**PUBLIC SUMMARY**

# Workload management for warning signals at high speeds

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**About this document**

This is **not** the full thesis, but a public summary that holds information about research that has been conducted at the AUDI AG's research and development department between January 2017 and August 2017. The master's thesis that has been written as a result of this research is marked as confidential until December 2022. Therefore, this document wraps up the information that may be disclosed to the public before the non-disclosure agreement ends. Consequently, much of the information is disclosed and masked by terms like "Auditroy warning signal" and "Visual warning signal". Other parts of the thesis had to be omitted altogether.

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### Reducing workload at high speeds

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.

There is a need to customize information messages for situations where they are absolutely needed or where the drivers have spare processing 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 the 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). 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 factors, 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). 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 master thesis project. Also 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 experiment in this thesis, the knowledge of the multiple resource model by Wickens (2002) was the basis to the idea of changing the way to present warning messages.

The current 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. 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 the present research is driver workload at a speed of 130 km/h, 180 km/h and 230 km/h on highways. 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. To find whether workload can be reduced by an adaptive interface compared to the standard interface, two simulator studies were conducted. The first investigated the increase in workload with an increase in speed and the second investigated the workload differences when transmitting waning sigals via the auditory and visual channels. Originating from Eddy and Glass (1981) and Shelton and Kumar (2010) who found that visual information processing shows larger reaction times than auditory information processing. The complete suppression of an information message was seen as a too radical change for the customers regarding the warning concept known to them. The experiments attempted 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?*

Most of the literature about cognitive functions while driving involves how humans perceive and process information. This usually involves attention (Porter, 2011). Since driving demands a high amount of attention when for example interacting with other drivers, navigating in an unknown environment and driving on an icy road. To actively perceive, interpret and understand information while driving, attention is required (Schneider & Shiffrin, 1977; Porter, 2011). 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 in which "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 the presented information. A key 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, 2002). The primary driving task, inlducing for instance course keeping, is mainly a visual-spatial-manual task (Strayer & Johnston, 2001; Wickens, 2002). The above outlined knowledge indicates 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 focussed on gaining insights into the influence of driving at high speeds on workload and the second experiment focussed on the different channels of receiving information.

## Method Experiment 1

### 2.1 Participants

The experiment was conducted with 36 participants ($M_{age}$ = 34, 28% female). The participants were Audi employees as well as subcontractors, working for AUDI AG. 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. The participants were distributed over the three age groups as following: 11 people in the first group, 14 in the second and 11 in the third group. Participants were distributed equally between six scenarios meaning that there were six participants for each scenario. None of the participants were removed from the data. All participants were German or at least capable of using the German language since all questionnaires and instructions were provided in German language. Good vision (with or without correction) and a driver's license were required for participation. None of the participants stood in a relation to the experimenter that might have had an influence on the results. 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.

## 2.2 Apparatus and setting

**Material.** A traffic simulation software was used to create a scripted highway scenario. The simulated highway had 3 lanes. It included other road users that were controlled by the computer.

**Experiment.** When driving the scenarios, the driver was driving on a highway with three lanes. 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. 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 whereas in the high density scenario there were about 60 cars.

**Measures.** Subjective measurements were done to determine the workload of the participants. For the *subjective measurement* the NASA TLX was used. Its weighting process was eliminated. Thisversion is also referred to as the 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).

**Setting.** 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 simulation was projected on three 6x3m canvases in front of the mockup, and to the sides and the back. This means the driver had a surround view and was able to use the mirrors.

## 2.3 Design

This study involved between-participant and within-participant manipulations. The first within-subject factor was Speed and included three conditions: 130 km/h, 180 km/h and 230 km/h. The second within-subject factor was Traffic Density with a high and low density. The between-subjects factor was age, since Cantin, Lavalliere Simoneau and Teasdale (2009) found in their research that age has an influence on driver workload in a simulator. The dependent variable was workload. The driving scenarios where counter balanced using a Latin square design to prevent possible order effects. This process resulted in six driving scenarios, three speeds multiplied by two traffic densities.

