had driven every route. This ensured that the participants' driving style was not changing due to adjustment to the route. The experimenter functioned as a navigator and told the participants verbally where to turn left or right according to the present route. The verbal instructions were held short and explicit (e.g., at the next possibility turn right). Each route took about more or less five minutes.

2.5 Task

After the participants were introduced and adjusted comfortably in the simulator (See Figure 4), the test trial was started. The participants were allowed to drive through the city freely in order to get adjusted with the functioning and behaviour of the car and simulator. Every participant was able to decide themselves how much time they needed in order to feel comfortable driving in the VR-environment. As soon as they felt comfortable the experiment was started. Altogether, the experiment consisted of four conditions (four driving sessions) with each lasting approximately five minutes in total.

Figure 4

The participant adjusted in the seat with VR headset on and ready for the experiment

In the Feedback condition, the battery had a bright green colour (See Figure 1). This represented a low range anxiety condition. A route was chosen as explained in section 2.4 and a timer was started. The participant started driving and was navigated by the experimenter. After approximately five minutes, the participants were asked to stop at the end of the street. Upon stopping the car, the VR headset was taken off and a small break of five to ten minutes followed. The Feedback Low Battery condition was a high range anxiety condition (See Figure 5). Therefore, the participant got an instruction by the experimenter before driving, namely: “Only a small amount of battery is left. That means you might run out of charge since this happened to other participants before, either way, drive as you normally would under these circumstances.” Next, the same procedure repeated itself with choosing the route and driving for about five minutes. At the end of this drive, the participants were granted a longer break where they could walk around or use the bathroom facilities.

No Feedback and No Feedback Low Battery were control conditions. Before the condition No Feedback, the participants’ attention was directed towards the missing efficiency gauge. Afterwards, the same procedure followed where they were solely navigated by the experimenter. After five minutes this condition was finished, and another small break followed. The last condition No Feedback Low Battery, was again high range anxiety. Therefore, the experimenter instructed the participant accordingly. After this drive the experiment was finished.

Figure 5

The dashboard in condition two with efficiency gauge and low battery

2.6 Procedure

The experiment took place in the BMS Lab of the University of Twente and lasted approximately 90 minutes per participant. Due to the corona pandemic some preventative measures needed to be taken into account before entering the simulator room. Upon arrival, participant and present experimenters had to sign a Corona regulation form and disinfect their hands. Next to this, every person involved had to wear a mask, at least one window was open during the entire experiment and a maximum of three people were allowed in the room. All equipment of the driving simulator (VR headset, chair, steering wheel) was disinfected following every participant.

After entering the room, the participants were explained the procedure of the experiment. Thereafter, they took a seat in the driving simulator and got introduced to the simulator. They were told that this vehicle has an automatic gearshift and they only needed the throttle and the brake pedal. Subsequently, for hygienic reasons, an eye-mask and a hairnet were provided to the participants and the VR headset was adjusted on their head. In Unity, the participants visual viewpoint was manually positioned, to mimic their realistic viewpoint in the physical set-up which should establish a realistic driving experience. Next, the functioning of the efficiency gauge and the battery was explained. Following, the participants started the test drive and at the end, they were asked whether motion sickness was encountered and whether they preferred to take a break or start the first trial immediately. As soon as the participant was ready, the eye-tracking calibration was started in the Varjo software. The simulation was started in Unity. Finally, the experiment was started as explained in section 2.5.

At the end of the four conditions, the participant was debriefed, asked about potential complications they encountered during their drive and thanked for their participation in the study.

2.7 Data Analysis

In order to generate a clear dataset, the variance was calculated for every participant's speed (km/h) and steering angle (degree angle). The variance was chosen for two reasons. First, it states how much the steering and speed variances are varying from the mean. With this information an identification can be made which condition has the highest and lowest variation between values. Second, the variance is sensitive in identifying outliers. Therefore, outliers were identified with boxplots and deleted in order to generate a precise dataset with a lower the risk of misleading results. To examine potential distraction of the efficiency gauge, t-tests were used to test whether there is a significant difference. The tests were separately performed for speed and steering variances. For the hypothesis concerning range anxiety, the same procedure with two t-tests was used but with the variables of the condition high range anxiety (Feedback Low Battery & No Feedback Low Battery) and low range anxiety (Feedback & No Feedback).

3. Results

3.1 Distraction

To test whether participants were more distracted when being presented with an efficiency gauge than when they do not have one available on the dashboard, the variances of speed (in km/h) and steering (in degree) were analyzed.

