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Workload management for warning signals at high speeds

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Abstract

Purpose – The purpose of this paper was to identify influences on driver workload. In this case identifying the influence of high speeds on driver workload as well as investigating the differences of transmitting warning signals via the visual and auditory channel.

Design and Methodology – Two simulator studies were conducted. The first one was with 36 participants and the second one with 43 participants. The subjective workload was measured using the NASA TLX and the objective workload was measured comparing the standard deviation of the steering movement. The main analysis of the collected data was done by using a repeated measures ANOVA.

Findings – There was a significant increase of driver workload with an increase in speed. Also the workload was higher when presenting a warning signal via the visual channel than presenting the same information via the auditory channel.

Originality/value – The novelty of this study lies in the exploration of the relationship of high speeds and driver workload. The concept of reducing workload by changing the channel by which information are transmitted is a well-known concept but was not yet implemented on showing warning information.

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1. Introduction

In modern cars the amount of information signals for the driver has increased. As a result, drivers often suffer from visual overload (Ho & Spence, 2009). This may lead to crashes or dangerous situations (Green, 2000) but driver overload cannot only be caused by visual signals. Many researchers refer to overload in the context of the workload concept, particularly if the workload is too high for the driver (Wickens, 2008). Today's cars are containing significantly more computer technology than nearly 20 years ago. In 2000, Verwey addressed the problem of driver overload caused by driver information systems. He researched determinants of driver workload and the effects of an adaptive interface on workload. He already suggested to use steering frequency as an indicator for workload and therewith improve adaptive interfaces. He also proposed that in some road situations no messages should be presented to the driver, because too many messages can lead to driver overload.

However, cars nowadays have an increasing number of assistant systems, extended infotainment offers and a permanent connection to the internet, which all peak in more visual and auditory stimulus for the driver. Drivers are able to surf the internet, get traffic data and get information messages from the assistant systems. Those systems are developed to make the drive more convenient for the drivers, but are also a great distraction and increase the workload. Those additional information intend to be an extra service but are not directly relevant for the driving task itself. In some situations, where the driver is already heavily loaded and has no more attentional capacities, those systems can decrease the driving performance of the actual driving task. The industry is well aware of the problem but there is no good solution implemented yet. According to the information collected during the collaboration with the AUDI AG in the last 7 months, the lack of an implemented system is due to the fact that many systems were actually functional but too complex and costly to implement. Many reviewed systems were based on the input of a large number of sensors e.g. front camera, rear camera, GPS or a driver camera. The information extracted from those sensors were used to estimate the driving situation and driver workload. Based on those estimates the information passed on to the driver were regulated. Those systems can be described as an adaptive car interface which manages the information passed on the driver. The intent of such an adaptive interface was to reduce workload. But this universal approach to multiple situations namely the inner city, roundabouts or urban roads increased the system's requirements and costs which made it difficult to implement such an information manager into new cars. The situations that are highly

demanding are mainly known but the question about which adaptions reduce the workload still has a lot of potential.
In the course of this thesis, the idea was to develop a system applicable for a specific situation which would need less sensory information, thus less sensors. The objective was to have a much narrower approach to an adaptive interface. There is a need to customize information messages to situations where they are absolutely needed or where the drivers have spare workload capacity to minimize the risk of an overload. The importance of such a regulation becomes more obvious when looking at the consequences of driver overload (Wickens, 2008). Overload can have a serious influence on safe driving (Verwey, 2000). Regarding the theoretical background of workload, one needs to differentiate between visual and mental workload. The driver is visually loaded by primary driving tasks, like lane keeping and steering, but mentally loaded by tasks using the navigation system, talking or planning the route (de Waard, 1996; Verwey, 2000). To understand when overload arises, the concept of workload needs to be explained.

Workload is described as the relation between the cognitive resources demanded by a task and the cognitive resources available to the human operator of that task (Parasuraman, Sheridan, & Wickens, 2008). Processing resources are limited and mistakes are likely to be made if those resources are divided between too many tasks (de Waard, 1996). Mental workload is defined as the amount of information processing recourses required to execute a task. In case of the driving task this could be a navigation task (Patten, Kircher, Östlund, & Nilsson, 2004). Most literature about workload arose around the 60's to 70's and was intensively reviewed by Moray (1979). The results from these studies about cognitive (or: mental) workload helps to improve human-machine interaction and to prevent operating errors. Various authors have already investigated the influence of workload on driving performance and found that a high workload can lead to a decrease in driving performance (Salvendy, 2012; Engström, Johansson and Östlund, 2005; Verwey, 2000). Many variables, like mobile phone usage, the environment and traffic have been examined and have been shown to negatively influence the driving task due to an increase in workload (Patten, Kircher, Östlund, Nilsson, & Svenson, 2006; Törnros & Bolling, 2006). Based on those experiments, some researchers tried to develop a workload manager (or: information manager), which regulates the outgoing information messages for the driver (Köhler, Bengler, Mergl, Maier, & Wimmer, 2015; Totzke, Rauch, Ufer, Krüger, & Rothe, 2004; Verwey, 2000). Those solutions developed by the aforementioned researchers depended on workload estimations based on situational information. Generally, those authors concluded that it is beneficial to have such a workload manager but this conclusion was mainly based on situations that were limited to a certain speed, like driving on suburban roads or in the inner city. Especially making a turn has been a focus of those researchers, which led to the conclusion to present information on straight roads (Köhler et al., 2015). Currently, only Volvo has some kind of information manager installed in their models build after 2003, it is called IDIS (Intelligent Driver Information System). The system takes into account the driving speed, the steering angle, the infotainment usage and the current gear selection. According to Volvo, if the system detects a high workload for the driver it can suppress a call or message up to five seconds ("The all-new Volvo", 2003). To gather information for this thesis, a self-arranged test drive in a Volvo XC 90 was conducted but the system's benefits could not be experienced by the researcher and a colleague. Even at a roundabout or while driving in reverse the system would not suppress any incoming calls done by the researchers. This suggests that the system did not function properly or at least not the suppression of a call, but the general principle of such a system has been proven to be beneficial by other researchers.

The literature about information managers is mainly focused on situations within the city or on urban roads but is lacking a closer look at workload at high speed drives with 130 km/h or even faster. The focus on speed of this research is based on the fact that speeding is a major cause for traffic accidents. Also the sensor that measures speed is available in every car, which simplifies a later implementation. Inattention and driving at high speeds is a major cause for accidents (Jo & Lee, 2014; Klauer et. al. 2006). According to the German Federal Statistical Office around 15% of all 305659 car accidents in Germany in 2015 were due to inappropriate high speeds (German Federal Statistical Office, 2016). The focus of this paper is driver workload at a speed of 130 km/h, 180 km/h and 230 km/h on highways and whether it can be reduced by an adaptive interface comparing it to the standard interface. The first increment of 130 km/h was chosen because it is the highest limit by law on the German highway. The next two increments were both an increase of 50 km/h, 180 km/h and 230 km/h respectively. A difference of 50 km/h between the increments was considered to be reasonable gradation. At some point the driver will not be able to deal with any other additional information, at that point the information manager should adapt the way of presenting information massages.

Considering the practical relevance of the integration of such an adaptive interface for drivers, the following research question guides the investigation reported in this paper: To what extent does driving with high speed influence the workload of the driver and does an adaptation of particular signals decrease the workload in that situation? At the beginning of this research, the original idea was to suppress a warning signal but this has changed during the course of the reported study. The complete suppression of an information message was seen as a too radical change for the customers regarding the warning concept known to them. Therefore, it was decided to test if presenting warning messages only via the auditory channel is an alternative option. The warning messages used in the later study, were copied from Audi's today's standard warning messages. In case of this study three warning messages were presented: Wash-Water Min, Oil Min and Break Error warning. The content of those messages is outlined in the experiment section.

