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Part 3

1
Introduction

Introduction to This Thesis

Technology forecasters predict that, in the future, vehicles as we know them nowadays will disappear. Intelligent systems, also known as Advanced Driver Assistance Systems (ADAS) and Automated Driving Systems (ADS), will allow drivers to delegate driving activities such as steering, accelerating, and decelerating to the vehicle, and ultimately all driving controls may be executed by the vehicle (Nirschl, 2007) resulting in fully automated vehicles. The purpose of the development of ADAS and ADS is to increase the traffic flow, reduce traffic accidents as well as driver's workload, distraction, and drowsiness, to create safer driving environments and mobility for everyone, and enhance convenience and sustainability. Several vehicle manufacturers and technology companies claim to have their first self-driven vehicle on the market by 2020 (Halleck, n.d.). Ultimately, these fully automated vehicles will be able to drive by themselves without any human assistance or intervention. The transfer of control from the driver to the vehicle has already started with the introduction of navigation systems. With the introduction of these systems, the route to be taken is now determined by a system instead of the driver or passengers. With Cruise Control (CC), the vehicle itself maintains the speed instead of the driver. Among other things, this results in a higher average speed and a decrease in the number of shock-waves leading to congestions (Schakel, Arem, & Netten, 2010). The increased use of these systems can, therefore, have a large impact on traffic safety and traffic flow conditions. This leads to the question how to increase the acceptance of drivers to use of intelligent systems in vehicles.

Issues with Manual Driving

In manual driving, the decisions drivers have to make such as changing lanes or accelerating are based on assumptions about the intentions of other drivers in their proximity, therefore, some level of risk-taking is unavoidable in driving (Sukthankar, 1997). Risk Homeostasis Theory (RHT) is one of the most well-known theories about risk-taking, focusing on the risk of being involved in an accident as a component of the decision-making process of drivers (Lewis-Evans, De Waard, & Brookhuis, 2010). RHT assumes that people seek to maintain a preferred level of risk by adjusting their behavior to the perceived level of risk. As a driver may detect a change in the driving conditions, he or she may perceive a change in the level of risk, for example, a change in sight distance along the road can result in a behavioral adaptation (Kulmala, 2010). If the environment is perceived to be more dangerous, drivers will change their behavior accordingly by being more cautious (Stanton & Marsden, 1996). According to Fuller (Fuller, 2005), not only the intentionally risky drivers but also the incompetent and lazy drivers are at risk in the traffic environment. Whereby risk is seen as an indicator of task difficulty, which is seen as inversely proportional to the difference between task demand and driver capability. When the task demand exceeds the driver's capability to perform that task the probability of a collision will increase.

Towards Automated Driving

Parasuraman and Riley (Parasuraman & Riley, 1997) defined automation as the execution of a function that was previously carried out by a human but is now executed by a machine agent (usually a computer). In relation to automated vehicles, one or more primary driving tasks are now performed by the vehicle itself. The transition from a manually driven vehicle to a fully automated driven vehicle, in which all driving tasks are delegated to the vehicle and a human driver is no longer needed, will not happen overnight. In between, there are multiple stages corresponding to the different levels of the automation of a vehicle (SAE International, n.d.). Ranging from level 0 (driver only) tot level 5 (fully automation). In the in-between stages, the driver still has the ability to intervene with the system to regain the control back. To enable drivers to do so, these automated vehicles will contain driving controls such as a steering wheel, throttle, and brake. Not only from a technical point of view may interventions be needed in the in-between phases. As mentioned by Ishibashi et al. (Ishibashi, Okuwa, Doi, & Akamatsu, 2007) with respect to perceiving the situation around the vehicle a mismatch may occur between the driver and the system, which can lead to distrust of the system and an increase of moments of intervention from a human perspective reducing the acceptance of these systems. Trust is mentioned as one of the aspects of adapting to and accepting automated technologies in vehicles by drivers as mentioned by Lee and See (Lee & See, 2004). People tend to rely more on automation when they trust it and will more often reject the automation if they do not (Parasuraman & Riley, 1997).

Decisions that are made during driving are dependent on multiple factors including, for example, the speed of the driven vehicle, preferred and allowed speed and information about vehicles in proximity to the driven vehicle. This task-specific understanding of the situation is referred to as Situation Awareness (Endsley, 1995). The automation of driving tasks may have a negative influence on the situation awareness of drivers as drivers are no longer involved in the automated tasks. Performing driving tasks manually may cause a higher workload. However, these manual tasks will also contribute to a better situation awareness (Stanton, Young, & McCaulder, 1997). The decrease of situation awareness when driving more automated may result in more dangerous situations when the driver has to regain control when the system has to go back from an automated driving mode to a manual driving mode. The decrease of situation awareness does not apply for all the driver support systems, as Ma & Kaber (Ma & Kaber, 2005) mentioned that it appears evident that the use of adaptive cruise control can benefit the situation awareness of a driver. Adaptive cruise control may reduce the workload because some of the vehicle controls do not have to be monitored, which can lead to a better understanding of the driving environment as more cognitive resources can be allocated towards monitoring the driving environment, resulting in an increased situation awareness.

The use of ADAS and ADS is intended to increase safety and ease of driving for the driver. As mentioned by Wickens and Hollands (Wickens & Hollands, 2000), when using automation, it is not just workload that is reduced, but also driving performance is improving according to the level of automation. However, several issues related to human factors do arise at any level of automation. Driver's situation awareness might decrease at a higher level of automation, as drivers are less engaged in the driving tasks and therefore the driving environment and vehicle state are less often monitored by the driver. Studies about the effects of ADAS supporting the driver have shown that drivers tend to engage more in secondary tasks like reading and texting while driving (Llaneras, Salinger, & Green, 2013). It is shown that drivers who are engaged in secondary tasks when driving in highly automated settings have a lower situation awareness and driving-related workload compared to drivers who drive manually (de Winter, Happee, Martens, & Stanton, 2014; Strand, Nilsson, Karlsson, & Nilsson, 2014). Workload is seen as the overall attention resources that are required to perform a task or multiple tasks simultaneously (de Waard, 1996), which may increase due to poorly designed and overly sensitive systems, requiring the driver to monitor a system for possible malfunctions (Hancock & Parasuraman, 1992). An increase in workload can again reduce situation awareness and comfort (Vahidi & Eskandarian, 2003). In addition, drivers respond to variations in task difficulty in terms of autonomic arousal and adjustments in speed (Fuller, 2005). As mentioned by Merat et al. (Merat & Lee, 2012) human factors need to be addressed and understood in order to design systems that are in line with the customers' needs.

As ADAS and ADS are developed with a strong focus on safety, the behavior of highly automated vehicles is expected to be cautious and defensive. Next, as the delegation of control to the vehicle creates automated vehicles, the role of the driver gradually changes from an actuator to an operator, and ultimately to a passenger, along with a change in the driving experience (Eckoldt, Knobel, Hassenzahl, & Schumann, 2012). The change in user experience leads to the question of how to design for this transition phase within automated vehicles. As ADS are developed with the aim to be cautious and defensive, the possible change in user experience and deviation of the behavior performed by an ADS from the driver's typical and preferred behavior, may have a negative effect on people's willingness to use such systems. The question arises how to influence user experience that comes along with the introduction of automated driving without adjusting the behavior of ADS. This question is relevant as long as the driver has the opportunity to regain the control over the vehicle, especially when there is no objective necessity to regain control, however, the driver will still disable the automated functions.

State of the Art

Automated Driving

As long as automated vehicles are not able to operate in all possible situations, the driver needs to regain control when the vehicle is not able to proceed by itself. As the technology for intelligent systems becomes more complex and sophisticated, the level of automation becomes higher. According to the SAE automation taxonomy (SAE International, n.d.), the driving task for vehicles corresponding to level 0 of automation, defined as no automation, is solely executed by the driver. In level 1 of automation, driver assistance, one specific function, for example, either keeps the vehicle in the lane or maintains a safe distance from other vehicles, assists the driver. Intelligent systems that correspond to level 2 of automation, also known as partial automation, control at least two primary driving functions, working unison. This level of automation still requires full attention throughout the driving task. Here, the driver is responsible for identifying situations where the system runs into its limitations. Level 3 automated vehicles, defined as conditional automation, enable the driver to delegate full control to the vehicle and do not require supervision. When the system runs into its limitations, it will issue a request to the driver to regain control. When no response is recorded and the vehicle is able to handle critical situations without compromising safety it is defined as level 4 of automation, high automation. At the highest level, level 5, full automation, vehicles should be able to fully control all the primary functions of driving for an entire trip. Given that vehicles in either level 0 to 4 still contain driving controls such as a steering wheel, throttle, and brake, the driver also has the possibility to regain control over the vehicle even when the system does not run into the boundaries of the technology. For example, when the behavior of the systems in the vehicle deviates from the desired driving behavior. The behavior of the intelligent systems may, therefore, influence the willingness to accept intelligent systems in the vehicle that allow drivers to delegate driving activities such as steering, accelerating, and decelerating to the vehicle.

User Acceptance

The use of new technologies or intelligent systems in vehicles is often related to the willingness of drivers to accept and use these applications. The decision to make use of a system or not is often depending on multiple aspects. Venkatesh et al. (Venkatesh, Morris, Davis, & Davis, 2003a) integrated different theories and research about the acceptance of information technology into one comprehensive model called the Unified Theory of Acceptance and Use of Technology (UTAUT). This model creates an overview of different aspects that may influence the willingness to use certain systems or technologies. The UTAUT (Venkatesh et al., 2003a) model consists of four constructs: performance expectancy, effort expectancy, social influence and facilitating conditions. These are influenced by one or more moderators, gender, age, experience and voluntariness of use. (1) Performance Expectancy concerns the extent that the user believes that the use of the system will help in reaching goals in driving performance (Osswald, Wurhofer, Trösterer, Beck, & Tscheligi, 2012), for example, reaching the destination safely. (2) Effort Expectancy concerns the amount of effort the user expects when using the system. For example, systems that need to be activated while driving should not take too much effort as it may distract the driver from the essential task of driving. This is influenced by age, gender and experience, having a stronger effect on women and older people who have limited experience with the system. (3) Social Influence relates to the degree of others influencing the decision of the driver to use the system. This is mostly applicable in mandatory settings with a stronger influence on women and older people who have limit experience (Venkatesh et al., 2003a). At last, the (4) Facilitating Conditions relates to the extent that there are facilities that support the driver in using the system.

Personalized Persuasion

There may be several reasons for drivers to decide not to accept the assistance provided by ADS. Thus, there is a need for ways to increase people's willingness to adopt intelligent systems. One way is the use of persuasive technologies (Fogg, 2003; Kaptein, De Ruyter, Markopoulos, & Aarts, 2012). These interactive technologies are often developed with the aim to change user's attitude or behavior without coercion or deception. These technologies aim at behavior or attitude change through the use of persuasion and social influence

(Fogg, 2003). However, since people differ in their needs and interests, strategies that are intended to persuade one type of driver to use intelligent systems may have no or even a negative influence on other types of drivers (Taubman-Ben-Ari & Yehiel, 2012). For example, a careful driver who receives an advice to slow down to create a gap for another vehicle will likely comply with this advice, while an angry driver who receives the same advice may just neglect this advice and speed up to close the gap. Taking the differences in driving behavior and style into account may increase the willingness to use intelligent systems while driving by creating tailored, more personalized persuasion.

Multiple factors may influence drivers' behavior, such as the driving environment, traffic situation, the driver's condition and personal characteristics (age, gender, driving experience, etc.) (Constantinescu, Marinoiu, & Vladoiu, 2010). The DRIVABILITY model (Bekiaris, Amditis, & Panou, 2003) was created with the notion that driver behavior is not necessarily static, but can evolve over time and in context. This model defines driving performance as determined by the influences of individual resources, knowledge/skills, environmental factors, workload, and risk awareness. Behavior that is more static, resulting in typical behavioral patterns of drivers, is usually referred to by the term 'driving style' (Ishibashi et al., 2007). The willingness to use ADS may be jeopardized as the behavior of ADS may deviate from driver's typical driving style. To learn more about the acceptance of driver support systems, gathering and using information about driver's driving styles and behavior may be a good start. This information may be useful to create driver profiles to learn what influences drivers according to these profiles in order to endorse acceptance. This information is needed as it appears evident that what might influence one group of drivers may not work at all with another group of drivers, or may even encourage greater involvement in risky behavior (Taubman-Ben-Ari & Yehiel, 2012). This results in the question of how to design for an increase of the acceptance of intelligent systems used by different types of drivers.

Research Objectives and Approach

In order to learn more about the acceptance of ADS, it is needed to understand how the acceptance of ADS is influenced by people's driving style. Such insight enables the exploration of means to influence people's willingness to accept systems that are tuned to the needs and interest of specific driver groups. There may be several reasons for drivers to decide not to accept the assistance provided by ADS. Since people differ in their needs and interests, strategies that are intended to persuade one type of driver to accept the assistance provided by ADS may have no or even a negative influence on other types of drivers (Taubman-Ben-Ari & Yehiel, 2012). Systems that take the differences in driving behavior and style into account may increase the willingness of users to use intelligent systems while driving. This may be achieved by creating systems that are tailored to drivers' driving style, also known as personalized persuasion. Using interactive technologies with the aim to change user's attitude or behavior without coercion or deception through persuasion (Fogg, 2003) tailored to specific driver groups. The aim of the research presented in this thesis was to learn more about the influence of driving styles on the acceptance of ADS and to explore the design potential for in-car applications to increase the overall acceptance of intelligent systems by different types of drivers through the use of more personalized persuasive technologies. Depending on the driving styles, specific approaches and strategies may be explored to influence driving behavior. This results in the main research question:

How to increase the acceptance of intelligent systems through the use of personalized persuasion?

In order to answer this question, an understanding is needed how to distinguish drivers. Only then personalized persuasive strategies can be developed and applied effectively. One approach is to make use of drivers' driving style as a mean to categorize drivers, as the behavior of ADS may deviate from the driver's typical driving style. This raises the following question:

To what extent can driving style be used to categorize drivers on the base of personalized persuasion?

To answer this question, driving style was investigated through a questionnaire and compared with typical behavior performed in a driving simulator. Building further on the concept of driving styles, a framework was created from which eight personas could be derived as a tool for categorizing drivers and revealing different design opportunities.

The idea emerged that, in particular for drivers who pursue an exciting driving experience, the decline in the experience due to the cautiousness and defensiveness of automated vehicles can be compensated for by intensifying visual, tactile and/or auditory sensations (Petiot, Kristensen, & Maier, 2013). Two of the design opportunities revealed from the framework, related to visual and auditory sensation, were further explored within two driving simulator studies. The effect of ambient light and the effect of sound on the experience within a vehicle were investigated in these studies.