Speed Variance

For the first hypothesis, a t-test was performed with the conditions Feedback/ Feedback Low Battery and No Feedback/No Feedback Low Battery. The t-test showed that no significant difference was found in speed (km/h) between the condition with feedback gauge and the condition without, $t(39)= 0.3$, $p=0.79$ (Table 1).

Steering Variance

For steering variances (degree) a separate t-test was performed on the same conditions as for speed variance. This t-test also showed no significant difference in steering (degree) between the conditions with feedback gauge and without feedback gauge, $t(38)= -0.6$, $p=0.58$.

Table 1

Inferential Statistics of the distraction potential of an efficiency gauge based on speed and steering variances

	Feedback (N=40)		No_Feedback (N=40)		Feedback*No_Feedback (N=40)		
	M	*SD*	*M*	*SD*	*p*	*t*	*df*
Speed (km/h)	262.2	127.8	255.8	147.9	0.79	0.3	39
Steering (degree)	5.7	2.9	6.3	5.5	0.58	-0.6	38

Note. Feedback*No_Feedback stands for the paired t-test on the conditions with feedback gauge and without feedback gauge.

3.2 Range Anxiety

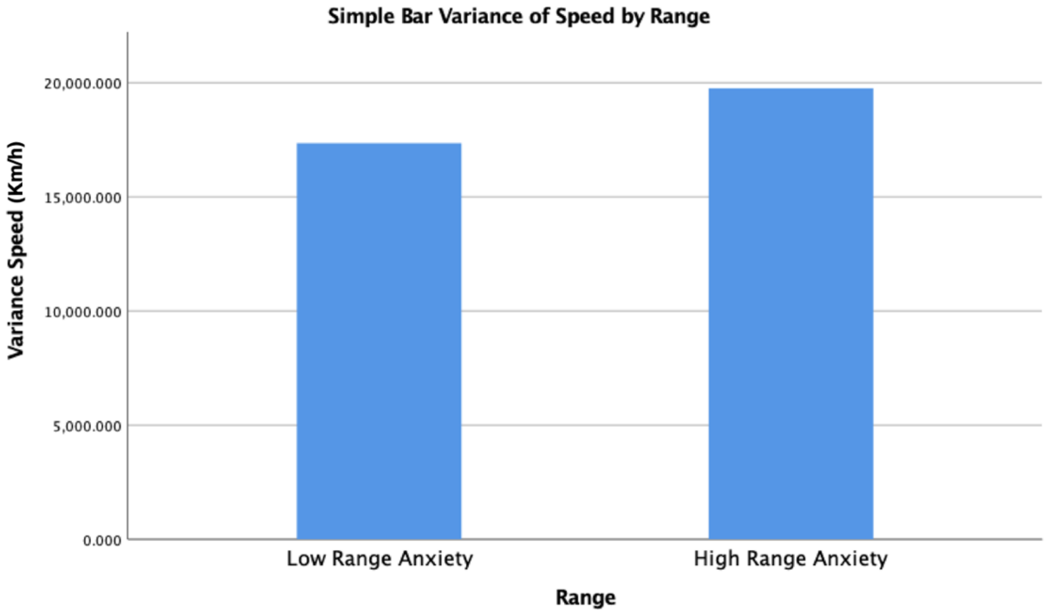
To test whether participants get more distracted in a high range anxiety situation by a feedback tool compared to a situation where no tool was available, the variances of speed and steering were analysed.

3.2.1 Speed Variance

To examine this hypothesis a t-test was performed (See Table 2). The speed variance (km/h) of the conditions high range anxiety and low range anxiety were compared for this analysis. These variances showed that there is a significant difference between the two conditions, $t(39)=2.5$, $p=0.02$. As expected, in the low range anxiety situation, the speed variance (km/h) is higher ($M=288.3$, $SD=131.6$). During an induced high range anxiety situation, the participants drove considerably slower ($M=236.2$, $SD=143.1$). This shows that the participants reduced their overall speed while being in a high range anxiety situation (Figure 6).

Figure 6

Bar chart of the significant difference in speed variances between low and high range anxiety



3.2.2 Steering Variance

In order to test whether these results of speed variance significantly differentiating between low and high range anxiety situations are the same also for the steering variances (degree) a t-test was performed on the conditions of high (Feedback Low Battery/No Feedback Low Battery) and low range anxiety (Feedback /No Feedback). Unexpectedly, the results of this t-test showed no significant difference between the conditions *t*(38)= -1.5, *p*=0.15).