1.1. Theoretical framework

1.1.1. Cognitive functions used while driving

Most of the literature about cognitive functions while driving involves how humans perceive and process information, which is often based on attention (Porter, 2011). Since driving demands a high amount of attention when for example interacting with other drivers, navigating in an unknown environment or driving on an icy road, it is an important component for the framework developed during this thesis. To actively perceive, interpret and understand information while driving, attention is required (Schneider & Shiffrin, 1977; Porter, 2011). Focused attention is needed to process information as information will only get stored in memory, if the information is attended consciously. In order to process multiple stimuli, people need to be able to shift their attention, which is referred to as selective attention (Eby & Molnar, 1998). Lavie, Hirst, Fockert and Viding (2004) defined selective attention as a process where "Goal-directed behavior requires focusing attention on goal–relevant stimuli while ignoring irrelevant distractors" (p.1). Goal-directed behavior can be explained by an example: Suppose drivers are driving at high speed, which requires their attention, and the car suddenly shows a warning message. Then, these drivers have to pay attention to use the presented information.

Another important model is the multiple resource model which distinguishes 3 types of resources in the information processing procedure. The 3 types are the input and output modalities (visual vs. auditory), processing stages (perception vs. responses) and responses (vocal vs. manual) (Wickens, 1984). The primary driving task, as for instance course keeping, is mainly a visual-spatial-manual task (Strayer & Johnston, 2001; Wickens, 2002). The model, as presented in figure 1, shows which processes use the same resources and that there can be a cognitive overload if two tasks use the same resources. The information provided by the multiple resource model is the basis for the assumptions made regarding the experimental manipulations of the second experiment. The assumptions are outlined in the introduction to experiment 2 later on.

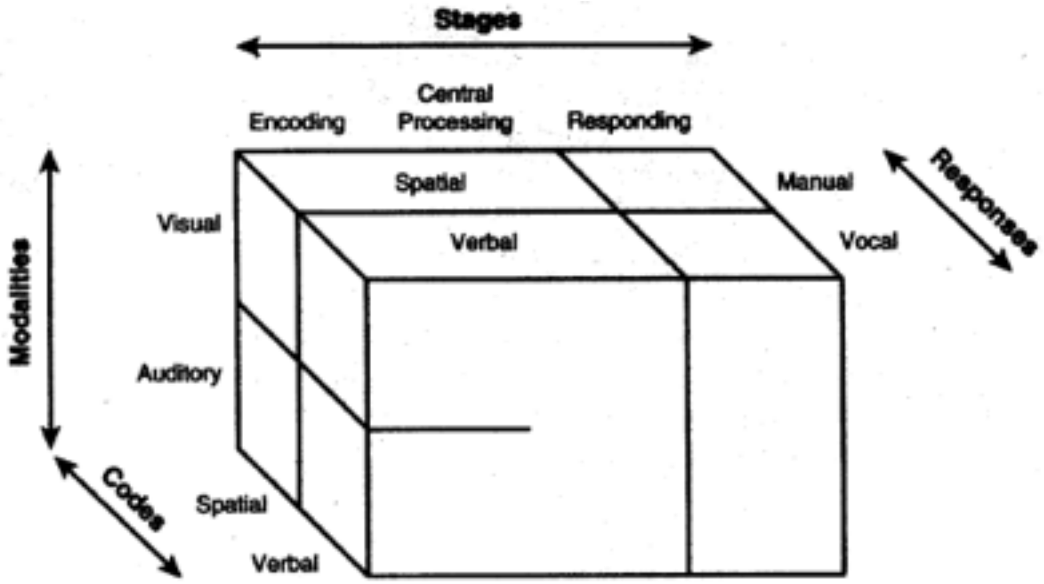

Figure 1. Multiple resource model (Wickens, 1984).

How the above mentioned mechanism of information processing and behavior adaptation can be transferred onto the driving task, is described by the approach of Bellet et. al. (2011). They propose that the driving task can be distinguished between four cognitive subtasks: 1. The selection of relevant information from the environment; 2. The processing and comprehension of the information; 3. The interaction with the processed information as the road conditions or other drivers and 4. The management of resource capacities to finish the task in a satisfying manner. Setting those steps in context to the before stated problem of driver overload and relating it to the multiple resource model, a representative example of the four cognitive subtasks would be: 1. Analyzing the environment and factors that influence the risk on driving at high speed (road, traffic, car itself), this task is a mainly visual demanding task; 2. Evaluation of the selected factors, to ensure that the environment allows driving at high speed, this is the central processing and increases the cognitive workload; 3. Adjusting of the speed accordingly, this can be seen as a manual response to the information encoded from the visual input; 4. Focus on the aforementioned conditions to adapt the intensity of breaking or speeding, this is basically starting at step 1 again. How demanding the driving task is for the driver, depends on four elements stated by Porter (2011). The first element is the task difficulty (1), which is determined by the driver's capabilities. Driver capabilities (2) arise from physiological characteristics, education and experience. The element of task demand (3) is influenced by the environment as road characteristics or visibility. The last element is the 'Task Difficulty Homeostasis' (4), which is a process where drivers adapt their driving behavior according to the driving situation. The factors play an important role, in the sense that they determine how safe the driver can accomplish the driving task (Porter, 2011). The above outlined knowledge was useful to understand that information can be perceived via different modalities by the driver and that too many information can lead to overload of driver workload. It was also important to see that the difficulty of a driving task is influenced by multiple conditions. The knowledge from above was adapted in both experiments. The first experiment had the focus on gaining insights into the influence of driving at high speeds on workload and the second experiment had the focus on the different channels of receiving information.

1.1.2. Models of Driving

The second part of the theoretical framework consists of the models that are needed to understand the relation of steering behavior and workload. This is the foundation for the evaluation of the second experiment. Since it is not only important to find out about the subjective workload differences but also to analyze if it is possible to find differences in the driving data for driver workload. The model that builds the foundation for further assumptions about steering movements and driver's attention is the STI compensatory driver model by McRuer et. Al. (1977). In their model the authors show how vehicle dynamics can account for driver reactions (figure 2). The model shows the loop of the driver interaction with the environment in relation of the lateral position, which is controlled by the steering angle. According to Godthelp, Milgram and Blaauw (1984), if drivers' attention is diverted from the road because of a high visual load, they cannot give any tracking response. This results in periods with a fixed steering wheel angle, which can result in heading errors. That would lead to correction maneuvers. Their findings are confirmed by Engström, Johansson and Östlund (2005) who state that "lane keeping errors resulting from visual time sharing have to be corrected by steering maneuvers which generally are larger and more disruptive than steering movements during normal straight road driving" (p.99) , which would result in a higher mean standard deviation of steering movement. The effects of visual demand on steering can also be quantified in terms of the disorder, or entropy, of steering wheel movements (Boer, 2000). In the second experiment the mean standard deviation of the steering movement will be the core of the analysis.

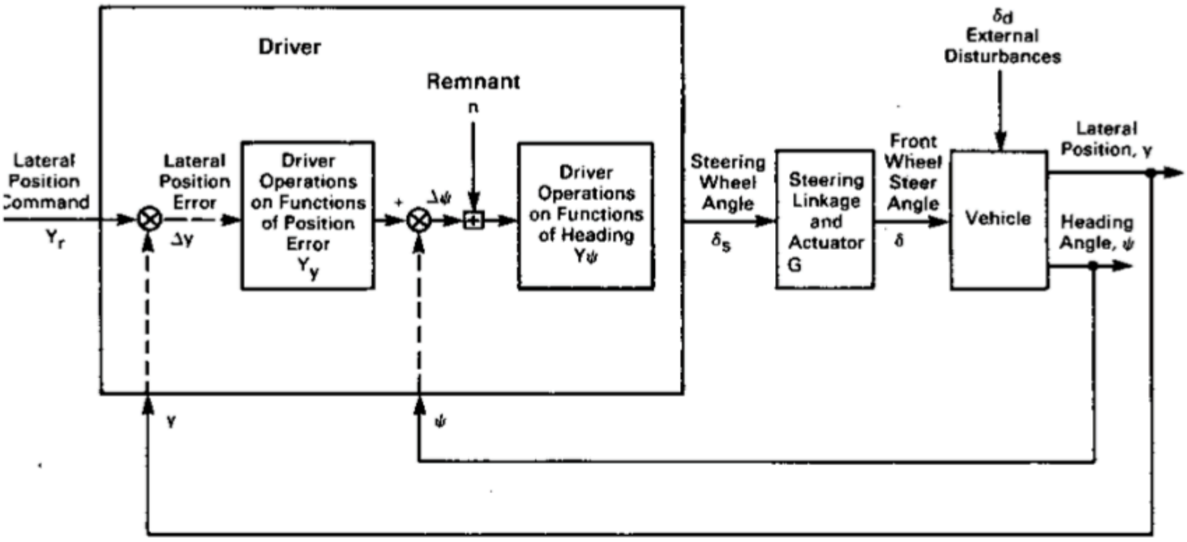

Figure 2. The STI compensatory driver model (McRuer et. al., 1977).