Simulator

To be able to explore people's driving behavior as well as to investigate the effect of different persuasive strategies on the use of automated driving systems, a driving simulator was used. The use of a driving simulator has several advantages over the use of an instrumented vehicle on public roads (Helman & Reed, 2014). Firstly, a driving simulator provides more control and consistency among different participants and allows eliciting particular behaviors in situations that may be difficult to realize, unsafe or impractical in the real world (Reimer, D'Ambrosio, Coughlin, Kafrissen, & Biederman, 2006). Secondly, driving in a driving simulator enables risky behavior or situations without real threats for the drivers themselves, giving participants the opportunity to practice tendencies that are difficult to practice on real roads, because of the constraints on real-life behavior. Lastly, next to a controlled environment that makes it easier to reproduce particular situations it is also easier to extract data for analyses about the driver, the vehicle, and the environment. However, the use of a driving simulator may also have disadvantages that may affect the observed behavior. In the first place, the fidelity of the simulator may influence the perception of the driver. Secondly, some drivers interpret events and situations in a simulator as less dangerous compared to the same type of events and situations encountering on the road, as no one will be injured when being involved in an accident in the simulator (Helman & Reed, 2014). Several studies indicate that a driving simulator is a valid tool for the study of driving behavior. For example, Changbin et al. (Changbin, Junhua, & Yangming, 2015) confirmed that the behavior in a driving simulator was reliable compared to the behavior at the entrance of an underground road. Zhao et al. (Zhao et al., 2014) found good agreement between average corridor-level travel time, acceleration and deceleration profiles and the number of lane changes in a driving simulator and on the road. Also, Meuleners et al. (Meuleners & Fraser, 2015) found good agreement between the speed at intersections, maintaining speed, obeying traffic lights and stop signs in a simulator and on the road.

Gender

Åberg et al. (Åberg & Rimmo, 1998) mentioned that violations and mistakes measured by the Driver Behavior Questionnaire (Reason, Manstead, Stradling, Baxter, & Campbell, 1990) are related to gender as their results indicate that male drivers exhibit more frequent violations and mistakes than female drivers, as well as, male adolescents tend to be more engaged in undesirable driving behavior (Starkey & Isler, 2016). The main focus of the studies described in this thesis is on driving style and the influence of personalized persuasion on the use of automated systems according to drivers' own style of driving. For this purpose, drivers were categorized according to their driving style, counteracting the unequal distribution of gender as the studies described in this thesis were not gender balanced. The results related to gender should, therefore, be interpreted with caution due to the unequal distribution of gender.

Structure of This Thesis

This thesis is divided into three main parts: (1) Driving styles and how to measure them; (2) categorizing drivers through the use of personas derived from a three-dimensional framework; and (3) personalized persuasion through the use of ambient light and sound.

One way to determine a person's driving style is by means of a questionnaire, providing information about someone's self-reported driving style. The stability of the different factors of the Multidimensional Driving Style Inventory (MDSI) (Taubman-Ben-Ari, Mikulincer, & Gillath, 2004) was validated in **Chapter 2**. Taubman-Ben-Ari et al. (Taubman-Ben-Ari et al., 2004) conducted their study in various geographical areas in Israel. Wang et al. (M. Wang, Lundgren Lyckvi, & Chen, 2016) mentioned that traffic safety cultures differ between different parts of the world, and this, in turn, affects how drivers respond to advisory traffic information. To be able to use the MDSI in future studies within the Netherlands, an independent validation of the questionnaire was needed.

Next to the validation of the MDSI, the predictive value of the MDSI for driving behavior in a driving simulator was investigated in **Chapter 3**, in terms of speeding, braking, steering, lateral positioning and maintaining distance to a preceding vehicle. Eighty-eight participants filled in the MDSI and drove in a simulator for thirty minutes. Different driving style metrics, including complying with the maximum speed, lateral position and the distance to preceding vehicles, were recorded. The objective data retrieved from the simulator were compared with scores resulting from the questionnaire data.

Taking a closer look at Risky and Careful driving style, these can be analyzed in terms of three bi-polar dimensions: the behavior, knowing the consequences of the behavior and the motivation of the behavior. This results in eight different spaces within the framework characterizing eight different types of drivers discussed in **Chapter 4**. The eight personas that are derived from the three-dimensional model capturing differences between drivers were validated. A survey was conducted with 202 respondents who indicated for each persona how much they recognized themselves in that persona. Several design opportunities derived from the framework are outlined for future research.

In modern traffic, measures are implemented to regulate speeding, which may annoy drivers who pursue an exciting and riskier driving experience and make them exceed speed limits. Others prefer a more relaxing experience resulting in socially desired driving behavior. The capacity of ambient light to alter the perception of speed and therefore influence the driving experience was investigated in **Chapter 5**. The aim was to determine how different drivers experience the concept of an ambient light moving along the A-pillar inside the vehicle. In different conditions, the light moved at different speeds.

Another way to compensate for the degradation in the driving experience, which is likely due to more automated driving, may be by offering proper soundscapes. **Chapter 6** presents a study in which the influence of two different soundscapes on the driving experience was investigated, one giving a more thrilling experience, the other giving a more relaxing experience. Forty-four participants representing two different driving styles, assertive/risky or calm/careful, drove in a simulated autonomous vehicle, where they could put the autopilot function on or off. When the autopilot was enabled, one of the two soundscapes designed for this study was played. In the discussion, several possible explanations are considered and directions for future research are outlined.

Lastly, the study in **Chapter 7** zoomed out again and investigated different reasons why drivers may disengage the autopilot. This was done through a simulator study in which participants had the ability to drive autonomously, but also disengage the system. Several design opportunities related to the reoccurring themes, covering the reasons why participants disabled the autopilot without the need to intervene, are proposed to counteract the driver's inclination to disengage the automated driving system when there is no objective necessity to do so.

Finally, **Chapter 8** presents the discussions and conclusions of our research, summarizing the insights gained throughout the thesis and discussing the limitations and proposing research directions for future work.

Part 1

2

Measuring Driving Styles: A Validation of the Multidimensional Driving Style Inventory

Abstract

The aim of the study described in this chapter was to validate the stability of the different factors of the Multidimensional Driving Style Inventory (MDSI) (Taubman-Ben-Ari et al., 2004), which was originally developed and validated with participants in different geographical areas of Israel. In this study, the questionnaire was distributed in the Netherlands and Belgium. A factor analysis of the data of 364 participants revealed five of the eight factors that resulted from the original factor analysis: Angry driving, Anxious driving, Dissociative driving, Distress-reduction driving, and Careful driving style. In addition, 24 items divided over the five factors seem to be stable compared to the 44 items divided over the eight factors of the original analysis. The factors revealed through the analysis of these data were used to determine driver profiles, being either Angry driving, Anxious driving, Dissociative driving, Distress-reduction driving, Risky driving and Careful driving or consisting out of a combination of two of those driving styles.

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Introduction

As stated in the introduction of this thesis, Advanced Driver Assistance Systems (ADAS) are developed with the purpose of increasing safety, efficiency and driver comfort and to reduce driver's workload. These systems interact with the driver with the purpose to advise or assist the driver or take over control altogether in certain driving situations (Nirschl, 2007). To the extent that the advice or assistance requires drivers to deviate from their typical behavioral patterns, acceptance of those systems may be jeopardized. For instance, if a speed advice system advises the driver to slow down or if a speed control system reduces the speed of the car without a clearly perceivable and obvious need, drivers who are used to drive at a higher speed may not adopt the advice or allow the vehicle to reduce the speed of the vehicle.

The typical behavioral patterns of drivers are usually referred to by the term 'driving style' (Ishibashi et al., 2007). This includes the choice of driving speed, headway, overtaking of other vehicles and the tendency to commit traffic violations (Elander, West, & French, 1993). In order to learn more about the acceptance of ADAS, we need to understand how the acceptance of ADAS is influenced by people's driving style. Such insight will enable us to explore means to influence people's willingness to accept such systems that are tuned to the needs and interests of specific driver groups. It appears evident that what might influence or persuade one group may not work at all for another group (Kaptein et al., 2012), or may even encourage greater involvement in risky behavior (Taubman-Ben-Ari & Yehiel, 2012).

An easy way to determine drivers' driving style is by means of a questionnaire, giving information about someone's self-reported driving style. Several self-report measures of driving behavior, style and cognition have been constructed and validated over the last couple of years. In this chapter, we will review seven driving style questionnaires that have been proposed in the literature and then validate one to be used for future research.

Related Work

Gulian et al. (Gulian, Matthews, Glendon, Davies, & Debney, 1989) developed the Driver Behavior Inventory (DBI) to study dimensions causing driver stress. This questionnaire covered vehicle use, demographics, accidents, convictions and attitudes towards those, health, work and personal problems, moods, emotions and attitudes towards driving and other road users. The 35 items of the questionnaire highlighted driver stress reactions. A factor analysis of the 35 items revealed five factors including feelings as aggression, irritation when overtaking, alertness, dislike, and frustration when failing to overtake. As the DBI focuses on driver stress, other factors determining driving style are not addressed in this questionnaire, rendering the DBI less useful for our research.

Reason et al. (Reason et al., 1990) developed a Driver Behavior Questionnaire (DBQ) consisting of 50 items covering five classes of aberrant behavior: slips, lapses, mistakes, unintended violations, and deliberate violations. Participants had to indicate for each item on a five-point scale how often they committed that behavior while driving. The analyses of the results of this questionnaire resulted in three factors: violations, dangerous errors and silly errors. As the DBQ focuses on aberrant behaviors, non-aberrant aspects of typical driving behavior are not addressed, therewith rendering the DBI less useful for our current purpose.

Furnham and Saipe (Furnham & Saipe, 1993) developed a Driver Behavior Questionnaire measuring risk-taking on the road. The results of the 25 items of the questionnaire revealed five factors: feeling and expressing aggression, law-breaking behavior, expressing confidence in taking driving risks, the excitement of driving and taking risks when driving. These factors describe differences in driving behavior but do not represent different driving styles. Breaking the law, for example, can be part of a driving style, but is not a driving style by itself.

French et al (French, West, Elander, & Wilding, 1993) revealed six dimensions labeled speed, calmness, planning, focus, social resistance (advise) and deviance through a principal component analysis of fifteen driving style questions. The outcomes of the Driver Style Questionnaire (DSQ) (French et al., 1993) were used to describe the relation between driving style, decision-making style, and accident liability. The results showed that thoroughness (one of the factors resulting from the analysis of the decision-making style questionnaire) correlated with all the driving styles and idealism correlated with none of the driving styles. The weakness of this questionnaire is the distribution of fifteen items over six dimensions resulting in two or three items per dimension.

Lajunen and Summala (Lajunen & Summala, 1995) developed the driver Skill Inventory (DSI) to measure self-reported safety motive and skill dimensions. The 29 items relate to perceptual-motor skills and safety orientation (Lajunen, Parker, & Stradling, 1998), referring to the ability to drive in a safe and skillful manner by assessing people's abilities relative to a hypothetical average driver on a five-point scale. This questionnaire taps into driving skills and safety motives rather than driving style.

Ishibashi et al. (Ishibashi et al., 2007) define driving style as an attitude, orientation and way of thinking for daily driving. They developed a Driving Style Questionnaire consisting of eighteen questions divided over eight components: Confidence in driving skill, Hesitation for driving, Impatience in driving, Methodical driving, Preparatory maneuvers at traffic signals, Importance of automobile for self-expression, Moodiness in driving and Anxiety about traffic accidents. Through analysis of car following behavior at low speed, they examined the validity of the questionnaire. Results showed, for example, a positive relationship between confidence in driving skill and the use of the gas pedal. The weakness of the questionnaire is that each component consists of two items.

Taubman-Ben-Ari et al. (Taubman-Ben-Ari et al., 2004) suggested four broad driving styles: (1) Reckless and careless driving, which is correlated with violations and thrill-seeking while driving, characterized by for example higher speed. (2) Anxious driving, referring to feelings of alertness and tension. (3) Angry and hostile driving, characterized by more use of the horn and flash functionality. (4) Patient and careful driving, reflecting a well-adjusted driving style. Building on these four broad styles they created the Multidimensional Driving Style Inventory (MDSI) (Taubman-Ben-Ari et al., 2004) consisting of 44 items. A factor analysis revealed eight main factors. (a) Dissociative driving, in which people are easily distracted and dissociated during driving. (b) Anxious driving, in which people show signs of anxiety and lack of confidence. (c) Risky driving, in which people seek for sensation and more risky driving. (d) Angry driving, in which people tend to be hostile and aggressive. (e) High-velocity driving, in which people tend to drive faster and are more time driven. (f) Distress-reduction driving, in which people engage in relaxing activities to reduce stress. (g) Patient driving, in which people are polite to other road users and have no pressure of time. (h) Careful driving, in which people drive carefully and structured.

The MDSI (Taubman-Ben-Ari et al., 2004) consists of items which were adapted from several other existing surveys, such as the DBI of Gulian et al. [7] studying dimensions defining driver stress, the DBQ (Reason et al., 1990) developed by Reason et al. about aberrant behavior, the DBQ developed by Furnham and Saipe (Furnham & Saipe, 1993) measuring risk taking on the road, and the DSQ of French et al. (French et al., 1993) describing the relation between driving style, decision-making style and accident liability. Additionally, original items were created to complete the questionnaire.

The use of a questionnaire is an easy way to determine drivers' driving style, giving information about someone's self-reported driving style. The seven driving style questionnaires reviewed in this chapter lead to the conclusion that for future research the MDSI questionnaire seems the best fit as this questionnaire incorporates three of the other six questionnaires resulting in eight different driving styles.

Taubman-Ben-Ari et al. (Taubman-Ben-Ari et al., 2004) conducted their study in various geographical areas in Israel. To be able to use the MDSI in future studies in another geographical region we needed to conduct an independent validation of the questionnaire. The aim of the study described in this chapter is to validate the eight main factors and loadings found by Taubman-Ben-Ari et al. through the distribution of the same questionnaire among drivers in the Netherlands and the Dutch-speaking part of Belgium.

Method

Participants

Three hundred twenty-five participants volunteered to participate in this study and completed the online questionnaire. In addition, forty participants who volunteered to participate in the study of a master student Industrial Design completed the same questionnaire.

Of the participants who filled in the online questionnaire (N=365) the majority drove most of their miles in the Netherlands (N=197, 54%) and Belgium (N=116, 32%). Other participants drove most of their miles in: Greece (N=11), Germany (N=8), United Kingdom (N=4), India (N=4), Malaysia (N=4), Europa (N=3), Italy (N=2), Portugal (N=2), Turkey (N=2), Australia (N=2), United Stated (N=2), Bulgaria (N=1), Ireland (N=1), Sweden (N=1), Russia (N=1), Mexico (N=1), Japan (N=1), United Arab Emirates (N=1) and South Africa (N=1).

Two hundred eighty-one participants completing the online questionnaire were male and eighty-four were female. Twenty-one percent were within the age category 17 to 24, forty-one percent were between the age of 25 and 39, thirty-five percent were between the age of 40 and 65, and three percent were older than 65. Three-quarter of the participants indicated that they make use of a navigation system (N=278, 76%) and half of the participants indicated that they use Cruise Control (N=189, 52%). A fifth indicated that they make use of an Advanced Parking Assist System (N=81, 22%), five percent (N=20) indicated that they make use of Adaptive Cruise Control, four percent (N=14) make use of a Blind Spot Warning System and one percent (N=4) of the participants indicated to use a Lane Departure Warning System.