Table 2

Inferential Statistics of the range anxiety hypothesis on speed and steering variance

	Low Range Anxiety (N=40)		High Range Anxiety (N=40)		Low RA*High RA (N=40)		
	M	*SD*	*M*	*SD*	*p*	*t*	*df*
Speed (km/h)	288.3	131.6	236.2	143.1	0.02	2.5	39
Steering (degree)	5.4	3.6	6.3	4.3	0.15	-1.5	38

4. Discussion

The present study was part of a larger body of research aimed at gaining insights about eco-feedback tools in electric vehicles (EVs). More explicitly, this study focused on the potential distraction factor of an eco-feedback gauge of an electric vehicle. It was suspected that the participants' speed variances (km/h) varied more, and they had higher steering (degree) action when a feedback gauge was available on the dashboard of the EVs which would indicate higher distraction. The findings showed no indication that feedback gauges were distracting the driver under normal circumstances (like Feedback). Thus, the first hypothesis can be rejected. The second hypothesis led to the expectation that the participants would use the feedback gauge more during high range anxiety situations in order to relieve anxiety, which would result in higher steering and higher or lower speed variances. However, when participants were in high range anxiety situations (like Feedback Low Battery), their speed variances were significantly lower compared to the fully loaded battery situation, indicating a form of visual distraction. Still, the steering variances did not suggest the same results which concludes that the second hypothesis of a distraction potential under range anxiety can be partially confirmed.

4.1 Distraction Potential of a Feedback Gauge

Opposed to the hypothesis, no significant difference was found in speed and steering variances between the conditions with (Feedback/Feedback Low Battery) and without feedback gauge (No Feedback/No Feedback Low Battery). This means that participants were not significantly distracted by the displayed feedback gauge. Therefore, it can be assumed that the hypothesis of feedback tools in EVs distracting the driver cannot be confirmed. However, participants were actually driving faster indicated by the higher speed variances and had a lower steering variance when having a feedback tool at hand. This contradicts what was expected based on Yusoff et al. (2017). Their study showed an increase in steering and a high variance in speed while the participant is visually distracted which was not the case in the current study.

4.2 Distraction by High Range Anxiety

While being exposed to a low range anxiety situation, speed differentiated significantly compared to the high range anxiety provoking conditions, which is opposed to steering. We will focus on the results of speed first.

4.2.1 Speed

There was a significant difference in speed variances when participants drove under a provoked high range anxiety condition opposed to a low range anxiety one. Yusoff et al. (2017) stated that visual distraction can be identified by the driver reducing their speed considerably. In this study, participants showed significantly lower speed variances when being told that they might be running out of battery. This could be an indication that the drivers tended to use the provided eco-feedback tool more while having anxiety or just compensated for their driving style. According to Yuan et al. (2018), drivers try to avoid or reduce stress while driving by adopting coping styles. In this case, participants potentially tried to cope with stress by using the gauge to get feedback on their performance and adjust their speed. However, it might be also possible that the participants only tried to reduce their battery usage. By compensating their driving style and speed, they tried to keep the battery usage to a minimum.

4.2.2 Steering

Regarding steering variances, no significant difference was found in distraction between high and low range anxiety situations. This was unexpected since earlier research indicated distraction under range stress. Next to this, the results are in contrast to the findings of Yusoff et al. (2017) stating that more steering is needed while being distracted and this was not the case in this study. Thus, participants of this study were not distracted in their driving performance. There might be two explanations for this. First, the participants might have been more concentrated on their lane keeping while looking at the feedback gauge but forgot to focus on their speed. Doing multiple things next to the primary task of driving can reduce the focus on other tasks like speed maintenance (Liang & Lee, 2010). This shifting in focus might have caused the participants focus on lane keeping rather than on their speed. Second, it might be possible that experience with EVs, have something to do with this result (Rauh et al., 2015).

4.3 Findings of this Study

In the distraction condition no significant difference was found between the conditions with (Feedback/Feedback Low Battery) and without feedback gauge (No Feedback/No Feedback Low Battery) in speed and steering variances. Therefore, the feedback tool did not lead to distraction in terms of lower driving performance in the current study. This contradicts the results by Liang & Lee (2010). They stated that shifting focus from the primary task, which is driving, leads to distraction. Since the participants were not distracted, two things might have occurred. First, it can be that the participants were not interested in the efficiency gauge. The participants got an introduction to the gauge and what it can do for them. However, it might be possible that they did not use it as much as expected. They might have utilised it once in a while just because it was there but did not spend a larger amount of time using it. A shift in focus needs to happen over a longer period of time in order to become distracted (Liang & Lee, 2010). Second, the efficiency gauge was potentially not used at all by the participants. The gauge gave feedback constantly, which meant that whenever the participant was in need of feedback on their efficiency, they could get it immediately. Due to this, they might have not found it valuable enough to spend more time using it.