1.1.3. Summary of Models

The models and theories described above are essential for the experiments conducted in the course of the thesis. It is important to understand the concept of workload in relation to driving because that relationship is the basis for the studies done in the course of the thesis. Also to driver workload is not a simple concept, it is necessary to understand that there is not 'the one factor' that drives workload but rather that there is an environment of various variables i.e. speed, driver capabilities or the way information is transmitted, those together influence driver workload. Especially for the design of the second study, the knowledge of the multiple resource model was the basis to the idea of changing the way to present warning messages. Also it is necessary to understand the measurements used to assess workload, to understand that a questionnaire can be used to assess workload but if a pattern in the steering movement can be found it might be used to detect workload. The basis for such an assessment is the STI compensatory model and predictions made by Godthelp et. al. (1984). In the following the theoretical knowledge as described above, is the basis for the experiments and will at the end help to make suggestions for an improvement of the warning concept.

2. Overview and Objectives of the Experiments

Two experiments have been conducted during the course of this master thesis project. The first study has been done to test the first hypothesis if: An increase in speed from 130 km/h to 180 km/h to 230 km/h will result in an increase of subjective driver workload. The first experiment was also important to get information about how the participants perceived the speed differences in the driving simulator. It was important to know if the simulation can convey the feeling of driving at high speed, because otherwise the results would not be transferable to real driving. The second experiment has been conducted to test the second and third hypotheses. Second hypothesis: Presenting warning signals via a purely auditory channel results in a decrease of subjective driver workload relative to the workload created by normal Audi messages. The content of those messages will be outlined in the introduction of experiment 2. This was also done to test a new concept of presenting warning messages to the drivers. The third hypothesis was: That presenting warning signals via a purely auditory channel results in a lower mean SD of steering movement. The intend of this hypothesis was to find out if not only an increase in subjective workload can be detected using the NASA TLX, but also using an objective measure as the SD of steering movement.

3. Experiment 1.

Experiment 1 was the first step to answer the first part of the research question: if driver workload increases at high speeds. It was conducted with the aim of getting an impression to what extent a simulator study is applicable for driving at high speeds, if participants find it comparable to their driving experience in real life and if they perceive a different workload for different speeds and traffic. Since Cantin, Lavalliere Simoneau and Teasdale (2009) found in their research that age has an influence on driver workload in a simulator, therefore Age was checked as between-subject factor. The independent variable is speed, with three conditions: 130 km/h, 180 km/h and 230 km/h. Also, the environment varied in two traffic conditions, namely low and high traffic density. According to Recarte and Nunes (2002) Traffic is suspected to have a moderating role of the relationship between driving Speed and Workload. Therefore, the change in the environment was part of the study. In addition, when doing test runs of the experiment, it was perceived as very unrealistic to drive on a highway with no traffic at all. The dependent variable was workload. The hypothesis tested here was: An increase in speed from 130 km/h to 180 km/h to 230 km/h will result in an increase of subjective driver workload, this effect will be increased by a higher traffic density.

3.1. Method

3.1.2. Participants

The experiment was conducted with 36 participants (N=36), 10 females and 26 males. The mean age was 33.8 years, with a minimum of 21 and a maximum of 60 years, and a standard deviation of 10.9 years. The participants were Audi employees as well as subcontractors, working for the AUDI AG. People that volunteered for the study, received a general introduction about how experiments are done and were made aware that all experiments are voluntary, anonymous and can be stopped at any time. Upfront they were informed about the procedure and the general objectives of the experiment. There were three age groups: younger than 24, between 25 and 40 and older than 40. This condition was chosen to enable the analysis for age differences at a later point. Based on the limited number of volunteers, it was not possible to have the participants equally distributed, however it was manageable to have 11 people in the first group, 14 in the second and 11 in the third group. The study consisted of 6 driving scenarios. Participants were distributed equally between those six scenarios meaning that there were six participants for each scenario. None of the participants were removed from the data. The variable kilometer (km) driven last year was measured in thousand and the mean was 21.2 thousand km with a minimum of 2 thousand and a maximum of 70 thousand km. The standard deviation is 14.0 thousand km.

3.1.3. Apparatus

The study was conducted using a driving simulator, which had a fixed base. The driving simulator is property of the AUDI AG and is situated in Ingolstadt, Germany. The driving simulator consists of a circular 2.6 m x 13.3m 250° frontal and side projection surface, with 16 million pixels and a 6m x 3m projection surface behind the car mockup. This means the driver had a surround view and was able to use the mirrors. The mockup was an Audi A8 manufactured around 2002 (Figure 3). The researcher was situated in a control room where he could observe the same content as the participant. From that control room the simulation was started and supervised. Throughout the entire experiment the researcher was able to communicate with the participants via a microphone in case any problems occurred or any questions arose.

Figure 3. Interior (*left*) and exterior (*right*) of the driving simulator.

3.1.4. Procedure

Participants were first familiarized with the driving simulator. Each experiment took about 45 minutes and consisted of six trials where the participant drove on a three lane highway and maintained the speed of 130 km/h, 180 km/h and 230 km/h for about three minutes, once with a low traffic density and once with a high traffic density. In case the participants would deviate from the speed more than 5 km/h, the researcher told them to correct their speed. This process resulted in six different driving scenarios. In the low density scenario there were 30 cars in a 1 km radius around the car where in the high density scenario there were about 60 cars. Additionally the low traffic density condition was presented with traffic on only the outer right lane (figure 4), meaning that there was no lane changing of other cars. The high traffic density condition was with traffic on the outer right and middle lane (figure 5), where the virtual cars were changing lanes. Subsequently after each drive the participants had to fill out a questionnaire which was used to assess subjective workload. After the trials in the simulator, there was a brief interview with the participants to receive additional information including km driven each year, age, and what they considered the speed limit at which they would not want to be distracted from driving.

Figure 4. Driver’s view in the low traffic density condition.

Figure 5. Driver's view in the high traffic density condition.

3.1.5. Design, Measures and Data analysis

The design of the study was 3 (Speed 130, 180, 230 km/h) x 2 (Traffic Densities: Low vs. High). The first within factor was Speed, with three conditions 130 km/h, 180 km/h and 230 km/h. The second within factor was Traffic Density with a high and low density. The driving scenarios where counter balanced using a Latin square design to prevent possible order effects (Appendix 6.3). This process resulted in six driving scenarios, three speeds multiplied by two traffic densities. The dependent variable in this paper is workload and was measured with a NASA TLX where the weighting process was eliminated also referred to as Raw TLX, which is known for its reliability (Hart & Sandra, 2006). The Raw TLX consists of six subscales, namely mental demand, physical demand, temporal demand, performance, effort and frustration. Participants had to tick a box on a paper with a scale from 1 to 20, from 'very low' to 'very high', for each subscale. The workload score was calculated by adding the scores of all subscales divided by six (number of subscales). The Raw TLX was used instead of the full NASA TLX because it is easier to apply, thus reducing the complication rate. The RAW TLX is perceived to be equally reliable in comparison to the full NASA TLX (Hart & Sandra, 2006). The analysis was done using a repeated measures ANOVA, with two within-subjects factors (Speed and Traffic), one between-subject factor (Age Group) and their interaction terms. The ANOVA was done with SPSS using a standard α of 0.05.