Procedure and Measure

The questionnaire was offered in two different languages: English and Dutch. Instead of literally translating the questions from English, the English version was translated into Dutch with the aim to preserve the meaning of the questions as much as possible. This was done through discussion between two researchers who are native Dutch speakers and proficient

English speakers. Both versions were distributed through Facebook, email and both Dutch and Flemish online automotive forums.

Participants were asked to complete an online questionnaire that consisted out of six questions relating to their demographic data and driving history and the multidimensional driving style inventory of Taubman-Ben-Ari et al (Taubman-Ben-Ari et al., 2004) consisting of 44 statements.

The questions related to the demographic data and driving history concerned gender, age category, duration of being in possession of a driver's license, miles driven per year, in which country the most annual mileage was driven and which driver's support systems are used.

The multidimensional driving style inventory (MDSI) (Taubman-Ben-Ari et al., 2004) is a validated self-report questionnaire by which each statement is rated on a six-point scale ("not at all" to "very much" and in the Dutch version also "never" to "always" depending on the statement). This questionnaire assesses eight factors resulting from the original analysis: Dissociative driving (8 items, Cronbach's alpha .82), Anxious driving (7 items, Cronbach's alpha .82), Risky driving (5 items, Cronbach's alpha .83), Angry driving (5 items, Cronbach's .80). High-velocity driving (6 items, Cronbach's alpha .76), Distress-reduction driving (4 items, Cronbach's alpha 75), Patient driving (4 items, Cronbach's alpha 74) and Careful driving (5 items, Cronbach's alpha 0.76).

Two different statistical analyses were performed on the data. A factor analyses with Varimax rotation equal to the analyses performed by Taubman-Ben-Ari et al. (Taubman-Ben-Ari et al., 2004) and an Oblique Principal Component Cluster Analysis (OPCCA). The first analysis allowed to compare and validate the results with the original results as the second analyses validated if the results would still hold when the items are projected within one dimension resulting in clusters that are often easier to interpret.

Results and Discussion

MDSI Factors Reproduced

Identical to the factor analyses performed by Taubman-Ben-Ari et al. (Taubman-Ben-Ari et al., 2004), a factor analysis with Varimax rotation was conducted with eight factors to determine if the items would be divided over the same eight factors compared to the results of Taubman-Ben-Ari et al. (Taubman-Ben-Ari et al., 2004). Next to the factor analysis with eight factors a second analysis with six factors was conducted as a follow up on the results of the first analysis. The first analysis revealed eight factors of which two factors did not have enough items to have a meaningful contribution. Finally, an Oblique Principal

	Factor 1 | Angry Driving	Loadings
43	Honk my horn at others	.803
3	Blow my horn or "flash" the car in front as a way of expressing frustrations	.771
28	When someone does something on the road that annoys me, I flash them with high beam	.733
12	Swear at other drivers	.657
17	*When a traffic light turns green and the car in front of me doesn't get going immediately, I try to urge the driver to move on*	*.692*
13	*When a traffic light turns green and the car in front of me doesn't get going, I wait for a while until it moves [-]*	*.503*
2	*Purposely tailgate other drivers*	*.413*
	Factor 2 | Risky Driving	
44	Enjoy the excitement of dangerous driving	.832
22	Like to take risks while driving	.737
24	Like the thrill of flirting with death or disaster	.701
6	Enjoy the sensation of driving on the limit	.657
29	*Get a thrill out of breaking the law*	*.732*
	Factor 3 | Anxious Driving	
31	Feel nervous while driving	.799
10	Driving makes me feel frustrated	.744
40	Feel comfortable while driving [-]	.720
4	Feel I have control over driving [-]	.534
25	It worries me when driving in bad weather	.499
33	Feel distressed while driving	.445
41	*Always ready to react to unexpected maneuvers by other drivers [-]*	*.429*
8	*While driving, I try to relax myself [-]*	*.331*
	Factor 4 | Dissociative Driving	
35	Attempt to drive away from traffic lights in third gear (or on the neutral mode in automatic cars)	.648
27	Forget that my lights are on full beam until flashed by another motorist	.597
39	Nearly hit something due to misjudging my gap in a parking lot	.530
36	Plan my route badly, so that I hit traffic that I could have avoided	.465
34	Intend to switch on the windscreen wipers, but switch on the lights instead	.453
20	*Fix my hair / makeup while driving*	*.508*
21	*Distracted or preoccupied, and suddenly realize the vehicle ahead has slowed down, and have to slam on the breaks to avoid a collision*	*.496*

5	*Drive through traffic lights that have just turned red*	*.447*
19	*When someone tries to skirt in front of me on the road, I drive in an assertive way in order to prevent it*	
	Factor 5 | Careful Driving	
42	Tend to drive cautiously	.706
14	Drive cautiously	.686
23	*Base my behavior on the motto “better safe than sorry”*	*.581*
7	*On a clear freeway, I usually drive at or a little below the speed limit*	*.425*
41	Always ready to react to unexpected maneuvers by other drivers	.403
	Factor 6 | Distress-Reduction Driving Style	
1	Do relaxing activities while driving	.683
37	Use muscle relaxation techniques while driving	.662
26	Meditate while driving	.518
11	*I daydream to pass the time while driving*	*.617*
	Factor 7	
15	*Lost in thoughts or distracted, I fail to notice someone at the pedestrian crossings*	
30	*Misjudge the speed of an upcoming vehicle when passing*	
	Factor 8	
38	*Plan long journeys in advance*	
16	*In a traffic jam, I think about ways to get through traffic faster*	
18	*At an intersection where I have to give right-of-way to oncoming traffic, I wait patiently for crossing traffic to pass*	
32	*Get impatient during rush hour*	
9	*When in a traffic jam and the lane next to me starts to move, I try to move into that lane as soon as possible*	

The grey items were removed from the second analysis; the italic items do not correlate with the same items compared to the original factor analysis; items with [-] negatively correlate with that factor

Table 1: Results of two-factor analysis (Loadings are from the second analysis)

Component Cluster Analysis (OPCCA) was conducted as a check to the results of the Varimax factor analysis. In OPCCA the dimensions do not have to be orthogonal, which tends to deliver factors that are easier to interpret. In all three analyses, item nine was not taken into consideration due to a mistake in the set-up of the questionnaire, which resulted in missing data of item nine for 146 participants (40%). In addition, one of the participants was removed from the analyses. SPSS indicated multiple answers of this participant as outliers and inspection of the answers for this participant revealed internal inconsistencies, indicating that this person's answers were not reliable.

The first factor analysis was conducted with the answers of 364 participants revealing a distribution of the 43 items over eight factors explaining 49% of the variance. In Table 1 the item distribution can be found.

Factor 1 consists of seven items addressing angry and frustrated behavior when driving. This factor, explaining 14% of the variance (Cronbach's alpha .81), was labeled "Angry driving style". Factor 2 consists of five items addressing risky and thrill-seeking behavior. This factor, explaining 11% of the variance (Cronbach's alpha .83), was labeled "Risky driving style". Factor 3 consists of seven items addressing nervous and anxious driving behavior. This factor, explaining 6% of the variance (Cronbach's alpha .74), was labeled "Anxious driving style". Factor 4 consists of nine items addressing nonchalant, dissociated behavior, except for item 19, which addresses assertive, risky behavior. This factor, explaining 5% of the variance (Cronbach's alpha .67), was labeled "Dissociative driving style". Factor 5 consists of five items addressing careful and cautious behavior. This factor, explaining 4% of the variance (Cronbach's alpha .63), was labeled "Careful driving style". Factor 6 consists of four items addressing behavior to become relaxed, less stressed. This factor, explaining 3% of the variance (Cronbach's alpha .54), was labeled "De-stress driving style". Factor 7 consists of two items addressing dissociated behavior. This factor explains 3% of the variance (Cronbach's alpha .11). Factor 8 consists of four items addressing two different types of behaviors, two items address careful behavior and two items address frustrated risky behavior. This factor explains 3% of the variance (Cronbach's alpha .31). A constraint was set to have at least three items per factor (Raubenheimer, 2004) and in combination with the low Cronbach's alpha factor 7 was removed from the analysis. As a Cronbach alpha value indicates the overall reliability of a questionnaire of which at least 0.7 is considered good (Field, 2009, p. 681). The items in factor 8 are heterogeneous which makes it difficult to label this factor and in combination with the low Cronbach's alpha, the decision was made to also remove this factor from the analysis. As item 19 addresses assertive, risky behavior which is not in line with the other items in factor 4 this item was also removed from further analysis.

As a follow up on the results of the first factor analysis a second factor analysis with Varimax rotation consisting of six factors was conducted in which items 9, 15, 16, 18, 19, 30, 32 and 38 were left out as those do not fit in the six main factors used in this analysis. This analysis revealed a distribution of 36 items over six factors explaining 48% of the variance. In Table 1 the item distribution can be found, as mentioned above, the items in grey are discarded in this analysis and the last column provides the factor loadings of each item.

Factor 1 consists of seven items labeled “Angry driving style”. This factor explains 16% of the variance (Cronbach’s alpha .81). Factor 2 consists of five items labeled “Risky driving style”. This factor explains 12% of the variance (Cronbach’s alpha .83). Factor 3 consists of eight items labeled “Anxious driving style”. This factor explains 6% the variance (Cronbach’s alpha .76). Factor 4 consists of eight items labeled “Dissociative driving style”. This factor explains 5% of the variance (Cronbach’s alpha .68). Factor 5 consists of four items labeled “Careful driving style”. This factor explains 4% of the variance (Cronbach’s alpha .65). Factor 6 consists of four items labeled “De-stress driving style”. This factor explains 4% of the variance (Cronbach’s alpha .54).

Another method to investigate different clusters of items projected within one dimension is an Oblique Principal Component Cluster Analysis (OPCCA). This analysis was performed as a validation of the factors resulting from the second analysis.

For the OPCCA analysis, the same 37 items used for the second factor analysis were used. This analysis revealed five main clusters with a second eigenvalue smaller than 1,2 (indicating that they are indeed clustered one-dimensionally): Factor 1, Careful Driving (Cronbach’s alpha .85); Factor 2, Anxious Driving (Cronbach’s alpha .75); Factor 3, Angry Driving (Cronbach’s alpha .81); Factor 4 Distress-Reduction Driving (Cronbach’s alpha .55); and Factor 5 Dissociative Driving (Cronbach’s alpha .70). In this analysis, the items of Careful driving and Risky driving (resulting from the second analysis) were combined into one factor, labeled Careful driving (as the items of Risky driving are negative in this factor).

MDSI Factors Original and Reproduced

The original factor analysis of the MDSI (Taubman-Ben-Ari et al., 2004) revealed eight factors: Dissociative driving, Anxious driving, Risky driving, Angry driving, High-velocity driving, Distress-reduction driving, Patient driving, and Careful driving. As can be seen in Table 1, six of these factors could be reproduced with a Varimax rotation using data mainly collected within the Netherlands and Belgium. The items in italics in Table 1 are items that are assigned to other factors within the original factor analysis compared to the second analysis performed within this study. Removing these items resulted in twenty-four items divided over six factors that seem to be stable. Five factors still have enough items when taking the constraint of at least three items per factor. The factor Careful driving resulting from the second analysis does not have enough items left to have a meaningful contribution. The OPCCA revealed five factors of which the factor labeled Careful Driving in the second analysis is combined with Risky Driving. If we compare the outcomes of the one-dimensional OPCCA with the original factor analysis by Taubman-Ben-Ari et al. (Taubman-Ben-Ari et al., 2004), we arrive at five stable factors with a minimum of at least three items per factor in which Careful and Risky are combined to six items. These analyses result in a questionnaire that exists of twenty-four items tapping into feelings, attitudes, and behaviors, with a distribution over five clusters: Careful driving, Angry Driving, Anxious Driving, Dissociative driving and Distress-Reduction Driving.

Driving Styles and Driver Profiles

One of the reasons to conduct this study was to investigate the possibility to categorize people's driving style on the basis of their self-reported driving behavior. The categorization of people's driving style can help in understanding how to incorporate certain aspects of behaviors in ADAS to increase the acceptance of these systems. For example, drivers who are categorized as Risky drivers may prefer a smaller headway compared to Careful drivers. This aspect might be incorporated in an ADAS to increase the acceptance.

The next question is how we can determine people's driving style. The factor analysis with Varimax rotation revealed six driving styles. The simplest method is to use the average scores for each factor (adding the scores of the items assigned to each factor and dividing the sum by the number of items) and taking the highest scoring factor as someone's driving style. This method identifies 331 (91%) participants as Careful drivers. Thus, this method has little discriminating power. A second method takes the factor loadings into consideration for the different items. In this method, a person's score for each item is multiplied by the factor loading of that item and then the average score for each factor is calculated for each person. This method identifies 299 (82%) participants as Careful drivers, still having little discriminating power. In the third method, "the factor loadings are adjusted to take account of the initial correlations between items" (Field, 2009). Accordingly, the item scores are multiplied by the adjusted factor loadings, and the average of the resulting scores is taken across the items for each factor for each individual. The factor with the highest average is taken as the participants driving style. This method revealed an almost equal distribution of participants over the six different factors when taking the highest score as identifying someone's driving style. As mentioned by Field (Field, 2009, p. 634), this is a more sophisticated method for calculating factor scores, providing factor scores which show the deviation of each participant from the mean of that factor. If someone scores high on a factor according to the factor score, that person scores high relative to the average of the scores of all participants within the same factor.

It should be noticed, however, that all these methods take the highest scoring factor as indicative of someone's driving style, therewith ignoring the scores for the other factors. This may be satisfactory for one-dimensional constructs, but there is no a priori reason to assume that driving style is a one-dimensional construct. If we take driving style as a multi-dimensional construct, it might be more appropriate to talk about driver profiles, so that someone might be said to be both a careful and attentive driver.