For speed, a significant difference was found between induced high range anxiety and low range anxiety situations. This indicates a distraction of the driver while being in a high range anxiety situation, which goes against the study of Yuan et al. (2018). In their study, they found that IVISs are able to reduce range anxiety in the driver since it gives them feedback on their performance. Drivers feel safer because the feedback tool gives them a feeling of guidance which depletes anxiety. This deviation from former results can be caused by a few factors. First, it might be possible that the feedback gauge was not trustworthy enough to lessen the stress in the driver. People tend to have increased range stress, when the feedback systems are, in their opinion, untrustworthy or not accurate enough (Yuan et al., 2018). Second, giving the driver too much information at the same time can also increase their anxiety. Giving feedback to the driver should be timed and should not come too early or too late (Yuan et al., 2018). In the current study, the efficiency gauge gave constant feedback. As soon as the participant was pushing the throttle too much the gauge went into the red area. This might have caused range anxiety to appear, provoked by the feedback tool which was opposed to lessen it. However, the steering variances do not show the same results since no significant effect was found and participants were probably not distracted in their lane keeping. More steering is needed while being distracted because of errors in lane keeping (Yusoff et al., 2017). However, in the paper of Young et al. (2013) steering did not differ enough between a normal and distracted driver. It might be possible that this also happened in this study. Since speed variances indicated a distraction, the results from Young et al. (2013) might be applicable also here in the sense that steering is not a good indicator of distraction.

4.4 Contribution to Science

The aim was to investigate more on the tools of an EV and whether they might have a distractor potential. It can be concluded that the tested feedback tool was not found to distract the driver in low anxiety situations. This is a positive outcome since EVs gain in popularity and are becoming the cars of the future. However, range anxiety may lead to distraction in the driver. Therefore, it is important to keep investigating distraction in EVs, to cancel out or improve any form of distraction in order to ensure a safer future on the streets. Next to this, the simulation of the efficiency gauge was improved to mimic the functioning of a real efficiency gauge more accurately and fluently. This improvement will be used by other researchers in the future for similar studies. Consequently, the contribution is not only new knowledge in the direction of safety within the field of electric mobility but also an improvement in resources for future researchers.

4.5 Limitations

This study was conducted during the Corona pandemic which led to some time restrictions for executing the experiment and extra Corona measurements needed to be taken into account. Also, a few technical difficulties appeared in preparation of the experiment which could have negative implications on the results.

4.5.1 Software issues

The game programmed in Unity was lagging sometimes. Consequently, the programme had to be restarted after every condition in order to avoid lagging of the game. In other cases, the participants had to stop and restart a condition because the lagging was getting too much, and they were not able to focus on their drive. Other participants complained about blurry vision of the simulation. These restrictions might have limited the immersion into the simulated environment and therefore, the quality of the data. Thus, it is hard to apply these results to a real-life situation. Further, the other vehicles did not drive according to Dutch traffic rules. Some positioned themselves on the left lane but proceeded to turn to the right. This confused some participants and caused unforeseen accidents. Accidents during the simulation caused a disconnection between the steering wheel input and simulation, leading to a necessary restart of the condition. Thus, participants needed to stay longer and might have become unconcentrated which can influence the data quality.

4.5.2 Simulator

The driving simulator consisted of a professional set-up with well-known brands from the gaming industry (Logitech G), highly capable of realistic force feedback which simulates the feel of a car and tires. However, the brake, steering wheel, and throttle were perceived as too sensitive. Therefore, the braking was too abrupt, pushing the throttle was too sensitive and a feeling of a physical impact of acceleration force was missing. These limitations made staying at a consistent km/h difficult. Thus, participants did not have a realistic feeling of how fast they were driving and had to concentrate to maintain a constant speed. Next to this, steering was troublesome. It was perceived as if the car had no servo-assisted steering. These are limitations that might have impacted the quality of speed and steering data, since driving constantly was demanding and steering unrealistically complex.

4.6 Future Studies

Further research in the direction of distraction and the efficiency gauge is needed. Especially since there was a significant difference between high and low range anxiety situations, indicating a distraction potential. It would be important to have more insights into why range anxiety is distracting the driver and what can be adjusted in order to reduce anxiety. Next to this, including a more varied age group into future research would be valuable. It might be possible that steering variances did not show the same results as speed variances in high range anxiety conditions because of the young sample and inexperience. There is a possibility that experience has an impact on range anxiety in EVs (Rauh et al., 2015). For this reason, it would be interesting to investigate distraction on an older sample.