3.2. Results Experiment 1

Investigation into main and interaction effects via a repeated measures ANOVA explaining subjective workload with two within-factors, traffic density and speed. The repeated measures ANOVA is assumed to be robust against violations of the assumption of a normal distribution therefore it was decided to proceed with the ANOVA (Schmider, Ziegler, Danay, Beyer and Bühner, 2010). Via Mauchly's test, sphericity has been checked and if the assumptions was violated, the corrected values were used. As can be seen in the figure 6 below, an increase for the mean workload from the low to high speeds can be observed. This applies for both, the high and low traffic density condition. The main effect of Speed on Workload was statistically significant. To indicate the directions of the main effects (i.e. comparing the pairs of speed), Bonferroni pairwise comparisons were used. The higher the speed the higher the workload. 130 km/h vs. 180 km/h (28.52 vs. 35.32 mean Workload (WL), $p < .001$), 130 km/h vs. 230 km/h (28.52 vs. 44.04 mean WL, $p < 0.05$), 180 km/h vs. 230 km/h (35.32 vs. 44.04 mean WL, $p < 0.05$). The main effect of Traffic Density on Workload was statistically significant. Workload was higher for high traffic density than for low traffic density (38.62 vs. 33.31 mean WL, $p < .001$). The interaction effect of Speed and Traffic Density was not statistically significant. Even tough, if further analyzed the interaction effect of Speed and Traffic Density can be called marginally significant. When further investigating that effect, it showed that the interaction effect was significant for 130 km/h, low traffic density vs. high traffic density (26.86 vs. 30.19 Workload (WL), $p < .008$). Also it was significant for 180 km/h, low traffic density vs. high traffic density (31.01 vs. 39.63 Workload (WL), $p < .000$) but the effect was not significant for 230 km/h , low traffic density vs. high traffic density (42.04 vs. 46.04 Workload (WL), $p < .071$). The interaction effects of Age and Speed, Traffic and Age and Speed, Traffic and Age were all not significant.

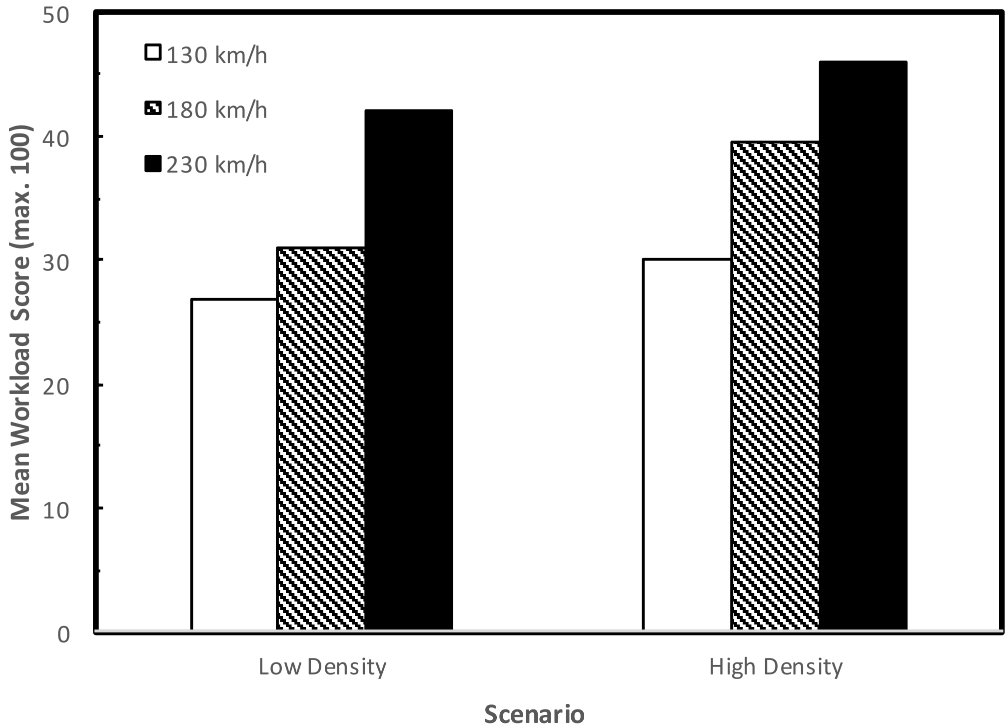

Figure 6. Mean workload scores for the different speeds and traffic densities.

Table 1. Results of repeated measures ANOVA Workload Score of Experiment 1.

	F	df1	df2	P	η^2p
Speed	37.828	1.282	44.868	.000**	.519
Traffic	18.261	1.000	35.000	.000**	.343
Speed*Traffic	3.009	2	70	.056	.079
Speed*Age	.167	4	66	.954	.009
Traffic*Age	.535	2	33	.591	.031
Speed*Traffic*Age	1.225	4	66	.309	.069

Note: * $p < .05$; ** $p < .001$

3.3. Discussion Experiment 1

The workload increases with an increase in speed. The results showed a significant difference between workload for the speed increments. The result is in line with the research of Recarte and Nunes (2002) which indicated that mental load increases with speed. They also argued that the risk of heavy injuries in case of an accident increases with higher speeds. Therefore it seems that the driver is more cautious to prevent an accident. The investigation of the marginally significant interaction effect of Speed and Traffic, showed that at the speed of 230 km/h the traffic condition does not significantly increase the workload anymore. Therefore, it can be assumed that at that speed, the main factor for higher workload is the speed. This is also confirmed by the effect sizes if interpreting them according to Cohen's (1985) benchmark which states 0.10, 0.25 and 0.50 equals small, medium and large respectively. The effect size found in Speed can be considered as large, where the effect found in Traffic is medium and for the other effects the effects can be considered small. Age which was checked as only between-subject factor showed no significant effect in this study. Age might have been cancelled out by another factor, know to influence driver workload e.g. driving experience which was not collected.

It was important to get the results that participants also experience a speed difference at the higher speeds namely 180 km/h and 230 km/h, as this represents the basis to continue with the second experiment. It was necessary since the usual studies done in the simulator are limited to lower speed. Therefore, there was a lack of experience on how participants react when driving in the simulator at those speeds. Besides, it was found that traffic density has a significant effect on subjective workload. This can be explained by the research design since in the lower speed condition the participants had two lanes to drive in whereas in the high density condition they had to drive on the most left lane and had to expect that another car would change onto their lane. A few participants reported that after a while they knew that no car would unexpectedly change to the left lane, even though they had not been told that this was the case. The experiment was indeed designed in this way to avoid any possible crash situation for the participants.

4. Experiment 2

The first experiment confirmed that workload increased with an increase in the driven speed. Also it showed that participants perceive a difference in workload in the simulator between the three different speed increments of 130 km/h, 180 km/h and 230 km/h. The second study was designed and conducted to find out whether participants would accept a change of the regular warning concept known to them. In the regular concept, a warning message is presented by a symbol and a text message in the cockpit preceded by a warning sound like a ‘beep’ or a kind of ‘gong’ (figure 7). A warning message presented in that way can be a distraction for the driver because an additional visual stimulus increases visual workload especially at high speeds (Jo & Lee, 2014). In the second study, warning messages will be presented via two Modalities (i.e. via the auditory and visual modality), instead of suppressing a warning signal completely, which was suggested by other researchers working on a workload manager. Because a suppression would obviously result in less distraction it was decided to present the warning message via the auditory channel. The aim of the second study was to test if presenting a warning message only via the auditory channel can reduce the workload compared to the workload created by the regular Audi concept of presenting warning messages (Visual channel). Additionally the Audi warning messages varied in Criticality. There are Audi guidelines that rate the criticality of the different warning messages. The criticality specification determines the severity of how the warnings are presented. In case of the following study, three warning messages were presented: Wash-Water Min, Oil Min and Break Error warning (table 2). The variable Time described whether the measurement was pre- or post the event of the warning message.