To determine driver profiles, the factors obtained from the second factor analysis were used, giving rise to six different factors. The factor scores of each participant as calculated by the third method above were normalized by subtracting the mean from each factor score and dividing by the standard deviation. The means and standard deviations (SD) were calculated across the six factor scores of each participant. Next, a threshold was calculated by taking the mean + 1 SD of each participant to see which factor scores for each individual driver exceeded the calculated threshold (this method is similar to the method used by

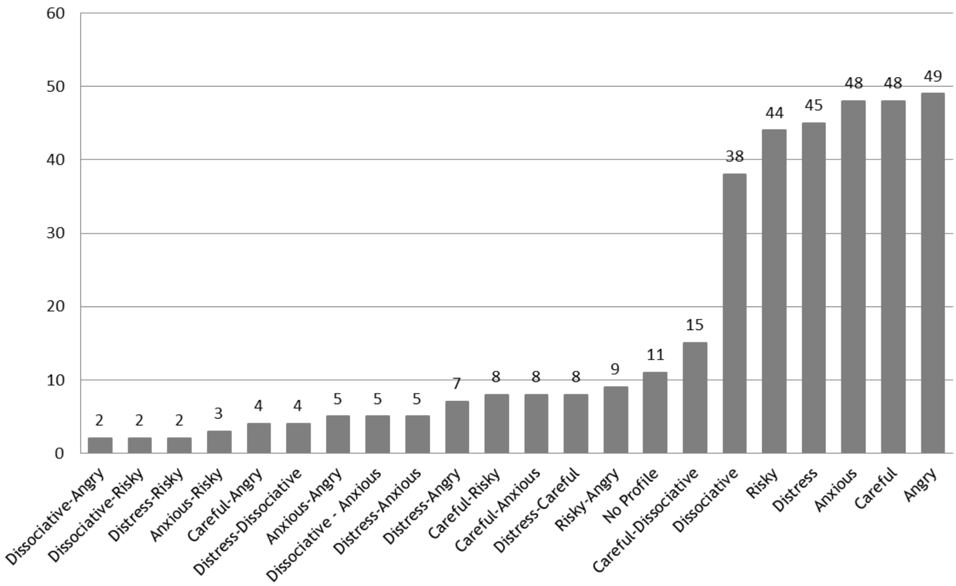

Figure 1: Distribution Driver Profiles

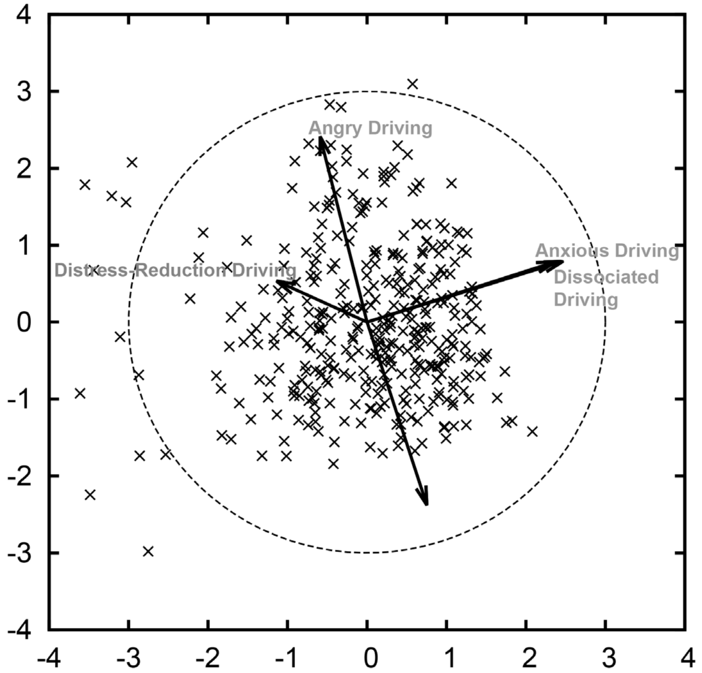

Figure 2: Two-Dimensional Visualization of One-Dimensional Analysis

Shahab et al. (Shahab, Terken, & Eggen, 2013)). The profile of an individual was then built on the factor(s) which exceed the threshold value.

Applying this method resulted in 21 different profiles being either Angry driving, Anxious driving, Dissociative driving, Distress-reduction driving, Risky driving and Careful driving or consisting out of a combination of two of those driving styles. For 11 participants no profile could be determined, due to the fact that none of their factor scores exceeds the threshold. As can be seen in Figure 1, 272 (75%) of the participants are allocated to a profile consisting of one driving style. The profiles shown in Figure 1 indicate that within the sample of 364 participants, for example, 49 participants are angry drivers compared to the other participants and 48 are careful drivers in comparison to the rest. Figure 1 provides an overview of the division of driving styles with respect to all the participants within the sample.

As a final check, driver profiles were also determined on the basis of the outcomes of the OPCCA analysis. In this method, the factor scores resulting from the OPCCA were subjected to multidimensional scaling and the outcomes were visualized in a two-dimensional plot, identifying both the relationships between these constructs and illustrating diversity of the drivers that participated in the survey (see Figure 2). This plot reveals no obvious clustering, from which it may be concluded that not all people can be categorized as for instance either an angry or careful driver. The scores on all the factors together determine what type of driver someone is, therewith providing further support for the notion of driver profile.

Conclusion and General Discussion

ADAS have the potential to improve traffic safety and throughput when drivers accept to use these systems. If these systems do not meet drivers' needs and expectations, drivers will refrain from using them. Provided that different people are sensitive to different forms of persuasion, as shown in (Kaptein et al., 2012), the notion of driver profiles may help to identify common differences in characteristics between groups of drivers.

A first step to identify differences between drivers is by means of a questionnaire giving information about someone's self-reported driving style. This chapter described the validation of the Multidimensional Driving Style Inventory developed by Taubman-Ben-Ari et al. (Taubman-Ben-Ari et al., 2004). The analysis of the results of 364 participants completing the questionnaire showed that most of the original factors could be replicated quite well, with 24 of the 44 original items divided over five or six main factors. A factor analysis with Varimax rotation revealed six factors among the 24 items and an OPCCA analysis revealed five factors: Dissociative driving, Anxious driving, Risky driving, Angry driving, Distress-reduction driving, and Careful driving (Risky and Careful driving are combined in OPCCA revealing five factors). As a side note, it needs to be kept in mind that the Cronbach alpha values of the Distress-reduction style within all the three analyses is below the acceptable threshold of 0.7 and therefore should be interpreted with caution.

The scores gained from the analysis were used to create driver profiles consisting of one or more driving styles. The first two methods that were used to identify driving styles identified most drivers as Careful drivers. This may be due either to respondents giving socially desirable answers or to the fact that people, in general, try to avoid accidents. Anyway, these methods are not discriminating enough. The third method resulted in 21 driver profiles. It needs to be kept in mind that these profiles created are relative within the sample. People who are categorized as angry drivers are angry drivers in comparison to the other drivers within the sample. This means that a driver who is categorized as an angry driver in this study may not be an angry driver in an absolute sense, comparing to all drivers outside this study.

The scores resulting from the OPCCA were used and rendered jointly in a two-dimensional space. The render of the scores does not reveal an obvious clustering of the drivers participating in the survey, indicating that characterizing drivers in terms of a single dominant driving style is too simple. The scores on all the factors together determine what type of driver someone is.

The two-dimensional plot resulting from the OPCCA analysis can be used for selection of participants in follow up studies to create a balanced representation of different driving styles.

Another aspect that has to be taken into consideration is that the results are a context-free and momentary self-report. Multiple factors may influence drivers' behavior, such as the driving environment, traffic conditions, the driver's condition and personal characteristics (gender, age, driving experience, etc.) (Constantinescu et al., 2010). As mentioned by Bekiaris et al. (Bekiaris et al., 2003) driver behavior is not necessarily static, but evolves over time and in context, as dependent on the ability to drive and the driving performance of a particular person in a specific environment and under specific circumstances. This notion should be taken into consideration when making use of a self-report measurement of someone's driving behavior.

The purpose of the study described in this chapter was to validate the MDSI questionnaire to learn if the items of this questionnaire would remain in the same factors compared to the original analysis. This study was also executed with the aim to learn if this questionnaire has the ability to categorize drivers according to their driving styles to determine if this questionnaire can be used in future studies. The question derived from this study is how the results of the MDSI (self-reported behavior) are correlated with actual behavior in a vehicle or driving simulator. For such driving style questionnaires to be meaningful, they should predict actual driving behavior. This can enhance the understanding of driving styles and the relation to certain behaviors and help to decide which direction to take when investigating how persuasive systems can be used to influence the acceptance of ADAS.

3

The Relation between Self-reported Driving Style and Driving Behavior. A Simulator Study

Abstract

The aim of this study was to investigate the predictive value of the Multidimensional Driving Style Inventory (MDSI) for driving behavior in a driving simulator, in terms of speeding, braking, steering, lateral positioning and maintaining distance to a preceding vehicle. Eighty-eight participants, mainly from the Netherlands and Belgium, filled in the MDSI and drove in a simulator for thirty minutes. Different driving behaviors, including complying with the maximum speed, lateral position and the distance to preceding vehicles, were recorded. The objective data retrieved from the simulator were compared with scores resulting from the questionnaire data. The analysis revealed modest correlations between the self-reported driving styles and the driving behavior in the driving simulator, similar to those reported in the literature. It is concluded that the current study supports the use of the MDSI as a diagnostic tool for screening participants with different driving styles for simulator studies.

THIS CHAPTER IS BASED ON:

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Introduction

From observations of everyday traffic it is clear that not all drivers behave in the same way. Research on differences between drivers has confirmed the existence of individual differences between drivers; the choice of driving speed, distance to a preceding vehicle, overtaking other vehicles and the tendency to commit traffic violations (Elander et al., 1993) constitute behavioral tendencies of drivers. These habits are usually referred to by the term 'driving style' (Ishibashi et al., 2007). Accordingly, drivers are typically characterized as, for instance, careful, risky or anxious drivers (Taubman-Ben-Ari et al., 2004). From a personal, interpersonal and societal perspective, some of these driving styles are less desirable, so that it is attractive to explore ways to influence the concerned drivers to change their driving style. As part of the project in which we develop and evaluate such personalized interventions aiming to influence drivers to exhibit desirable driving behavior, we need ways to identify people's driving styles. While in real-life situations the concerned drivers should be identified preferably from behavioral indices, for testing the effectiveness of the interventions in the laboratory, participants representing particular driving styles may be recruited by means of a questionnaire (Sundström, 2008; Taubman-Ben-Ari et al., 2004) as a questionnaire is, among other things, easy and cheap to administer to a larger group of respondents. Several self-report measures of driving behavior, style and cognition have been constructed and validated over the last couple of decades. Nonetheless, the use of self-reported measures has been questioned due to the possibility of reporting biases (af Wåhlberg, 2009; af Wåhlberg & Dorn, 2015). This raises the question of whether a questionnaire is a proper means to identify a person's driving style, or whether driving style can better be measured from, for example, driving behavior within a driving simulator. The aim of the current study was to determine whether the outcomes of a driving style questionnaire are in agreement with the driving behavior.

Related Work

While several driving style questionnaires have been created, the current study uses the MDSI questionnaire (Taubman-Ben-Ari et al., 2004) for collecting self-report driving style data. The MDSI questionnaire addressed multiple driving styles, providing the opportunity to use this questionnaire as a tool to categories driving according to their own driving style. The MDSI (Taubman-Ben-Ari et al., 2004) adapted items from several other existing surveys, such as the Driver Behavior Inventory (DBI) (Gulian et al., 1989), the Driver Behavior Questionnaire (DBQ) (Reason et al., 1990), the Driver Behavior Questionnaire (Furnham & Saipe, 1993) and the Driver Style Questionnaire (DSQ). Additionally, original items were created to complete the questionnaire (Taubman-Ben-Ari et al., 2004). A modified version of the MDSI questionnaire was used in the current study, which resulted from a validation study with mainly Dutch and Belgian respondents, and which contains 37 items that distinguish six of the original eight driving styles explained in the previous chapter. (1) Angry driving is characterized by swearing, making more use of the horn in the vehicle or beaming to other road users. Aggression to other road users is often referred to as road rage, affecting the driver's performance and safety on the road (Galovski & Blanchard, 2004). Road rage is seen as a threat to driving, next to drinking and not using a seatbelt (Jeon, 2015). (2) Risky driving is characterized by speeding and the excitement of dangerous driving. Some drivers drive at a higher speed for the thrill and sensation as a part of their attitude towards taking risks (Hatfield & Fernandes, 2009). Male adolescents are more likely to engage in undesirable driving behavior and tend to be more impulsive (Starkey & Isler, 2016) (3) Anxious driving is characterized by feeling distressed and worried while driving. According to Gwyther et al. (Gwyther & Holland, 2012) drivers who are less confident or more anxious tend to over-regulate driving, which can result in maladaptive responses. (4) Dissociative driving is characterized by inattentiveness. This may result in errors in gear shift or unawareness of still driving with lights on full beam. Inattention can also result in abrupt braking as the driver was unaware of the deceleration of a vehicle in front of him (Qu, Ge, Zhang, Zhao, & Zhang, 2015; Taubman-Ben-Ari et al., 2004). (5) Careful driving is characterized by calm driving and safe speed. Murphey et al. (Murphey, Milton, & Kiliaris, 2009) classified calm drivers as drivers who anticipate other road users' movements, traffic lights and speed limits. When the road conditions are perceived to be more dangerous, drivers will adapt their behavior accordingly (Stanton & Marsden, 1996). (6) Distress-reduction driving is characterized by the tendency to be engaged in relaxing activities allowing drivers to reduce stress, for example, listening to music.

Multiple studies have looked into the relation between self-reported driving behavior and actual behavior, both in vehicles and driving simulators. In summarizing the literature, we will report correlations as $r_{vehicle}$ and $r_{simulator}$, indicating whether the correlations between self-reported driving behavior and actual behavior stem from studies employing a vehicle or a driving simulator, respectively. A recent study by Helman and Reed (Helman & Reed, 2014), employing both a vehicle and a driving simulator study, showed significant correlations ranging between .38 and .48 between the Violations scale of the Driver Behavior Questionnaire (DBQ) (Reason et al., 1990) and the driving speed. The findings of their study indicate that the Violations scale of the DBQ has predictive value for the speed choice in both an instrumented vehicle and in a driving simulator. A study conducted by Amado et al. (Amado, Arıkan, Kaça, Koyuncu, & Turkan, 2014) reported significant correlations between the DBQ scale Violations / Errors and observed speed errors ($r_{vehicle}$ = -.24), traffic light errors ($r_{vehicle}$ = -.33), clearance and checking errors ($r_{vehicle}$ = -.18) and brake and gear errors ($r_{vehicle}$ = -.30) reported by an independent expert observer during an on-road driver assessment. Ishibashi et al. (Ishibashi et al., 2007) developed the Driving Style Questionnaire (DSQ) and examined the external validity of the questionnaire through analysis of on-road car-following behavior at low speed. The findings showed a positive relationship between some of the driving style scores resulting from the questionnaire and the use of the gas pedal when decelerating. For example, confidence in driving skill was positively correlated with the use of the gas pedal when driving between 4 – 20 km/h ($r_{vehicle}$ = .59) and when driving between 21 – 40 km/h ($r_{vehicle}$ = .70). West et al. (West, French, Kemp, & Elander, 1993) examined how well characteristics of self-reported behavior related to behavior reported by an observer who sat next to the participants in the vehicle and their results indicated that self-reported speed could be used to replace direct observations of speed. This was indicated for example by positive correlations between self-reported speed and average speed measured on two stretches of the motorway ($r_{vehicle}$ = .55 and $r_{vehicle}$ = .65). Next to speed, their results showed modest significant correlations between self-reports of deviant driving behavior and observer reports of attentiveness and carefulness ($r_{vehicle}$ = .29 and $r_{vehicle}$ = .38, respectively). Taubman-Ben-Ari et al. (Taubman-Ben-Ari, Eherenfreund – Hager, & Prato, 2016) found that risky event rates recorded with an in-vehicle data recorder were correlated significantly with the scores of four driving styles measured by the Multidimensional Driving Style Inventory (MDSI) (Taubman-Ben-Ari et al., 2004), correlating positively with the reckless-careless and the angry-hostile driving styles and negatively with the anxious and the careful-patient styles. Farah et al. (Farah, Bekhor, Polus, & Toledo, 2009) found a correlation between the MDSI score for the hostile driving style and passing gaps ($r_{simulator}$ = -.20) and speed ($r_{simulator}$ = .32) in a driving simulator experiment.