Furthermore, it is important to keep improving the simulation in Unity. Immersion into the simulation is important to ensure more accurate results and applicability to real-life situations. Therefore, a few things need to be adjusted for future studies in this direction. First, it is important to prevent lags. Next to this, the sensitivity of the gear should be adjusted. It was not perfectly resembling a real car, which made the situation look more like a video game rather than a simulation of an actual drive.

It would also make sense to add traffic signs to the environment. By doing this, the researcher can test, whether participants are driving significantly slower or faster is due to distraction. In this study the participant was only instructed to drive as they normally would and adhere to traffic rules, but after all, the speed was chosen by them. With the addition of signs, the complexity of the simulation will become more realistic and make the study more valuable.

4.7 Conclusion

This study aimed to answer the question whether eco-feedback tools distract the driver. We found that under normal circumstances drivers do not get distracted by the feedback tool. However, speed variances are significantly different between the high and low range anxiety situation which indicates that a high range anxiety situation interferes with the primary task of driving and distracts the driver. This needs to be further investigated to ensure safety in traffic. In conclusion, this study leans towards a new direction of research about electric mobility which is necessary to establish a safer, greener, and healthier future.

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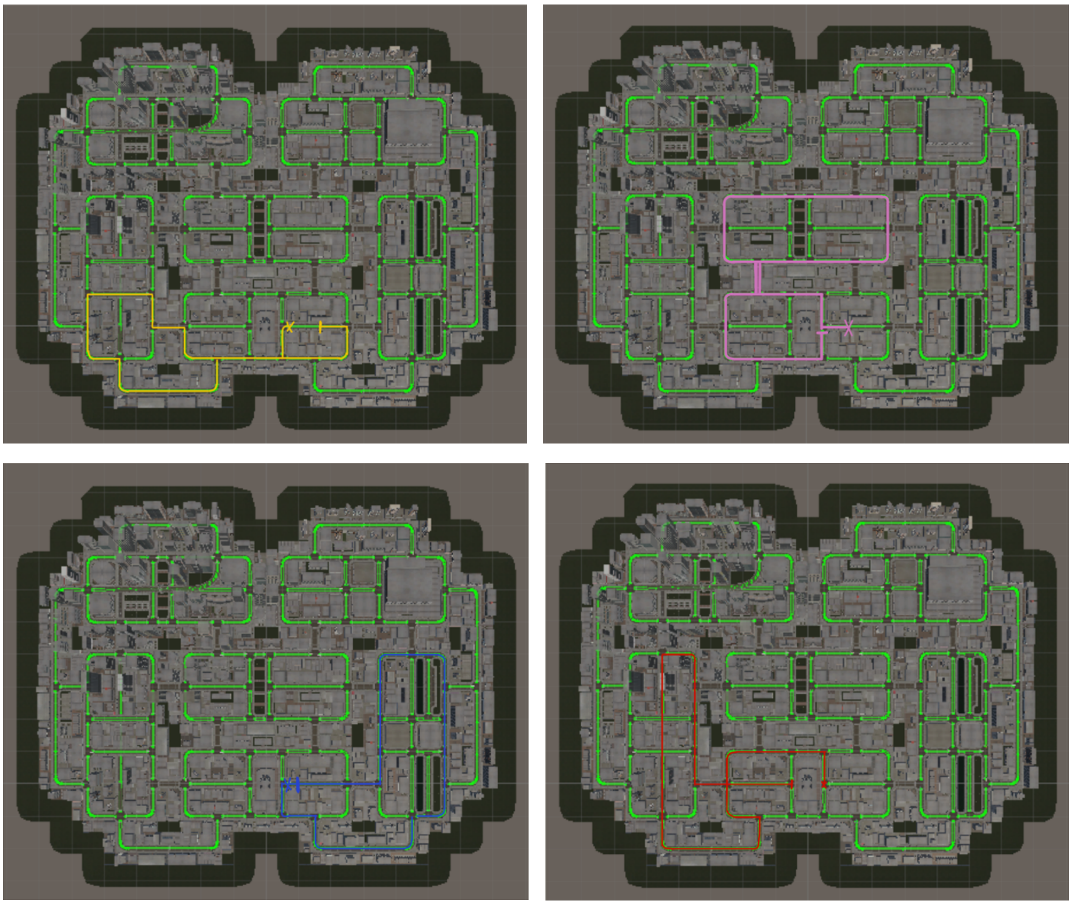
Appendix

Appendix A

Four routes used to navigate the participant around the city



Note. Every route has the starting point. The participant starts where the ‘X’ is.