The independent variable was an auditory versus the standard Audi warning signal (visual). The dependent variables which were analyzed were subjective workload and the steering movement. A high standard deviation (SD) of steering movement can indicate an increase of driver workload. For the simulation it was decided to take the track with high traffic density because participants showed a higher workload score for this scenario in the first experiment. This resulted in the hypotheses: That presenting warning signals via a purely auditory channel results in a decrease of subjective driver workload relative to the workload created by normal Audi messages. The third hypothesis was: That presenting warning signals via a purely auditory channel results in a lower mean SD of steering movement.

4.1. Method

4.1.1. Participants

The final analysis was done with 41 out of the 43 participants (30 males and 11 females) because for one participant the driving data was not recorded and the other participant had to stop because of simulator sickness. The mean age was 34.5 years, with a minimum of 22 and a maximum of 61, and a standard deviation of 10.5 years. The mean of km driven each year was 18.000 km with a minimum of 2.000 km and a maximum of 50.000 km, with a standard deviation of 12.000 km. Participants were invited via the same participant pool as in the first experiment, only this time it was decided to not have the pre-condition of three age groups because it was not possible to have three nearly equally sized groups due to organizational constraints.

4.1.2. Apparatus

The second experiment was done in the same driving simulator as in the first experiment. The settings of the simulator have not been changed. Besides that in this study the driving data was recorded. The driving data was recorded at a rate of 25 Hz. During the six drives the participants received three warnings either presented via the standard Audi concept (i.e. visual condition) or via the 'new' auditory concept (i.e. auditory condition). For the second condition the warning was read out loud to the participants, with no visual display. Meaning that there was a pure auditory scenario and a visual scenario where the symbols and the messages were presented in the cockpit (Figure 7), preceded by the typical warning sound.

According to Audi guidelines, the wash water and oil warning are presented in yellow and the break warning in red. In the visual condition the wash water is preceded by a 'gong' sound. The oil warning is forgone by a single 'beep' sound and the break warning is forgone by four 'beep' sounds (Table 2). In the auditory condition all warnings where only forgone by a 'gong' and the warning message was spoken by a simulated voice. The message presented to the participants were the same in both conditions and can be seen in Table 2.

4.1.3. Procedure:

During the study, the first driving scenario was the same for each participant. In total the participants had 7 trials. They were told to drive at the speed of their choice, where they would feel comfortable to familiarize with the simulator. Afterwards each participant had to drive on a three lane highway and maintain the speed of 130 km/h, 180 km/h and 230 km/h for about three minutes. In case the participants would deviate from the speed more than 5 km/h, the researcher reminded them to correct their speed. This was only the case if the participants seemed to the reduce the speed due to inattention but not if the situation demanded them to slow down. They drove three times in the auditory scenario and three times in the visual scenario. This process also resulted in six different driving scenarios. For each speed condition, the three different warning signals were presented to the participants. One warning for the minimum of screen wash water, another warning for the minimum of oil and a break error warning. Participants drove one time with no experimental manipulation and then six other times according to the scenario they were assigned to (Appendix 6.4). After each scenario, the participants had to fill out the Raw TLX, same as in the first study.

The order of the scenarios was counter balanced using a Latin square design, similar to the one used in the first experiment, to prevent order effects (Appendix 6.4). That means that some participants started driving 230 km/h with warning signals read out loud and others started driving 130 km/h getting the standard display. The same was done for the warning signals, the order of the warning signals was mixed. Meaning that sometimes the participants received the break error warning at first and then the two other warnings or the oil warning first and then the other two warnings. Those warnings were played randomly in three different timeslots within each three minute scenario, the first timeslot was between 20 sec. and 60 sec. The second timeslot was between 80 sec. and 120 sec. and the third slot was between 140 sec. and 180 sec. Therefore, the participants could not know when the next warning would be presented.

At the end of the experiment a short interview was held with the participants to receive information on km driven each year, age and also how they perceived the new concept of presenting warning signals and whether they had suggestions for improvements. These questions are included in appendix 6.5.

Figure 7. Screenshot of the Audi digital car instruments with the warning ‘Break: Error! Stop car safely’.

Table 2. Visualizations of warning messages according to the Audi guidelines used during the 2. study

	Sound	Symbol	Text
Wash-Water	1 x Gong		‘Please refill wash-water’
Oil Min	1 x long Beep		‘Oil at minimum, please refill 1 liter max.’
Break Error	4 x short Beeps		‘Break: Error! Stop car safely’

4.1.4. Design, Measures and Data analysis

The research design was similar to the first study. The road design was the high traffic density scenario from the first experiment. The 6 driving scenarios resulted from the study design 3 (Speed 130, 180, 230 km/h) x 2 (Modality: Auditory vs. Visual). The first within factor was speed with three conditions 130 km/h, 180 km/h and 230 km/h. The second factor was modality, which represents the way the warning messages were presented either auditory or visual. The dependent variables were subjective workload and the steering movement. Again the workload score was collected via the Raw TLX. The steering movement was recorded via a software connected to the driving simulator. The analysis of the steering movement was done with SPSS, using a repeated measures ANOVA with 4 within-subject factors (Speed: 130, 180, 230 km/h) x 2 (Warning: Auditory vs. Visual Audi) x 3 (Criticality: Wash-Water Min, Oil Min, Break

Error) x 2 (Time: Pre- vs. Post Message) and their interaction terms. For the analysis the standard deviation of steering movement was calculated for a timeframe of four seconds before the warning message (Pre-Message) and for the time where the warning message was displayed also four seconds (Post-Message). Four seconds was the duration of the display of the warning message. For the analysis SPSS with a standard α of 0.05 was used.

4.2. Results Experiment 2

Eventual main and interaction effects were investigated via a repeated measures ANOVA explaining subjective workload with four within-factors, Speed, Modality, Criticality and Time. The repeated measures ANOVA is assumed to be robust against violations of the assumption of a normal distribution, therefore it was decided to proceed with the ANOVA (Schmider, Ziegler, Danay, Beyer and Bühner, 2010). Via mauchly's test, sphericity has been checked and if the assumptions were violated, the corrected values were used. As it can be seen in the figure 8 below there is an increase of workload with speed. This applies for both the auditory and visual warning conditions. The main effect of Speed on Workload was statistically significant. To indicate the directions of the main effects (i.e. comparing the pairs of speed), Bonferroni pairwise comparisons were used. The higher the speed the higher the workload. 130 km/h vs. 180 km/h (32.99 vs. 35.64 mean Workload (WL), 130 km/h vs. 230 km/h (32.99 vs. 42.61 mean WL), 180 km/h vs. 230 km/h (35.64 vs. 42.61 mean WL). The main effect of the Modality (or: warning scenarios) on Workload was also statistically significant. Workload is higher for the visual warning condition than for auditory warning condition, (38.54 vs. 35.62 mean WL). The interaction effect of Speed and Modality was not statistically significant. The results from the ANOVA are displayed in Table 3.