As was mentioned above, differences in driving style typically relate to behaviors such as speeding, traffic light errors/violations, manner of acceleration/deceleration, distance to preceding vehicles, errors in gear shift and abrupt braking due to inattentiveness. For the current research, we focus on measures related to speed and distance, in particular, average speed and speed variability, jerk, deceleration and distance to a preceding vehicle, as these measures (1) can be gained directly from the vehicle and (2) be measured continuously. Further evidence that these measures are indicative of driving style is available from the literature. Average speed, speed variability and faster accelerations and decelerations have been linked to assertive driving, distinguishing assertive drivers from more calm and sustainable drivers (Murphey et al., 2009). Driving at higher speed increases the likelihood of creating dangerous situations and is associated with risky driving. This is often seen as socially unacceptable volitional behavior (Turner, McClure, & Pirozzo, 2004). It should be noted that driving at higher speed may not always be intentional as drivers do not always perceive the road conditions as hazardous and judge the risks lower (Montella et al., 2011). Others may not be aware of the current speed limit and/or the vehicle speed (Young, Regan, Triggs, Jontof-Hutter, & Newstead, 2010). A related measure is jerk, which is defined as the rate of change in acceleration or deceleration, and represents how smooth people drive on straight road segments. Braking more abruptly, accelerating faster and driving more irregularly result in a higher average jerk compared to drivers who decelerate and accelerate more smoothly and maintain a more stable speed. Jerk has shown to be effective in the classification of driving styles (Murphey et al., 2009). Calm drivers tend to anticipate more on other road users' movements and traffic lights, resulting in less abrupt braking (Murphey et al., 2009). Distance to the preceding vehicle has been associated with being annoyed and eagerness to overtake (Lajunen et al., 1998). Lastly, increases in lane position variability are indicative of distracted driving (Just, Keller, & Cynkar, 2008) and may therewith be associated with dissociative driving.

A final question is how to measure driving behavior. In the studies mentioned above, driving behavior was measured either on the road or in a driving simulator. As mentioned in the introduction of the thesis, the use of a driving simulator has several advantages over the use of an instrumented vehicle on public roads (Helman & Reed, 2014). For the reasons given in Chapter 1 of this thesis, we feel justified to use a driving simulator as a valid measurement tool for driving behavior.

On the basis of these considerations, we expect the following relations:

H1: The driving style for careful driving as emerging from a self-report questionnaire will be positively correlated with the distance to a preceding vehicle and negatively correlated with average speed, jerk, deceleration and speed variability as measured in a driving simulator.

H2: People's driving style for angry and risky driving as emerging from a self-report questionnaire will be positively correlated with the average speed, deceleration, jerk and speed variability, and negatively correlated with distance as measured in a driving simulator.

H3: People's driving style for anxious driving as emerging from a self-report questionnaire will be positively correlated with the distance to a preceding vehicle and speed variability as measured in a driving simulator

H4: The driving style for dissociative driving as emerging from a self-report questionnaire will be positively correlated with deceleration and negatively correlated to the distance to a preceding vehicle as measured in a driving simulator.

H5: People's driving style for distress-reduction driving as emerging from a self-report questionnaire will be positively correlated with the average speed and distance to a preceding vehicle as measured in a driving simulator.

In the following, we describe the method and the metrics that are used to characterize driving behavior within a driving simulator, we report the results concerning the agreement between the self-reported driving style and the driving behavior in the driving simulator, draw conclusions and discuss the implications.

Method

The study involved two tasks, filling in the MDSI questionnaire and driving in the driving simulator. Participants were asked to complete the MDSI questionnaire beforehand at home and to subscribe for a timeslot to participate in the driving simulator part of this study. The simulation part took place in the driving simulator located at Eindhoven University of Technology. Participants had to drive in the simulator for half an hour. The driving session was concluded with a brief interview.

Questionnaire

The multidimensional driving style inventory (MDSI) (Taubman-Ben-Ari et al., 2004) is a questionnaire containing statements that should be rated on a unipolar six-point scale ("not at all" to "very much"). In the Dutch version, some of the statements should be rated on a scale of "never" to "always" depending on the meaning of the statement. The questionnaire assesses six factors discussed in chapter two: Angry driving (7 items, Cronbach's alpha .81), Risky driving (5 items, Cronbach's alpha .83), Anxious driving (8 items, Cronbach's .76), Dissociative driving (8 items, Cronbach's alpha .68), Careful driving (4 items, Cronbach's alpha 0.65) and Distress-reduction driving (4 items, Cronbach's alpha .54). The responses of the participants on the relevant scales were averaged through the method of sum scores by factors (Distefano, Zhu, & Mîndrilă, 2009) to create six driving style scores, where a higher score indicates a higher loading for that particular driving style. The MDSI questionnaire was offered in two different languages: English and Dutch.

Next to the questions of the MDSI, the questionnaire also contained questions concerning demographic data such as gender and age and driving history such as the amount of time being in possession of a driver's license and the annual number of kilometers driven.

Driving Simulator

For the simulator part of the study, a medium-fidelity fixed based simulator was used that was designed and manufactured by the Dutch company Green Dino BV (see Figure 3). The simulator consists of a car seat, a Ford steering wheel, indicators, ignition key, pedals, a gear lever and a handbrake. The renderings are visualized on three 32 inch screens and the mirrors and dashboard are part of the 3D renderings. Speed, lane position, deceleration, acceleration, and braking were logged by the simulator at 50 Hertz.

Procedure

After signing the informed consent form participants were asked to take a seat in the driving simulator. Participants completed two familiarization scenarios and the test scenario. The familiarization scenarios took five minutes each and were meant to let the participants familiarize with the simulator dynamics, road environments, and navigation. In the first scenario, participants practiced in an urban area with intersections, traffic lights, pedestrians, etc. to get acquainted with the simulator. The second scenario occurred on the highway to get the participants acquainted with the simulator when driving at higher speeds. Participants were instructed to drive in the simulator as they would normally drive in their own vehicle.

The test scenario was a combination of situations and environments of the familiarization scenarios and took eighteen minutes to complete (see Figure 4). Approximate distance driven in the test scenario was 19 km of which 7.2 km were driven in the urban area. Navigation directions were provided through arrows appearing in the bottom right corner of the middle screen indicating if the participant had to go straight, left or right. In the first part of the scenario participants drove on two-lane urban and industrial roads encountering different speed limits, traffic lights, children crossing the street, other road users, a green wave section and a roundabout. In the second part, participants drove on the highway for about ten minutes until the end of the scenario. The speed limit on the highway was 120 kilometers per hour. The participants encountered dense traffic that resulted in mild traffic jams.

During the sessions, the researcher sat behind a partition monitoring the participant and scenario through a video connection and marked remarkable behaviors in the video recording. These were actions that were unexpected or deviated from normal socially desirable behavior, for example, exceeding the speed limit, driving through amber or red light, not driving in the center of the lane or performing dangerous maneuvers. After the three driving scenarios in the simulator had been completed, a brief interview of around ten minutes was conducted about the participant's driving behavior in relation to his/her behavior in their own vehicle to assess the validity of the participant's behaviors in the driving simulator. This was done by replaying actions that had been marked by the researcher and asking the participant to reflect on these actions by comparing them to 'real-life' situations in which they would drive their own vehicle.

Participants

Participants were invited through a mailing list containing people who had indicated their interest in participating in a driving simulator study during a previous study. Next to the email list, an invitation to participate was also placed on a local website and in a newsletter of a trade union. The invitation consisted of a short explanation of the current study and

Figure 3: Setup Driving Simulator

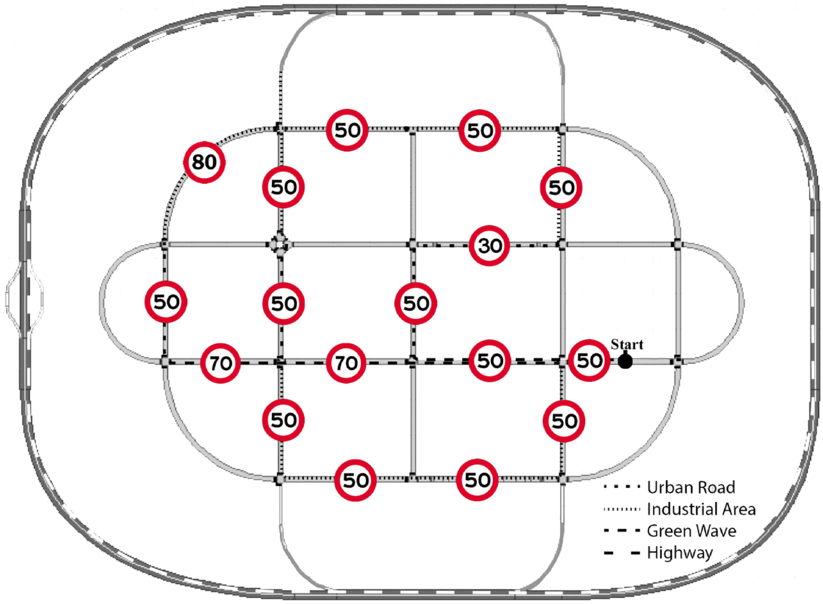


Figure 4: Scenario Driving Simulator

provided a link to fill in the online questionnaire in advance of the simulator study. A second link allowed the participants to choose a suitable timeslot for driving in the driving simulator.

Eighty-eight participants, of which the majority drive mainly in the Netherlands and Belgium, completed the MDSI questionnaire and volunteered to participate in the driving simulator part. Due to simulator sickness, fifteen participants (17%) were not able to complete the simulation part. Fifty-seven males (78.1%) and sixteen females (21.9%) completed the study. The participants were between 18 and 73 years, with a mean age of 48.57 years (SD: 15.32) and possessed a driver's license between 1 and 55 years (mean: 27.21, SD: 14.99) (See Tables 2 and 3). Six participants filled in the English questionnaire. Participants who completed the questionnaire and participated in the driving simulator part received a €7.50 gift voucher.

	Age				Possession License			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Men (n = 57)	50.85	15.184	18	73	29.52	14.971	1	55
Women (n = 16)	40.96	13.445	24	65	19.44	12.591	4	38

Table 2: Means and SD of age and years of possessing a driver's license according to gender

	<1000	1001 – 5000	5001 – 10000	10001 – 20000	20001 –30000	>30000
Men (n = 57)	3	5	7	17	13	12
Women (n = 16)	4	2	3	7	-	-

Table 3: Frequencies Annual Km

Data Collection

Raw behavior data were retrieved from the simulator and used for calculating driving behavior scores representing how well each participant drove, taking into consideration the speed on different road segments, speed variation, the average jerk, average deceleration, lateral position, and distance to preceding vehicles. Sampling frequency was 50 Hz.

The test scenario was divided into four different road segments; 30 km/h, 50 km/h, 70 km/h (a green wave section) and 120 km/h (the highway) (see Figure 4). For each of the different road segments the average speed in km/h and the standard deviation of the speed in km/h when driving on straight segments, the average jerk in m/s^3 , the lateral position and the standard deviation, average deceleration and the distance to preceding vehicles in meters were calculated per participant. The acceleration and deceleration at the beginning and end of each straight road segment were incorporated in the calculation of the average speed and the standard deviation of speed.

The average jerk was calculated to determine to which extent the speed of the participants varied while driving on straight road segments. The jerk (see Formula 1) is the derivative of the acceleration measured by the simulator. The mean jerk scores were calculated separately for the four different road segments.

$$\text{Jerk } (m/s^2) = (\Sigma(\text{Acceleration } (t) - \text{Acceleration}(t-1)/0.05) \ / \ (n-1) \quad (1)$$

In this study, the deceleration was recorded instead of the braking behavior. For each deceleration interval, the maximum deceleration in m/s^2 was calculated, and the mean and standard deviation of the maximum decelerations were calculated across participants. The rationale for taking deceleration behavior instead of braking behavior as a behavioral index was as follows. A careful driver may decelerate more smoothly compared to a more risky driver by just releasing the gas pedal and letting the vehicle roll, and pressing the brake pedal gently to come to a standstill. A risky driver is expected to continue driving at a high speed, so that s/he has to brake harshly at the end and therefore exhibits a stronger deceleration for a shorter moment of time.

	Mean	SD	Min	Max
Average Speed 30km (km/h)	27.32	4.53	16.25	35.92
Average Speed 50km (km/h)	38.71	3.92	30.90	47.81
Average Speed 70km (km/h)	48.63	8.97	26.41	71.59
Average Speed 120km (km/h)	108.56	6.46	87.19	124.16
SD Speed 30km (km/h)	10.09	2.68	4.59	18.54
SD Speed 50km (km/h)	16.06	2.42	11.09	24.49
SD Speed 70km (km/h)	17.13	3.76	6.44	29.81
SD Speed 120km (km/h)	13.25	5.43	4.36	39.83
Average Jerk 30km (m/s^3)	1.70	0.57	0.79	3.83
Average Jerk 50km (m/s^3)	1.50	0.33	0.93	2.46
Average Jerk 70km (m/s^3)	1.88	0.67	0.84	4.30
Average Jerk 120km (m/s^3)	0.53	0.15	0.28	0.94
Average Lateral Position	0.19	0.04	0.09	0.30
SD Lateral Position	0.14	0.03	0.09	0.19
Average Deceleration (m/s^2)	-4.45	0.95	-2.98	-1.09
SD Deceleration (m/s^2)	1.57	0.32	0.77	2.26
Distance 30km (m) (N = 71)	66.72	60.69	4.49	292.45
Distance 50km (m) (N = 73)	73.33	31.27	20.12	161.54
Distance 70km (m) (N = 50)	147.20	88.17	20.16	292.06
Distance 120km (m) (N = 73)	88.50	22.39	47.77	156.31
Angry	2.06	0.73	1.00	3.86
Risky	1.70	0.85	1.00	4.60
Anxious	1.47	0.58	0.50	3.00
Dissociative	1.55	0.40	1.00	2.63
Careful	4.43	0.97	1.75	6.00
Distress-Reduction	1.98	0.71	1.00	4.25

Table 4: Mean, Standard Deviations, Min and Max scores for behavioral measures (top) and driving style scores as resulting from the MDSI (bottom).

Lateral position in the lane was mapped onto a scale from -0.5 to +0.5. Driving in the middle of the lane corresponds to a value of zero, driving fully to the right gives a value of -0.5 and driving fully to the left gives a value of 0.5, measured from the center of the vehicle. The mean of the absolute values of the lateral position and the standard deviation of the average position were calculated. Different distance scores were calculated separately for the four different road segments. The distance scores represented the average distance in meters that participants maintained towards a preceding vehicle when driving in the simulator. Note that there is diversity in the number of participants who received a score for the average distance to a preceding vehicle. As participants differed in driving behavior not all participants had a preceding vehicle when driving in one or more of the four different road segments. This resulted in a lower number of participants included in the analysis of distance to preceding vehicles for the road segments with a 30 km/h and 70 km/h speed limit (See tables 4 and 5).

Results and Discussion

Table 4 shows the means and standard deviations of the scores resulting from the measured variables, as well as the means, standard deviations, and ranges for the driving style scores.