## 2.4 Procedure

Participants were first familiarized with the driving simulator and asked to adjust their seat and the mirrors to their liking. They 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. The test-drives took about 3 minutes. Subsequently, the participants filled 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.

## 2.5 Data analysis

The analysis was done using a repeated measures ANOVA, with two within-subjects factors, one between-subject factor and their interaction terms. The ANOVA was done with SPSS using a standard $\alpha$ of 0.05.

# Method Experiment 2

**Workload management for warning signals at high speeds**

## 3.1 Participants

The experiment was conducted with 43 participants ($M_{age}$= 35, 26% female). The final analysis was done with 41 participants because for one participant the driving data was not recorded and the other participant had to stop because of simulator sickness. The participants were Audi employees as well as subcontractors, working for the AUDI AG. Upfront they were informed about the procedure and the general objectives of the experiment. All participants were German or at least capable of using the German language since all questionnaires and instructions were provided in German language. Good vision (with or without correction) and a driver's license were required for participation. None of the participants stood in a relation to the experimenter that might have had an influence on the results.

## 3.2 Apparatus and setting

**Material.** Again the same traffic simulation software was used to create a scripted highway scenario. The simulated highway had 3 lanes. It included other road users that were controlled by the computer.

**Experiment.** In total the participants had to drive 7 scenarios. Each experiment took about 60 minutes and consisted of a test run plus six trials in which 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 auditory warning signals and once with visual warning signals. The test run gave the participants the chance to get familiar with the simulator and the road. The 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. In case the participants would deviate from the target speed more than 5 km/h, the researcher reminded them to correct their speed. This process resulted in six different driving scenarios and the first scenario which was equal for every participant. For each speed condition, three different warning signals were presented to the participants.

**Measures.** Measurements were done to determine the subjective and objective workload of the participants. For the *subjective measurement* the Raw TLX was again used. The *objective measurement* of workload was the standard deviation of steering movement which was compared before and after a warning signal was presented to the participants. This approach was adapted from 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. Since the effects of visual demand on steering can also be quantified in terms of the disorder, or entropy, of steering wheel movements (Boer, 2000) a high standard deviation (SD) of steering movement can indicate an increase of driver workload.

**Setting.** Same setting as in the first study. (see setting of the 1. Study)

## 3.3 Design

The research design was similar to the first study. But this study involved only within-subject observations. The first within-subject factor was speed with three conditions 130 km/h, 180 km/h and 230 km/h. The second within-subject factor was modality, which represents the way the warning messages were presented either auditory or visual. The dependent variables were subjective workload and the standard deviation of steering movement. The driving scenarios where counter balanced using a Latin square design to prevent possible order effects. This process resulted in six driving scenarios, three speeds multiplied by two modalities.

## 3.4 Procedure

Participants were first familiarized with the driving simulator and asked to adjust their seat and the mirrors to their liking. They 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. They were also asked to not switch on the radio or any other kind of distraction. Each test-drives took about 3 minutes. 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.

## 3.5 Data analysis

The analysis of the NASA TLX results was done using a repeated measures ANOVA, with two within-subjects factors and their interaction term. The analysis of the steering movement was done with SPSS, using a repeated measures ANOVA with 4 within-subject factors and their interactions terms. Both ANOVAs were done with SPSS using a standard α of 0.05.

## Summary of the findings

The reported experiments showed that workload increased with speed. This means that an adaptive interface can benefit the driver to reduce workload in stressfull situations. In the present study, the adaption was done by presenting warning signals to the driver via a different modality. It can be argued that presenting warning signals via the auditory channel causes less driver workload compared to presenting the same information via the visual channel. 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. Regarding 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. Also it would be interesting to test the auditory warning signals in other situations than on highways, like the inner city or urban roads.

The main limitation of the study is that it was a simulator study and there was no real driving experiment. This was necessary to avoid risks for the participants. Although the main insight of the present study concenrs the differences in driver workload caused by driving at high speeds, namely 130 km/h, 180 km/h and 230 km/h the reader should keep in mind when interpreting the findings that those speeds are rarely driven by most people, especially since 180 km/h and 230 km/h are basically only allowed on German highways.

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