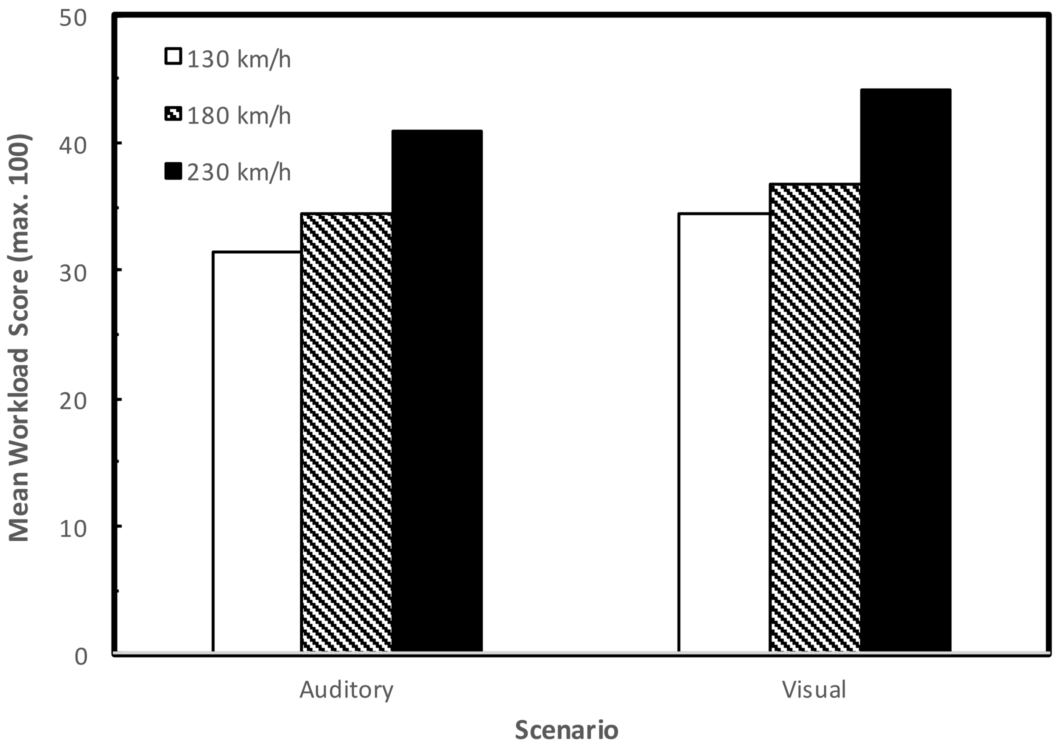

Figure 8. Mean workload scores for the different speeds and modalities.

Table 3. Results of repeated measures ANOVA Workload Score of Experiment 2.

	F	df1	df2	P	η^2p
Speed	34.370	1.613	66.123	.000**	.456
Modality	8.734	1	41	.005*	.176
Speed*Modality	.365	2	82	.695	.009

Note: * $p < .05$; ** $p < .001$

Of the recorded driving data the steering movement was analyzed. For each scenario about four minutes of data was recorded. R was used to prepare the data for SPSS by sorting out the relevant data of the warning messages and calculate the standard deviation of steering movement. Afterwards the data set was ready to be analyzed using SPSS. The mean standard deviation of the steering movement was generated for the duration of the warning events and then compared with the standard deviation for the same duration before the event. Since the participants were told that they could choose the lane they wanted to drive on and the warning signals were triggered at a randomized point in time. It sometimes happened that a lane change occurred at the time of a message. Since a lane change has an irregular influence on steering movement, those data points were excluded. This resulted in a lot of missing data. The missing data were replaced by the mean of valid cases of that particular condition. The analysis was done using a repeated measures ANOVA using a 3 (Speed) x 2 (Modality) x 3 (Criticality) x 2

(Time) design explaining mean SD of steering movement. The main and interaction effects are displayed in Table 4. The main effect of Modality on the mean SD of the steering movement was statistically significant. The main effect of Criticality on the mean SD of the steering movement was statistically significant. The main effect of Time on the mean SD of the steering movement was also statistically significant. A higher mean SD of the steering movement indicates a higher workload. Post hoc tests for the differences in the mean SD of the steering movement using the Bonferroni pairwise comparison revealed a higher SD in the visual scenario than in the auditory scenario, (0.0114 vs. 0.0107 mean SD of steering movement). For Criticality it revealed oil minimum had a higher SD than wash water, (0.0112 vs. 0.0101 mean SD). For Criticality it also revealed break error had a higher SD than wash water, (0.0117 vs. 0.0101 mean SD). It revealed that there is no significant difference in SD between oil minimum and break error (0.0112 vs. 0.0117 mean SD). For Time it showed a higher SD for the post event than pre event, (0.0117 vs. 0.0103 mean SD).

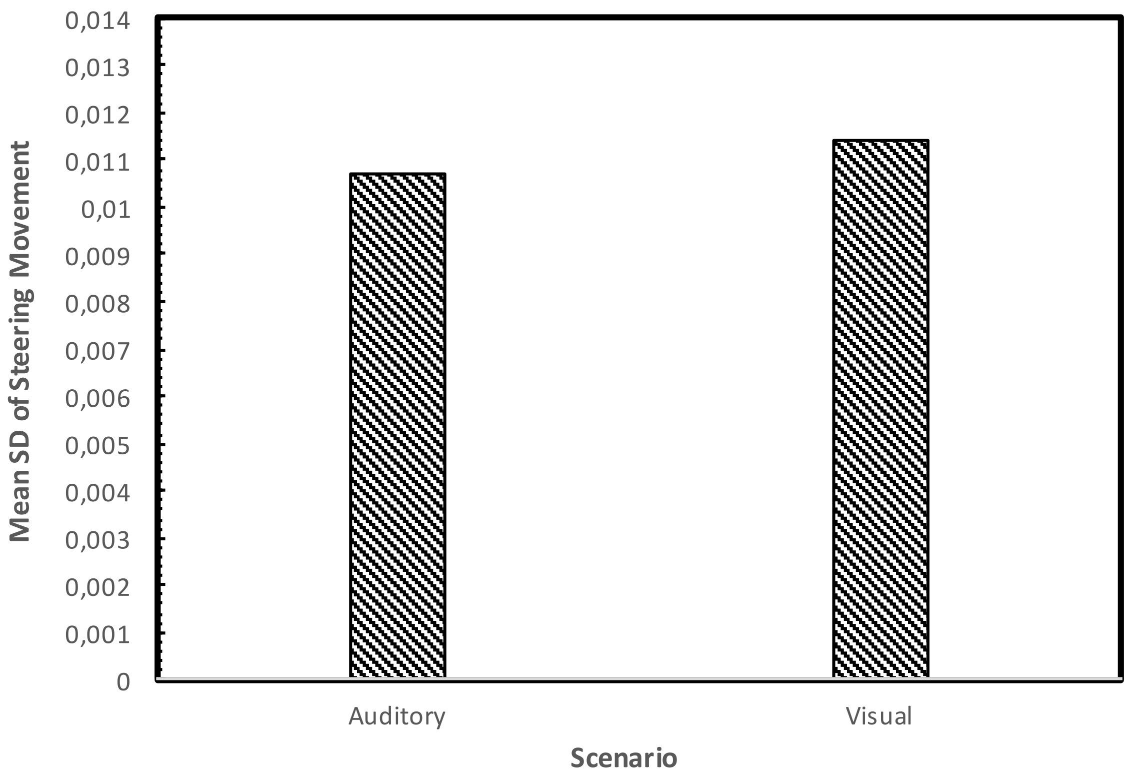

Figure 9. Representation of the main result that shows the mean Standard Deviation of the Steering Movement, implicating a lower visual workload for the Auditory scenario.

Table 4. Results of repeated measures ANOVA Steering Angle SD of Experiment 2.

	F	df1	df2	P	$\eta^2 p$
Speed	2.289	2	80	.113	.053
Modality	4.400	1	40	.042*	.099
Criticality	9.838	1.624	64.967	.000**	.197
Time	48.534	1	40	.000**	.548
Speed*Modality	1.051	1.595	63.801	.342	.026
Speed*Criticality	.827	4	160	.510	.020
Modality*Criticality	1.017	2	80	.366	.025
Speed*Modality*Criticality	1.266	4	160	.286	.031
Speed*Time	2.555	1.743	69.726	.092	.060
Modality*Time	3.795	1	40	.058	.087
Speed*Modality*Time	.215	1.818	72.725	.787	.005
Criticality*Time	.568	2	80	.569	.014
Speed*Criticality*Time	1.781	4	160	.135	.043
Modality*Criticality*Time	.236	2	80	.790	.006
Speed*Modality*Criticality *Time	1.270	4	160	.284	.031

Note: * $p < .05$; ** $p < .001$

The interview held with the participants at the end of experiment 2, revealed information into how the participants perceived the new concept of presenting a warning message (auditory channel). The questions guiding through the discussion can be found in the appendix 6.5. The summary of the most important questions are presented in table 5 below.