Table 5 shows the correlations between the driving style scores as resulting from the MDSI and age and gender. Scores for Anxious, Dissociative, and Distress-reduction are negatively correlated with Age, and the score for Careful is positively correlated with age, meaning that older drivers tend to have higher scores for Careful driving and lower scores for Anxious, Dissociative and Distress-reduction driving. Scores for Angry and Risky are negatively correlated with gender, and scores for Anxious and Dissociative are positively correlated with gender, meaning that male drivers tend to have higher scores for Angry and Risky driving and that female drivers tend to have higher scores for Anxious and Dissociative driving. These results should be interpreted with caution due to the small sample size in combination with the wide age-range and the unequal distribution of gender.

	Angry	**Risky**	**Anxious**	**Dissociative**	**Careful**	**Distress-Reduction**
Age	-.018	-.197	-.312**	-.385**	.240*	-.461**
Gender	-.293*	-.300**	.377**	.330**	.115	.119

*: p<0.05 **: p<0.01

Table 5: Correlation Coefficients between the driving styles and age and gender

As shown in Table 6, some of the driving behavior scores showed a significant correlation

	Angry	Risky	Anxious	Dissociative	Careful	Distress-Reduction	Age	Gender
Average Speed 30km (km/h)	.172	.264*	.080	.163	-.281*	-.026	-.114	.009
Average Speed 50km (km/h)	.001	.170	.022	.124	-.309**	.044	-.399**	.078
Average Speed 70km (km/h)	.053	.263*	-.137	-.010	-.152	.153	-.272*	-.036
Average Speed 120km (km/h)	.018	.168	-.188	-.078	-.257*	.148	-.298*	.060
SD Speed 30km (km/h)	.032	.109	.166	.029	-.169	-.091	.061	.325*
SD Speed 50km (km/h)	.221	.114	.147	.124	-.146	.105	-.085	.112
SD Speed 70km (km/h)	.004	-.104	.205	.270*	.022	-.037	-.049	.164
SD Speed 120km (km/h)	.253*	.234*	.154	.115	-.191	.011	.032	.086
Average Jerk 30km (m/s^3)	-.138	.091	.141	.018	-.082	-.113	.037	.243*
Average Jerk 50km (m/s^3)	.024	.044	.071	.053	.056	-.022	.103	.255*
Average Jerk 70km (m/s^3)	-.141	-.153	.246*	.086	.075	.021	.053	.160
Average Jerk 120km (m/s^3)	-.012	.108	-.048	.017	-.095	-.091	-.033	.310**
Average Lateral Position	.014	.134	-.160	.061	-.237*	-.008	-.131	.187
SD Lateral Position	.226	.305**	-.092	.165	-.302**	.072	-.302**	.058
Average Deceleration (m/s^2)	-.155	-.063	-.164	-.258*	.129	-.040	.108	-.276*
SD Deceleration (m/s^2)	-.112	-.025	.047	.091	-.098	-.158	.165	.132
Distance 30km (m) (N = 71)	.135	-.065	.112	-0.46	.068	-0.55	-.001	-.098
Distance 50km (m) (N = 73)	-.054	-0.65	-.011	.083	-.011	-.034	.046	.047
Distance 70km (m) (N = 50)	.049	.224	.184	-.050	-.193	.193	-.109	-.031
Distance 120km (m) (N = 73)	-.256*	-.193	.156	-.098	.294*	.117	.118	-.073

*: $p<0.05$ **: $p<0.01$

Table 6: Correlation Coefficients between the driving styles and the different driving behaviour scores

with either age or gender. The results showed significant negative correlations between age and the average speed on roads with a speed limit of 50 km/h (r=-.399), 70 km/h (r=-.272) and 120 km/h (r=-.298), and the standard deviation of the lateral position of the vehicle (r = -.302). This means that overall older people tend to have a lower average speed and less variation of their position within the lane. Gender correlates significantly with the average jerk on roads with a speed limit of 30 km/h (r=.243), 50 km/h (r=.255) and 120 km/h (r=.310), and with average deceleration (r = -.276). This means that men tend to have lower variation in their speed and decelerate faster. Finally, as can be seen from Table 5, the pattern of correlations is not homogeneous. For instance, average speed at 50, 70 and 120 km/h correlate well with age, but the average speed at 30 km/h does not. Likewise, average jerk at 30, 50 and 120 km/h correlate well with gender, but the average speed at 70 km/h does not.

To check whether the effects of driving style can be fully attributed to differences in age and gender or whether driving styles have an effect by themselves, partial correlations were calculated between the driving behavior scores and driving style scores, controlling for age and gender. There was a significant correlation between the score of the Careful driving style and the average speed on roads with a speed limit of 30 km/h (r = -.281), 50 km/h (r = -.309) and 120 km/h (r = -.257), the average and standard deviation of the lateral position of the vehicle (r = -.237, r = -.302, respectively) and the distance to preceding vehicles on the highway (r = .294). When controlling for age and gender all the correlations were still significant, the average speed on roads with a speed limit of 30 km/h (r = -.262), 50 km/h (r = -.243), 120 km/h (r = -.199), the average and standard deviation of the lateral position of the vehicle (r = -.254, r = -.248, respectively) and the distance to preceding vehicles on the highway (r = .293). This means that drivers who had a higher score for the Careful driving style score had a lower average speed on roads with a speed limit of 30 km/h, 50 km/h, and 120 km/h. Next to having a lower average speed, these drivers also drove more towards the center of the lane and showed less variation in their lateral position. Finally, drivers who scored higher on the Careful driving style score maintained a longer distance to preceding vehicles on the highway. These findings are in line with Hypothesis 1, stating that self-reported careful driving style correlates positively with distance and negatively with average speed. However, the parts of Hypothesis 1 stating that self-reported careful driving correlates negatively with deceleration, jerk and speed variability were not confirmed.

The Angry driving style score showed significant correlations with the standard deviation of speed driven on the highway and the distance to preceding vehicles on the highway, r =

.253 and r = -.256, respectively. When controlling for age and gender the correlations found were still significant, r = .300 and r = -.283, respectively. This means that drivers who had a higher score for the Angry driving style had a higher variation in their speed when driving on the highway. Also, they maintained a shorter distance to preceding vehicles on the highway. These findings are in line with Hypothesis 2, stating that self-reported angry driving style correlates positively with speed variability and negatively with distance. However, the parts of Hypothesis 2 stating that self-reported angry driving correlates positively with average speed, deceleration and jerk were not confirmed.

There was a significant relationship between the score of the Risky driving style and the average speed driven on roads with a speed limit of 30 km/h (r = .264), the average speed driven on roads with a speed limit of 70 km/h (r = .263), the standard deviation of speed driven on the highway (r = .234) and the standard deviation of the lateral position of the vehicle (r = .305). When controlling for age and gender, significant correlations were still found for average speed driven on roads with a speed limit of 30 km/h (r = .238), the standard deviation of speed driven on the highway (r = .299) and the standard deviation of the lateral position of the vehicle (r = -.277). This means that drivers who scored higher on the Risky driving style scale had a higher average speed on roads with speed limit of 30 km/h. Similar to drivers who scored higher for Angry driving, riskier drivers varied more in their speed when driving on the highway. Lastly, a higher score for risky driving style correlates with variation in lateral position while driving. Controlling for age and gender, the correlation between the score of the Risky driving style and the average speed driven on roads with a speed limit of 70 km/h was no longer significant, indicating that this relation is strongly influenced by age and gender. These findings are in line with Hypothesis 2, stating that self-reported risky driving style correlates positively with speed variability, specifically on the highway. However, the parts of Hypothesis 2 stating that self-reported risky driving correlates positively with an average speed in general, deceleration, and jerk and negatively with distance were not confirmed.

The score of the Anxious driving style was significantly correlated with the average jerk when driving in the green wave segment with a maximum speed of 70 km/h, r = .246. When controlling this relation for age and gender the correlation was still significant, r = .231. This means that drivers who reported themselves as more anxious drivers had a higher variation in their speed when driving on the green wave segment with a maximum speed of 70 km/h. However, no correlations were found between self-reported anxious driving style and distance to a preceding vehicle as well as speed variability. Thus Hypothesis 3 is not supported by these results.

The Dissociative driving style score was significantly correlated with the standard deviation of the speed when driving on the green wave segment with a maximum speed of 70 km/h and the average deceleration, r = .270 and r = -.258, respectively. When controlling for age and gender the standard deviation of the speed when driving on roads with a green wave was still significant, r = .229. This means that drivers who had a higher score for the Dissociative driving style had a higher variation in their speed when driving in the green wave segment with a maximum speed of 70 km/h. When controlling for age and gender the correlating between the Dissociative driving style score and the average deceleration was no longer significant indicating that these correlations are strongly influenced by age and gender. However, no correlations were found between self-reported dissociative driving style and deceleration as well as distance to a preceding vehicle. Thus Hypothesis 4 is not supported by these results.

Lastly, the score of the Distress-Reduction driving style did not show any significant correlation with one of the driving behavioral scores. This means that Hypothesis 5 is not confirmed. Sagberg et al. (Sagberg, Selpi, Piccinini, & Engström, 2015) mentioned that for the MDSI they do not count all the factors of the MDSI as driving styles as by their definition, the anxious and distress-reduction categories refer more to the emotional states of the drivers rather their driving behavior.

General Discussion

The pattern of findings emerging from the current study is in line with the findings from the literature (Amado et al., 2014; Farah et al., 2009; Helman & Reed, 2014; Taubman-Ben-Ari et al., 2016; West et al., 1993) showing significant correlations between people's self-reported driving style scores and their driving behavior in a driving simulator. Given the relatively small sample size in combination with the wide age-range and the unequal distribution of gender, the modest but significant correlations found in this study are encouraging. This supports the idea that the outcomes of the Multidimensional Driving Style Inventory (MDSI) have predictive value of driving behavior in a simulator. However, some of the studies reported in the literature show higher correlations than the ones obtained in the current study. For these, it should be noted that they made use of self-reports of actual behavior, using questions like, "do you break the speed limit" or "do you keep sufficient distance to preceding vehicles without minding another car cutting in". On the other hand, the MDSI questionnaire used in this study focuses more on preferences for driving behavior, asking, for example, to what extent you like to take risks while driving. There are two ways how this may affect the correlations between self-report data and the driving behavior in a simulator. In the first place, people may have different interpretations of what is risky behavior. In addition, the fact that people indicate a higher appreciation for taking risks does not necessarily mean that they actually engage in risk-taking behavior. Overall the questions within the MDSI questionnaire vary between specific moments as “When a traffic light turns green and the car in front of me doesn’t get going, I wait for a while until it moves” and general statements like “Drive cautiously”. Furthermore, the test scenario was chosen such that it covered a representative range of the situations that were addressed in the MDSI questionnaire. However, this may also have influenced the results, as including a wider range of situations may cause more variation in behavior compared to including one specific situation, and lower the correlations. It may, therefore, be of interest to see what the results will be when the questionnaire is used in a specific environment, for example, the highway and adapted for this specific environment.

The results concerning the association between driving behavior scores and age and gender are in line with those reported in the literature deploying self-report methods. An increase in age is associated with a decrease in average speed as measured from behavior and with a higher score for self-reported careful driving (Starkey & Isler, 2016; Taubman-Ben-Ari et al., 2004). Also, male behavior shows steeper deceleration, which is compatible with the finding that men score higher on risky driving in self-report questionnaires (Starkey & Isler, 2016), while female behavior shows more variation in speed, which is compatible with the finding that women score higher for anxious driving in self-report questionnaires (Gwyther & Holland, 2012).

For reasons explained in the Introduction of this thesis, this study was conducted in a driving simulator, and this may have affected the results. More specifically, the driving behavior in a driving simulator may be different from actual driving behavior on the road. The interviews held after the participants drove in the simulator revealed that driving in a simulator was experienced as less realistic in some respects compared to driving on the road. Multiple participants mentioned that, when they drive in their own vehicle, they rely more on the feel and sound of the vehicle to judge the speed instead of closely monitoring the dashboard and gears. The simulator used is a fixed based simulator that provides no proprioceptive feedback about acceleration, deceleration and lateral movement. Most participants mentioned that having no proprioceptive feedback of acceleration, deceleration and lateral movement makes the driving experience less realistic and as a consequence, makes some of the driving tasks such as taking turns more difficult. During the observations, it was already noticed that most participants experienced more difficulty with taking a correct turn and it was decided not to use the data of these parts in the analyses of the data. Participants tended to steer too fast and abrupt when turning left or right and by correcting their steering wheel too abruptly they lost the control over the vehicle for a short moment in time resulting in a short increase of steering corrections. The lack of proprioceptive feedback when accelerating or decelerating also resulted in participants often accelerating faster than they realized, sometimes causing participants to drive at a higher speed than allowed and preferred. Participants also did not always notice that the vehicle was decelerating when braking; resulting in more abrupt braking behavior or participants taking their foot off the gas pedal to let the vehicle decelerate far in advance of intersections in comparison with driving in their own vehicle. In this interpretation, the modest correlations between self-reported driving style and the driving behavior obtained in this study are due to the fact that driving in a simulator produces atypical behavior, and therewith underestimate the correlations that might be observed in real life. However, as stated before, the correlations obtained in the current study are not much lower than those reported for behavior observed in real-life contexts.

Alternatively, the modest correlations between driving styles and driving behavior in the driving simulator, as well as the inconsistencies in the pattern of correlations with age and gender may indicate that other factors in addition to driving style, age and gender determine the behavior of drivers in a driving simulator. To some extent, this may be due to random variation, but to some extent, the differences may also be accounted for in terms of contextual variation. For instance, while average speed at 50, 70 and 120 km/h shows negative correlations with age, average speed in areas with a 30 km/h limit does not. Possibly, the 30 km/h context neutralizes the effect of age. Similar observations on the effect of context can be made for self-report studies. Thus, the driving environment, traffic conditions, and the driver's conditions may also influence driver's behavior (Constantinescu et al., 2010). Furthermore, driving behavior may be determined by someone's goals and motives, as they determine what behavior and driving style is considered justifiable (Summala, 1997). These goals and motives may change according to dynamically changing situations and environments. For instance, a study about the influence of multiple goals on driving behavior (Dogan, Steg, & Delhomme, 2011) revealed that in urban areas people prioritize safety as the traffic environment is more complex compared to highways where time is more often prioritized as a driving goal. Driving behavior should maybe not be seen as static behavior, but as behavior that evolves over time and context (Bekiaris et al., 2003) according to the goals and motives, therewith complicating the direct relation between self-reported and driving behavior.

Finally, it should be kept in mind that questionnaires may be sensitive to biases such as social desirability or overestimating one's own skills compared to the skills of other drivers (Delhomme, 1991; Freund, Colgrove, Burke, & McLeod, 2005).

Conclusion

The results of this study show significant correlations between the driving styles scores retrieved from the Multidimensional Driving Style Inventory (MDSI) questionnaire and several behavioral scores derived from driving behavior in the driving simulator. Modest but significant correlations were found between self-reported careful driving and speed in the simulator on road segments with a speed limit of 30 km/h, 50 km/h and 120 km/h, the average and standard deviation of the lateral position of the vehicle and the distance to preceding vehicles on the highway. These findings are in line with Hypothesis 1, stating that a self-reported careful driving style is positively correlated with the distance to a preceding vehicle and negatively correlated with average speed. Furthermore, the results show modest but significant correlations between self-reported risky driving and the average speed driven in the simulator on roads with a speed limit of 30 km/h, the standard deviation of speed driven on the highway and the standard deviation of the lateral position of the vehicle. In addition, self-reported scores for angry driving show modest but significant correlations with the standard deviation of the speed driven on the highway and the distance to preceding vehicles on the highway. Both findings are in line with Hypothesis 2, stating that self-reported angry and risky driving styles correlate positively with speed variability and negatively with distance, specifically on the highway. On the other hand, the parts of Hypothesis 2 stating that self-reported angry driving correlates positively with average speed, deceleration, and jerk, and that self-reported risky driving correlates positively with an average speed in general, deceleration, jerk and negatively with distance were not confirmed. Hypotheses 3, 4 and 5 concerning anxious, dissociative and distress-reduction driving were not supported by the results of this study. So, while we find evidence that self-reported driving style correlates with actual driving behavior in a driving simulator for careful, risky and angry driving, we do not find evidence that self-reported anxious, dissociative and distress-reduction driving styles correlate with driving behavior in a driving simulator.

Both this and the previous chapter are a first step towards personalized persuasion. Ultimately, the hypothesis is that strategies for persuading people to accept and comply with advice and actions of an automated driving system can be made more effective if they are tuned to the driving styles of individual people. In real life contexts, the driving style of people needs to be inferred from actual driving behavior. In order to evaluate our hypothesis, we began with conducting studies with a driving simulator. For such studies, people's driving style is usually determined on the basis of their response to a driving style questionnaire. The first question is then whether there is a good correlation between people's response to a driving style questionnaire and their driving behavior in a simulator. If so, the practice of using a questionnaire to identify people's driving style is justified. Therefore, the current study was conducted to investigate whether the MDSI questionnaire, which classifies drivers in terms of six different driving styles (Angry, Risky, Anxious, Dissociative, Careful and Distress-Reduction), can be used to predict driving behavior. The results of the current study are overall in line with results from previous studies that have been conducted in vehicles and driving simulators, indicating that the outcomes of the MDSI have predictive value of driving behavior in a simulator.

It is concluded that the results from a driving style questionnaire may be used to get an indication of people's typical driving behavior in a driving simulator. The correlations between the self-reported driving style obtained from the questionnaire and the driving behavior in the driving simulator are modest and limited to some driving styles but in line with previous research. This indicates that the MDSI may be used as a diagnostic tool for identifying the typical driving behavior of individual people along a number of dimensions within a driving simulator.

However, using the MDSI to compose different groups of participants on the basis of their MDSI scores may lead to a large number of groups as the score of all factors combined determines what type of driver someone is. This is unworkable when the aim is to investigate the effect of personalized persuasion in vehicles. The MDSI may not be the best tool for the purpose of classifying drivers. The use of personas may be a more suitable method for classify drivers, providing a smaller amount of groups compared to the MDSI. The next chapter will investigate the possibility to make use of personas as a tool to categorize drivers and keep the number of groups small.

Part 2

4

Increasing the Acceptance of ADS by Making Use of Driver Profiles

Abstract

Differences in preferred driving behavior between drivers may influence their willingness to make use of intelligent systems in vehicles. Personas are a common way to capture differences between people and can be used as a tool for identifying typical driving behavior of people. This study aims at the validation of eight personas that were created according to a three-dimensional model capturing differences between drivers. A survey was conducted with 202 respondents who indicated for each persona how much they recognized themselves in that persona. With respect to the validation of the framework, it was found that the more characteristics personas have in common the higher the correlation, as well as that the results show that all personas are at least selected by some participants. These findings indicate that the framework is a valid basis for generating driver personas and that it may be used as a tool to categorize drivers in future studies.

Introduction

As mentioned before, ADAS and ADS are developed to support or automate one or multiple driving tasks to improve safety, efficiency, and comfort. For example, a Blind Spot Warning system alerts the driver when other vehicles are in the blind spot of the car, Intelligent Speed Advice advises the driver to adjust the speed, Advanced Emergency Braking System detects an imminent crash and acts accordingly, and an autopilot may control both lateral and longitudinal position of the vehicle. However, the driver has the possibility to ignore an advice or, in the case of an ADS, to regain control of the vehicle when the behavior of the vehicle deviates from the preferred behavior. Therefore, the willingness to comply with the advice of an ADAS or to accept the behavior displayed by an ADS is a crucial factor for the intended effects of such systems to materialize. To the extent that people do not comply with an ADAS advice or do not accept the behavior of an ADS, developers need to understand why people might not comply with an advice or accept the behavior and think about how to increase the driver's willingness to do so.

Factors that govern the willingness to accept an ADAS advice or the behavior of an ADS may relate to the situation or the driver. With respect to the situation, a certain advice or behavior may not be suitable for a specific situation. Here, developers need to make the advice or behavior more situationally appropriate or allow for exceptions (e.g. in the case of a driver being in a hurry to the hospital because his wife is about to give birth). With respect to the driver, differences between drivers such as driving style may affect the extent to which people's driving style reflects people's willingness to accept such automated constraints as well as the extent to which the behavior of an ADS meets the needs and interests of the driver. Here, developers may turn to persuasive technology to increase the driver's willingness to accept the ADS behavior.

When turning to persuasive technology, it is important to note that what might influence one person may not work at all for someone else. To the extent that advice or assistance of intelligent systems in vehicles requires drivers to deviate from their own way of driving, the use of intelligent systems may be jeopardized. For example, if an advice is given to reduce the speed, a driver who normally drives at higher speeds will perhaps neglect this advice as it is not in line with his or her typical driving behavior. This means that the persuasive strategies need to be personalized to different types of drivers. Understanding the differences in interests, motivations, and needs of different people and designing for these differences may increase the success of a product (Lindgren, Chen, Amdahl, & Chaikiat, 2007). Personas are a useful method to create an understanding of these differences as personas are hypothetical archetypes of real users that describe the needs, interests, and motivations of users in more detail (Lindgren et al., 2007). The idea behind the use of personas is that it is easier for people identify themselves with one of the personas as personas are based on characteristics and descriptions of real users.

The aim is to explore the design potential for in-car applications to increase the overall acceptance of intelligent systems by different types of drivers through the use of more personalized persuasive technologies. The exploration of the use of personalized persuasive technologies for in-car applications to increase the overall acceptance of intelligent systems is done through the creation and validation of a framework and the resulting personas. If successful, the personas can be used as a tool to categorize drivers and investigate the effect of personalized persuasive strategies that are developed with the aim to encourage the use of ADS by different types of drivers.

Related Work

Persuasive Technologies

Persuasive technologies are developed with the aim to change the attitude or behavior of users without coercion or deception. These technologies aim at behavior or attitude change through persuasion and social influence (Fogg, 2003).

Persuasion systems in vehicles can be roughly divided into two groups, systems that are permanently integrated in vehicles and systems designed as applications for mobile phones (Schätzl, 2015). In the context of automotive, the most known studied and developed persuasive technologies aim at eco-driving (Jamson, Hibberd, & Merat, 2015; Meschtscherjakov, Wilfinger, Scherndl, & Tscheligi, 2009). These systems may support reducing costs, increasing efficiency and provide additional information to encourage eco-efficient decisions (Schätzl, 2015). These systems provide different types of real-time feedback according to the current driving behavior, for example, showing a reduction in fuel consumption when using one of those systems that persuade the driver to change gear at low RPM or to accelerate less aggressively.

Most studies about persuasive technologies focus on a single, ‘one size fits all’ strategy or design that does not aim at a specific user group. However, it has been shown that tailored, more personalized persuasion is more effective in motivating behavior change (Kaptein et al., 2012). For example, Kaptein (Kaptein et al., 2012) showed that personalized persuasion may be made more effective in motivating behavior change by creating tailored persuasive messages to influence people’s behavior that deploys the strategies defined by

Cialdini (Cialdini, 2001). Cialdini identified six influence principles: reciprocity, consistency and commitment, social proof, liking, authority, and scarcity. These strategies are based on human preferences for automatic, shortcut responses to messages. For example, some people are more inclined to act on a request when they have to pay back a favor, others are more inclined when asked by an authority figure. The work of Kaptein (Kaptein, 2012) and Cialdini (Cialdini, 2001) is mostly aimed at marketing. The question arises how personalized persuasion can be used within the context of automotive. One way to personalize persuasion in the context of automotive is to look at people's driving style.

Driving Styles

Patterns of typical driving behavioral or the way a driver prefers to drive are usually referred to by the term 'driving style' (Ishibashi et al., 2007). This includes the choice of driving speed, headway, overtaking of other vehicles, the tendency to commit traffic violations, attentiveness and assertiveness while driving (Elander et al., 1993; West & Hall, 1997). Chapter 2 reviewed different questionnaires to determine a person's driving style. Using the MDSI, six driving styles could be identified: Angry, Risky, Anxious, Dissociative, Careful and Distress-Reduction driving style. Depending on the driving styles, specific approaches and strategies may be explored to influence driving behavior. One of the conclusions of the study described in Chapter 2 was that from a behavioral perspective the driving styles Risky and Careful can be considered as opposites. In the remainder of this chapter, the focus will be on these two driving styles.

Risky driving denotes more dangerous and thrill-seeking behavior. It is characterized by higher speeds and the excitement of driving and is often seen as socially unacceptable volitional behavior (Turner et al., 2004). This does not always mean that the law is broken but it increases the likelihood of creating dangerous situations. Drivers try to adapt their driving behavior to reach an optimum in risk/fear or task difficulty (Lewis-Evans & Rothengatter, 2009), and this optimum will be shifted towards taking more risk for risky drivers, compared to more careful drivers. Drivers may also show risky behavior intentionally for the thrill and sensation as a part of their attitude towards taking risks (Hatfield & Fernandes, 2009), or to give in to peer influence (Scott-Parker, Watson, & King, 2009) or the belief that it will save time.

Careful driving denotes sustainable and safe driving behavior and is characterized by more cautious behavior, keeping speed within the safety boundaries and preferring not to exceed the speed limit (Eboli, Mazzulla, & Pungillo, 2016). People who drive carefully often refer to the motto "better safe than sorry". Thus, careful drivers prefer to know what is happening in and outside the vehicle, resulting in a high situation awareness to maintain compliance with the traffic rules and plan ahead (Taubman-Ben-Ari & Yehiel, 2012). Calm drivers as classified by Murphey et al. (Murphey et al., 2009) anticipate other road users' movements, traffic lights, and speed limits. When the road conditions are perceived to be more dangerous, drivers will adapt their behavior being more cautious (Stanton & Marsden, 1996).

Framework

A noticeable difference between careful and risky drivers is the driving speed, as risky drivers tend to drive at or faster than the maximum speed, while careful drivers tend to drive below the maximum speed, being more cautious and sustainable while driving. As mentioned in Chapter 2, the driving styles Risky and Careful can be considered as opposites from a behavioral perspective. Another aspect to analyze the difference between risky and careful drivers relates to whether drivers are aware of the consequences of their driving behavior or not, and whether the consequences are intended or a by-product of their way of driving. Young et al. (Young et al., 2010) mentioned that drivers may speed for a variety of reasons. Some drivers may show intentionally risky behavior like speeding for the thrill and sensation or to save time [aware]. Where others may underestimate the risks of their behavior in terms of an increased risk of accidents (Hatfield & Fernandes, 2009) when showing off their presumed mastery in handling difficult situations or due to inattention (Qu et al., 2015) [unaware]. Likewise, for careful drivers, drivers may drive carefully intentionally, to reduce the risk of accidents or they enjoy driving in a calm and relaxed way [aware], while other drivers are less confident when driving (Lajunen & Summala, 1995) [unaware]. The dimension of awareness of the consequences can be placed perpendicular to the dimension of careful versus risky driving. Lastly, the behavior can occur through intrinsic (personality) or extrinsic motivations (goals or distractions). As people differ in needs and interests, they also vary in how much someone is motivated and the orientation of their motivation (Ryan & Deci, 2000). With respect to the orientation of the motivation, often two types of motivations are distinguished, intrinsic motivation and extrinsic motivation (Davis, Bagozzi, & Warshaw, 1992; Ryan & Deci, 2000). Intrinsic motivation refers to behavior that is encouraged through internal rewards, doing it for its inherent satisfaction as an enjoyable or interesting experience (Ryan & Deci, 2000), for example enjoying the thrill accompanied with speeding or the relaxing experience when driving sustainable. In contrast, extrinsic motivation refers to behavior that is encouraged through external rewards, goals or punishments as saving time or money, or counteracting boredom by performing secondary tasks. When external rewards, goals or punishment, used to motivate people to perform a certain behavior, will come to an end, it is expected that the encouraged behavior will also be less likely to occur. Thus, extrinsic motivation leads to less endurable behavior.

Thus, the difference between risky and careful drivers can be analyzed from different perspectives: the behavior, knowing the consequences of the behavior and the motivation of the behavior. Combining these perspectives results in eight different spaces within the framework characterizing eight different types of drivers (See Figure 5). In the following, the framework will be explained through personas created for each space.

Personas

To create a foundation for the development of the different personas three methods were used, semi-structured interviews, a brainstorm session and discussions of the personas created by Lindgren et al. (Lindgren et al., 2007). The data of semi-structured interviews that were conducted posterior to driving in the driving simulator during a study aiming to investigate the relation between drivers' self-reported driving style and driving behavior (See Chapter 3). These interviews provided us with insights of seventy-three participants between the ages of 18 and 73 years, with a mean age of 48.57 years (SD = 15.32), all possessing a driver's license. The purpose of these interviews was to gather more insight into the drivers' attitudes, styles, and motivations, by discussing their behavior in the driving simulator in comparison with their behavior when driving in their own vehicle. The interviews took around five to ten minutes and were audio recorded with the participants' approval. The answers were transcribed and subjected to thematic analysis by means of affinity diagramming (Martin & Hanington, 2012): The different statements provided by the participants were repeatedly clustered by the authors based on similarity and the resulting clusters were labeled as themes. Some of the themes resulted from the Affinity Diagram are mentioned in Table 7.

Speeding	Maintain safe speed	Decent driver
Frustration	Anticipating	Insecure
Inattentiveness	Driver support systems	Efficiency
Safety	Assertive driving	Joy of driving

Table 7: Themes emerging from the Affinity Diagram

Next to these semi-structured interviews, a brainstorm session was held among several colleagues with various backgrounds as psychology, mechanical engineering, and design.