Table 5. Summary of the most important questions from interview held after the second experiment.

	Answered 'Yes'	Answered 'No'
1.) Would you like having the warning messages read out loud to you?	86 %	14 %
2.) Should it be an option to adjust yourself if the message will be read out or displayed normally?	86 %	14 %
3.) Would you prefer getting an additional visual message after it was read out to you?	79 %	21 %
4.) Is a simple 'gong' sound sufficient for all 3 criticalities?	19 %	81 %
5.) Can the warning concept change between speeds? (e.g. visual at 50 km/h and auditory at 180 km/h)	45 %	43 %*
6.) Would it be 'okay' for you to suppress particular warning messages in some situations completely?	82 %	18 %

* Percentage of missing values originated from participants saying they were indifferent

Concerning the last question, it is important to state that the participants said yes under the condition that important warnings as the break warning will never be suppressed. The participant also remarked that it would be helpful to have the possibility to hear the voice message of the warning again or have the possibility to check the warning in a submenu at a time of their choosing.

4.3. Discussion Experiment 2

The second experiment showed that a reduction of driver workload as indicated by a lower mean SD of steering movement is possible by presenting a warning signal via a purely auditory channel. Those findings are confirmed by the results of the RAW TLX which also showed that the subjective workload was lower in the auditory condition. It could be suspected that the mental demand caused by thinking about the information and planning future actions is the same in the auditory and visual scenario. Since in the purely auditory scenario there was no symbol or text, the driver had no extra visual demand. Those results are in line with the findings by Verwey (2000), who stated that a reduction of visual signals can result in a lower visual workload. Again if using the benchmark for effect sizes by Cohen's (1985) The effect of speed on subjective workload was large and medium for modality but small for their interaction effect. The large effect of speed confirms the findings from the first experiment. When looking at Table 4. Only the effect size of steering angle SD on time can be considered large. The effect size of criticality is just below medium but all the other effect sizes are small. Some participants remarked that reading would be much quicker than listening to the warning messages. This is not in line with the findings of Eddy and Glass (1981) or Shelton and Kumar (2010) which found that visual information processing shows larger reaction times than auditory information processing. Presumably that does also depend on the familiarity with the presented information and all participants were familiar with those messaged since they work in the automobile industry. This would need to be investigated further, yet the focus of this study was to reduce workload and not the reaction time to given information.

The interviews with the participants showed that they would accept a change in the warning concept (86%), but also that they think it should be optional (86%). How this newly gained knowledge could be implemented, will be discussed in the next chapter. As was the case in the first experiment, a few participants reported that after a while they knew that no car would unexpectedly change to the left lane, even though they were not told that this was the case. As in the first experiment, the second experiment was cautiously designed in that way, to avoid any possible crash situation for the participants.

5. General Discussion

The aim of this research was to answer the question: To what extent does driving with high speed influence the workload of the driver and does an adaptation of particular signals decrease the workload in that situation? The first experiment confirms the first part of the research question. Subjective workload increased with high speeds. The second experiment showed that a reduction of the workload indicated by a lower mean SD of steering movement and Raw TLX is possible, by presenting a purely auditory warning signal. A suggestion for a new concept, implicated by the above listed findings could be the following: The customers get the options to enable the 'read warnings out loud' as well as setting a speed where the messages have no more visual symbols. Additionally, there would be a visual symbol following the voice message for high priority warnings e.g. the 'Break: Error! Stop car safely'.

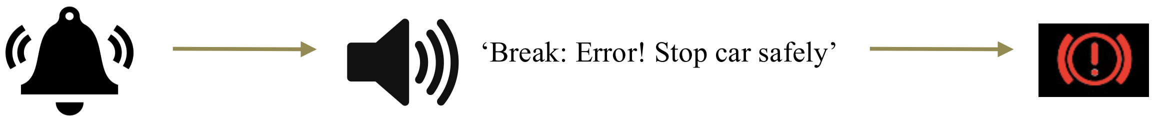

Figure 9. Simplified representation of a different concept for presenting warning messages as suggested by the research results.

This is based on the remarks of a few participants that it might be possible to miss an auditory warning if there are passengers in the car, which might distract the driver. But there is also the possibility of a positive effect that if the drivers have already heard the warning, they might need less time to process the information presented visually later on. This would need to be tested in a future experiment. As regards to a complete suppression of warning signal, further research is necessary to determine how reliable an estimation via the steering movement would be for other situations besides the tested scenario of a relatively straight highway with smooth curves. As mentioned in the introduction, Verwey (2000) already suggested to research the differences in steering movement and to use those to assess the driver situation if it would prove to be a valid indicator for visual workload. Therefore, if further analyzed it might be possible to use the differences found in the steering movement, to make a situational assessment. Those assessments could be used to estimate how visually demanded the driver is in particular situations. Afterwards those estimates could then be used to show warning signals at moments where the driver is less visually loaded. If this could be made possible, it would make it much easier to implement such a system into new car models because the data of the steering movement is available in each car anyway and would not demand any new sensors, which would result in lower cost. Also if it would be possible to detect workload in advance via the steering movement it would be possible to implement that situation onto other driving scenarios as the inner city where drivers can be very distracted as well (Köhler et al., 2015). The downside of a system managing workload, could be the effect of task difficulty homeostasis which in this case could make the driver more confident to drive faster and not accordingly to their skills. The same happened when the ABS was first introduced (Rothengatter, 2002). On the one hand most participants said that they would only drive that fast (230 km/h) when the situation allows it or that they usually never driver that fast but on the other hand there is juvenile thrill seeking and adventurous behavior (Anderle & Renner, 2002). Therefore, such a system needs to be implemented and advertised with caution. It could also be argued that such a system is redundant anyway since cars in the future will be enabled to drive autonomously but estimates are that by 2030 only 15% of the cars will be fully autonomous (Kaas et. al, 2016), therefore there will still be a long time of people driving themselves. Especially driving at high speeds might be done by the drivers themselves for the thrill or because it will take longer to trust an autonomous car to drive that fast. Additionally, the interaction of the driver with the autonomous car is one of the key challenges of the automotive industry in the next years, therefore the results of this study may also be used to get insights into how the car should interact with the driver. Which could be via visual or auditory presentations.

As mentioned earlier, 82% of the participants agreed with the idea that it would be good to suppress particular warning signals in stressful situations i.e. the warning that the wash water tank is soon to be empty is not perceived to be necessary at high speeds. This should even strengthen the effect of the decrease of workload, since then there would be neither an additional visual stimulus nor an auditory one. If suppressing the warning message anyway, the moment of displaying it again could be combined with GPS data to make it more convenient e.g. the wash water warning could be displayed when being close to your home address or a fuel station. This would benefit the user experience that they can easily take care of the warning. Of course this would not be possible for all messages especially because some warning messages need to be displayed immediately as the break error warning but for many others it would make sense.

After interviewing the participants it also became clear that there are different opinions about how the implementation of a new warning concept into future cars should be done. Some participants said that if the results show a clear indication of a lower workload, spoken warning messages should simply be implemented. They also argued that having spoken warning messages as a complementary option, it would only increase the complexity of the car interface. On the contrary, some participants said that they would definitely need an option to test the spoken messages on a longer period and turn them off if they do not like them anymore. They also wished for an option to set a speed limit themselves to when a message is spoken. This discussion clearly shows that potential customers are very different, as some like to get to know all the options of their cars and personalize it to their needs and others just want the car to work and do not want to adjust the settings. Having a universal design which suits all users is a well-known issue in the field of user experience or user interface design and has also been researched by Schmettow and Havinga (2013) and they found the challenge of user diversity can be best solved by using a robust design.

The main limitation of the study is that it has been a simulator study and there was no real driving experiment. To verify the results a study in real driving should be done. If doing a real driving study there would be the risk of a crash and the fatal results for the participants when driving 230 km/h. Also when interpreting the findings revealed in this thesis, the reader needs to keep in mind that those speeds are rarely driven by most people, especially since 180 km/h and 230 km/h are only allowed on German highways. As a limitation it could be argued that it is difficult to exactly differentiate the results between the auditory and visual channel because also the visual message was foregone by an auditory signal. Since this was the standard Audi signal it was part of the experimental design. But this only applies for the sound, the exact information about the content of the warning was only transmitted via the pop-up in the cockpit or via a simulated voice. In the first experiment age was not found to be a significant influencer but other researcher already found an effect of young and old drivers and workload. It might be possible that those effects were cancelled out during this study. Practice is also known as a very significant factor to reduce workload (Shinar, Tractinsky & Compton, 2005). Since all participants where working in the automobile industry it can be assumed that there is a higher interest in cars and driving. Some of the Participants were managers that drive powerful cars and are used to driving a lot. Those participants may also have influenced the outcome of the study.

6. Conclusion

To sum up, it can be said that presenting warning signals via the auditory channel causes less driver workload compared to presenting the same information via the visual channel. This can be confirmed by the results found in experiment 1 and 2 and is also in line with earlier findings from Verwey (2000). The novelty added by this research is the investigation of the differences in driver workload caused by driving at high speeds, namely 130 km/h, 180 km/h and 230 km/h.

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8. Appendix:

6.1) Table 1. Workload score (0 – 100) of the first experiment

	Low traffic density Workload score (mean)	High traffic density Workload score (mean)
130 km/h	26.85	30.19
180 km/h	31.01	39.62
230 km/h	42.03	46.04

6.2) Table 2. Workload score (0 – 100) of the second experiment

	Auditory Condition Workload score (mean)	Visual Condition Workload score (mean)
130 km/h	31.39	34.58
180 km/h	34.50	36.77
230 km/h	40.95	44.26

6.3) Table 3. Counterbalancing of the driving scenario order using a Latin square design for the first study.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
1.	130H	130L	180H	230H	230L	180L
2.	130L	180H	180L	230L	230H	130H
3.	230L	130H	130L	180H	180L	230H
4.	180H	180L	230H	130H	130L	230L
5.	230H	230L	130H	180L	180H	130L
6.	180L	230H	230L	130L	130L	180H

'H' represents the high traffic density condition and 'L' represents the low traffic density condition.

6.4) Table 4. Counterbalancing of the driving scenario order using a Latin square design for the second study.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
1.	130A	130V	180A	230A	230V	180V
2.	130V	180A	180V	230V	230A	130A
3.	230V	130A	130V	180A	180V	230A
4.	180A	180V	230A	130A	130V	230V
5.	230A	230V	130A	180V	180A	130V
6.	180V	230A	230V	130V	130V	180A

6.5) *Questions for the interview during the 2. workload study:*

Number: Scenarios:

1. How many km do you drive per year?
2. Male / Female
3. Do you like to drive fast? (If the traffic permits to do so?)
4. How old are you?
5. Is one warning signal sufficient for all warning messages?
6. Should the warning signal already say something about the criticality of the message?
7. Is a simple 'gong' sound sufficient for all 3 criticalities?
8. Would you prefer getting an additional visual message after it was read out to you?
9. Would you say that it's possible to startle by the Prio 1 warning signal?
10. Do you prefer a warning concept for different speeds?
11. Can the warning concept change between speeds? (e.g. visual at 50 km/h and auditory at 180 km/h)
12. Would you like having the warning messages read out loud to you?
13. Should it be an option to adjust yourself if the message will be read out or displayed normally?
14. Would it be 'okay' for you to suppress particular warning messages in some situations completely?

6.6) *R script for preparing the driving data for SPSS:*

```
probanden <- list.files("Daten/")

liste <- sapply(probanden, function(x) NULL)


library(zoo)

for (proband in probanden) {
  #Lies die Daten f¸r proband ein
  pfad <- paste0("Daten/", proband, "/DrivingDynamics/")
  datennamen <- list.files(pfad) #which data will be extracted for each participant

  datenpfad <- paste0(pfad, "DrivingDynamics-Journal-0000.txt")
  daten.baseline <- read.csv(datenpfad, sep = "\t", dec = ",")
  daten <- NULL

  for (name in setdiff(datennamen, "DrivingDynamics-Journal-0000.txt")) {
    datenpfad <- paste0(pfad, name)
    daten_neu <- read.csv(datenpfad, sep = "\t", dec = ",")
    daten <- rbind(daten, daten_neu)
  }

  #events L¸cken f¸llen
  event <- daten$event
  event[which(event == "")] <- NA
  daten$event <- na.locf(event, na.rm = FALSE)
  #Only take data from events
  event.namen = unique(daten$event)
  event.namen = na.trim(event.namen)
  event.namen = event.namen[grep("S", event.namen)]
  daten$indexgesamt = as.numeric(rownames(daten)) #add index for the whole data set

  eventnamenproband = unique(daten$event)[grepl("S", unique(daten$event))] #only take data
      with sevents

  #Baseline Events
  start.event.indizes = daten %>% group_by(event) %>% slice(1) %>% filter(event %in%
      eventnamenproband) #find event names in index
  start.event.indizes = start.event.indizes$indexgesamt

  laenge.event = 213

  baseline.events.vorher.indizes = setNames(lapply(start.event.indizes, function(x) (x -
      laenge.event):x), eventnamenproband) #find pre events
  baseline.events.nachher.indizes = setNames(lapply(eventnamenproband,
      function(x)which(daten$event == x)), eventnamenproband) # finde post events

  baseline.events = character(length = nrow(daten))
```

```
  fahrspurwechel.im.event = numeric(length = nrow(daten))
  #make column for pre and post events
  for (j in eventnamenproband) {
    indexvor = baseline.events.vorher.indizes[[as.character(j)]]
    indexvor = indexvor[indexvor >= 0]

    baseline.events[indexvor] = paste0(j, "vor")

    indexnach = baseline.events.nachher.indizes[[as.character(j)]]
    baseline.events[indexnach] = paste0(j, "nach")

    fahrspurwechel.im.event[c(indexvor, indexnach)] = ifelse(length(unique(daten[c(indexvor,
        indexnach), "Fahrspur"])) > 1, 1, 0)

  }

  daten$baseline.events = baseline.events
daten$fahrspurwechel.im.event = fahrspurwechel.im.event
#find lane changing at event data


df.proband = data.frame(proband = proband)
#produce dataset


std.steering = lapply(event.namen, function(x) sd(filter(daten, event == x)$Lenkwinkel, na.rm
      = TRUE))
  std.steering = setNames(std.steering, event.namen)
  std.steering = data.frame(std.steering)
  colnames(std.steering) = paste0(colnames(std.steering), ".std.steering")
  df.proband = data.frame(df.proband, std.steering)
  #calculate standard deviation for steering movement of events

  vornachevents = unique(daten$baseline.events)
  vornachevents = vornachevents[vornachevents != ""]
  #calculate standard deviation for steering movement of pre / post events


  std.steering.vornach = lapply(vornachevents, function(x) sd(filter(daten, baseline.events ==
      x, fahrspurwechel.im.event == 0)$Lenkwinkel, na.rm = TRUE))
  std.steering.vornach = setNames(std.steering.vornach, vornachevents)
  std.steering.vornach = data.frame(std.steering.vornach)
  colnames(std.steering.vornach) = paste0(colnames(std.steering.vornach), ".std.steering")
  df.proband = data.frame(df.proband, std.steering.vornach)


  liste[[proband]] <- list(daten = daten, df.proband = df.proband)
  print(paste0(round(which(proband == probanden) / length(probanden)*100, digits = 0),
      "%"))
}
```