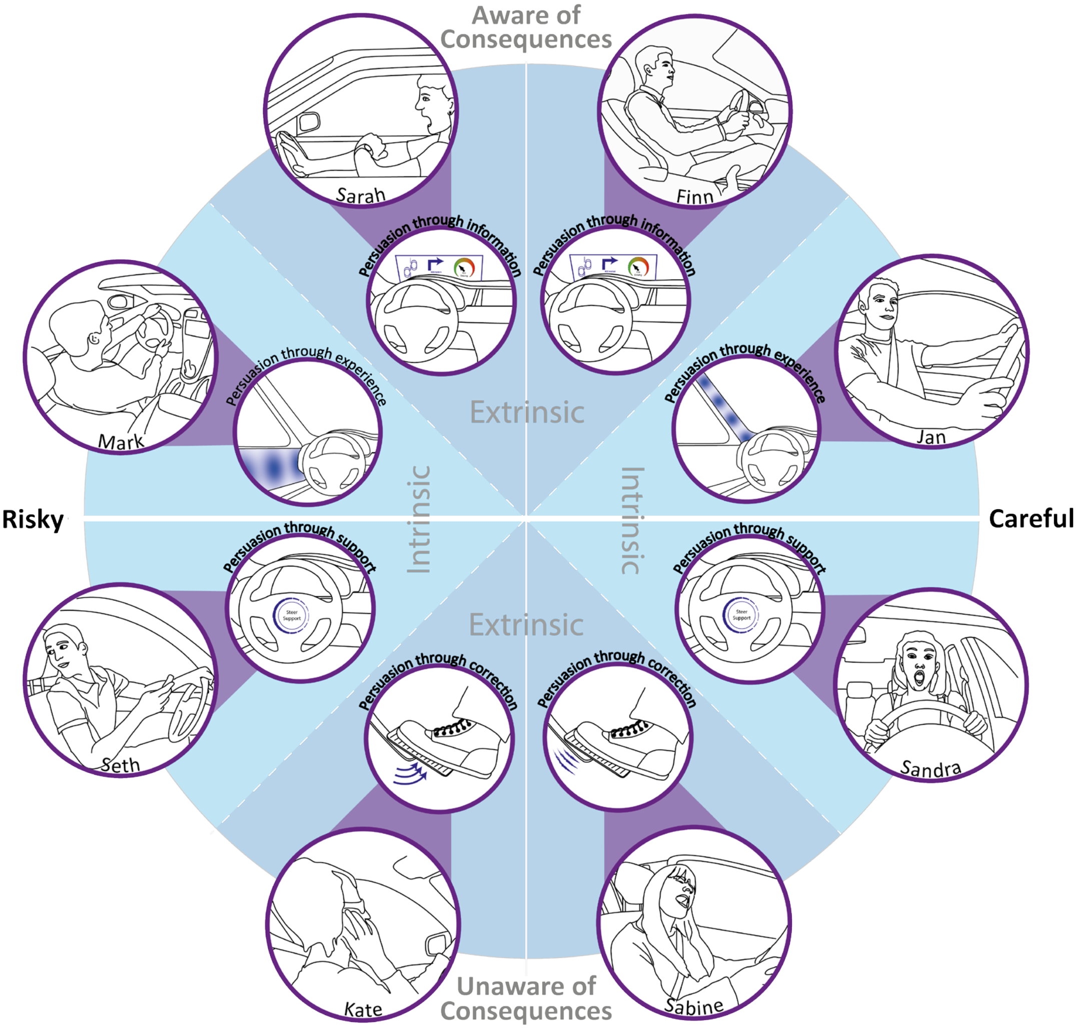


Figure 5: Framework of Risky and Careful Driving Styles

The aim of the brainstorm was to get a grip on the characteristics of different driving styles and the different needs and motives of people with different styles. Lastly, some discussions were held about the results of the previous two parts and the personas created by Lindgren et al. (Lindgren et al., 2007). The results of the different parts were used as a foundation for the development of eight different personas filling the eight different spaces of the framework. The following paragraphs present the eight personas. For each persona, two versions were created, a male and a female version. Below, the male versions are given. In the female versions, the male first name was replaced by a female first name and the pronouns were adjusted accordingly.

Finn / Lotte (careful, aware and extrinsically motivated)

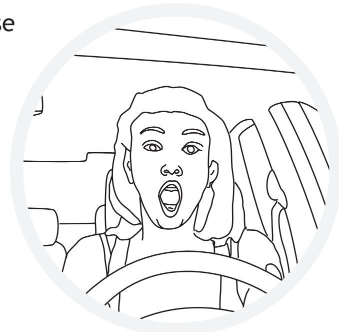
Finn spends quite some time in his vehicle while at work. Driving is not the main part of his work, however, it consumes quite some of his time. The number of hours Finn spends on the road makes him feel quite confident about his driving and for him it has become a sport to minimize the amount of fuel consumed when driving. Therefore he often drives below the speed limit. He finds technology that supports this way of driving very convenient, and when he buys a new vehicle he is always interested in innovations in the area of intelligent systems that support fuel efficiency when driving.

Jan / Kelly (careful, aware and intrinsically motivated)

Jan sees driving as a relaxing experience, giving a feeling of comfort and safety both for himself and his passengers. He always complies with the traffic rules as he believes that there is a reason why those rules exist. He has quite some driving experience as he drives daily to get to work but also to go on vacations. He does not mind driving in unfamiliar places and is quite confident about his driving. He is not convinced that he needs intelligent systems in his vehicle, as he believes that he has full control of his vehicle and with his driving experience, he knows how to deal with difficult situations.

Matt / Sandra (careful, unaware and intrinsically motivated)

Matt is not always fully confident when driving, partly due to a couple of negative experiences. Especially in more dense traffic and more complex situations he is more anxious. As Matt is more insecure when driving, he tries to avoid dense traffic and more complex situations when possible. To be prepared, he knows all the systems in the vehicle that support him with the driving task and with dealing with situations that he may encounter while driving. When buying a new vehicle he is always interested in the systems in a vehicle that can support him in driving.



Sam / Sabine (careful, unaware and extrinsically motivated)

Sam has a driving license already for some time and knows how to drive. However, driving itself is not something he is really fond of. Sam is a very social person who sometimes cannot stop talking. When other people are sitting with him in the vehicle he prefers to chat the whole way. When he is alone in his vehicle he often sings or hums along with the radio, fully focused on the music. Often, this causes Sam to be cognitively distracted when driving, so on the highway his speed will reduce and he will stay behind a truck for a longer time or he will drive 60 km/h where it is allowed to drive 80 km/h. As driving is not the thing that makes him happy he is open to use systems that may take over some of the tasks of driving.

Tom / Kate (risky, unaware and extrinsically motivated)

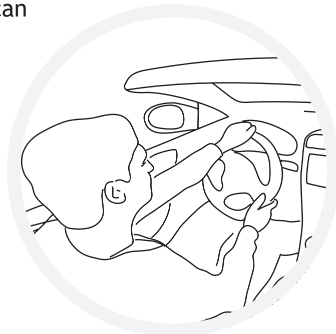
Tom sees driving more as a must than a lust and his family often criticizes his driving. They mention that he should pay more attention while driving to understand the situation around his vehicle resulting in less jerky driving behavior. Tom finds driving quite boring and he even sees it as a waste of time. When he is alone in the vehicle he is often engaged in other activities besides driving. For example, making a phone call or responding to messages on his phone, that does not enhance his driving behavior.

Seth / Melissa (risky, unaware and intrinsically motivated)

Seth is perhaps an overconfident driver who has his driver license for just over a couple of years. He is confident that he is in full control of his vehicle and that he is able to drive at a higher speed, can oversee everything and is able to stop in time. However, according to others, his overconfidence sometimes brings him to overestimating his skills and misjudging certain situations, creating risky behaviors and situations. His risky behavior is amplified as Seth does not see any problem with also using his cell phone while driving. As he enjoys driving he does not make use of systems that support

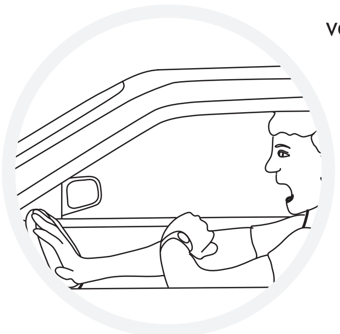
or take over some of the driving tasks.

Mark / Lexi (risky, aware and intrinsically motivated)



Mark loves the sensation of driving and the thrill that speed can create. He prefers to drive a vehicle with a very powerful engine, perhaps even the best he could choose when he bought his vehicle. He loves driving and sometimes on a Sunday he will take his car for a drive. He likes to drive in Germany to test the limits of his vehicle or go to Luxembourg and drive through the hills and experience the forces in those sharp curves. Supportive systems in a vehicle will only hold him back and make the experience less exciting so these systems will not be used.

John / Sarah (risky, aware and extrinsically motivated)



John does not worry about the costs and fuel consumption of his vehicle as long as he will be in time at his destination. His work demands him to travel a lot for appointments, which results in quite some hours on the road. John is a confident driver who is often in a rush. He has already had some traffic fines for speeding and he is always looking how he can go faster through the traffic, sometimes annoying and frustrating other road users. He tries to bend traffic rules to his benefits. He believes that intelligent systems in his vehicle will only hold him back in his driving.

The concrete goals for the current study are the following:

1. To find out whether all personas are represented in a reasonable sample of respondents
2. To validate the framework by inspecting the patterns of responses for the different personas.

Method

Task and Procedure

The eight personas were included in a questionnaire and respondents were asked to rate for each persona on a scale from 1 to 10 how well they recognized him or herself in each persona, taking in mind how they behave in typical driving situations. The questionnaire consisted of two parts: part 1 contained questions relating to demographic data. The demographic data concerned if they tended to drive more on the highway, in urban environments or both, gender, age and the duration of being in possession of a driver's license. In part 2, eight different driver descriptions were given. The respondents were asked to express the extent to which they recognized themselves in each persona, thinking about how you would behave in typical situations, and rate each persona on a scale from 1 to 10. Where 1 means you do not identify with the persona at all, and 10 means you fully identify with the persona. The personas were presented according to the respondents' gender to counteract gender effects. The order in which the personas were presented was unchanged between the different participants.

The questionnaire was offered in two different languages: English and Dutch. Both versions were distributed through Facebook, email and online automotive forums.

Respondents

Two hundred and two respondents completed the online questionnaire. Hundred forty-three respondents were male (71%) and fifty-nine were female (29%), age between 17 and 58 years old ($M = 27.1$, $SD = 10.1$) and having less than one year to 40 years of driving experience ($M = 8.8$, $SD = 9.5$). Ninety-three respondents (46%) indicated that they tended to drive equally on the highway and in urban environments, forty-eight participants (24%) tended to drive more on the highway and sixty-one (30%) tended to drive more in urban environments.

Results

Table 8 shows the distribution of participants across the eight different personas. The order of personas in the upcoming tables differs from the presentation in the framework (Figure 5) to do justice to the binary feature structure of the personas (further explained below). The best matching persona for each respondent was determined by taking the persona which received the highest score. If a respondent gave multiple personas the same maximum score, all of these personas were included in the table. The majority of the participants ($N = 148$, 73.3%) scored the highest for one persona, 37 (18.3%) had a match with two personas, 14 participants (6.9%) matched three personas, two participants (1%) scored equally high on four personas and one participant (0.5%) scored equally high on five personas. Of all the participants, one participant scored a 3 as the highest score for the best matching persona, three participants scored a 4 as the highest score for the best matching persona, three participants scored a 5 as the highest score for the best matching persona, and fourteen participants scored a 6 as the highest score for the best matching persona, the rest ($N = 181$, 90%) scored a 7 or higher.

		N	%	% Male (N = 191)	% Female (N = 86)	Lowest Max Score	Highest Max Score	Mean Max Score	Std. Deviation
Finn	+ + +	44	16	15	19	4	10	7.75	1.480
Jan	+ + -	76	27	30	21	3	10	7.84	1.532
Sam	+ - +	14	5	3	9	5	9	7.36	1.216
Matt	+ - -	30	11	7	19	4	10	7.83	1.341
John	- + +	19	7	5	10	4	10	7.63	1.802
Mark	- + -	63	23	29	9	6	10	8.63	1.299
Tom	- - +	14	5	4	8	5	10	8.00	1.240
Seth	- - -	17	6	7	5	6	9	7.94	.899

+ + + Careful, aware and extrinsically motivated - - - Risky, unaware and intrinsically motivated

Table 8: Deviation Maximum scores per Persona

As can be seen in Table 8 each individual persona was identified by at least 14 respondents as the best matching persona, although some respondents gave rather low maximum scores. It can also be seen that some personas were chosen more frequently than others. The personas with whom most male participants could identify were Jan / Kelly (30%) and Mark / Lexi (29%). The female participants identified themselves the most with Finn / Lotte (19%), Jan / Kelly (21%) and Matt / Sandra (19%).

For the next step, pairwise Pearson correlations were calculated between the scores for pairs of personas (see Table 9). As explained before, the personas are derived from the framework identifying three bi-polar dimensions: driving style, being aware of the consequences of their driving behavior and the motivation of that behavior. Thus, each persona can be represented as being positively or negatively loaded for each dimension, so that for instance Finn, who is a careful driver, aware of the consequences and extrinsically motivated can be represented as [+++] and Seth, who is a risky driver, unaware of the consequences of his behavior and intrinsically motivated, can be represented as [---]. Accordingly, we predict that personas who have more features in common show a higher correlation than personas who have fewer features in common. The results are shown in Table 9.

- The average correlation of the personas with two characteristics in common is .232 (the correlations of these personas are marked with the color yellow)
- The average correlation of the personas with one characteristic in common is .109 (the

correlations of these personas are marked with the color blue)

- The average correlation of the personas with no characteristics in common is .029 (the correlations of these personas are marked with the color green)

		Finn + + +	Jan + + -	Sam + - +	Matt + - -	John - + +	Mark - + -	Tom - - +	Seth - - -
Finn	+ + +		.052	.111	.252**	.102	-.069	.199**	-.019
Jan	+ + -			-.150*	-.186**	.149*	.304**	-.065	.137
Sam	+ - +				.512**	.156*	-.224**	.430**	.140*
Matt	+ - -					.190**	-.198**	.318**	.142*
John	- + +						.357**	.196**	.410**
Mark	- + -							-.030	.426**
Tom	- - +								.336**
Seth	- - -								

**. Correlation is significant at the 0.01 level *. Correlation is significant at the 0.05 level

+ + + Careful, aware and extrinsically motivated - - - Risky, unaware and intrinsically motivated

Table 9: Pearson Correlation between the eight personas

To see whether features are weighted differently by the respondents, we can abstract away from two features and calculate the average correlations for those comparisons where the personas have a specific feature in common. This gives the following results.

- The average correlation of the personas who have only their driving style in common is .120 (Finn – Matt, Jan – Sam, John – Seth and Mark – Tom)

- The average correlation of the personas who have only in common that they are either aware or unaware of the consequences of their behavior is .134 (Finn – Mark, Jan – John, Sam – Seth and Matt - Tom)

- The average correlation of the personas who have only their motivation in common is .073 (Finn – Tom, Jan – Seth, Sam – John and Matt – Mark)

As can be seen, the average correlations are about the same for the three different characteristics, indicating that the different characteristics are of equal importance in determining whether a persona matches the respondent.

Discussion

Differences between drivers may affect the extent to which the behavior of an ADS meets the needs and interests of the driver. Persuasive technologies may support the increase of drivers' willingness to accept the behavior of ADS. However, taking in consideration that what might influence one person may not work at all for someone else, a better understanding of what differentiates different groups of drivers is needed as well as a method to allocate drivers to categories. Personas are a useful method to create and communicate an understanding of different driver categories (Lindgren et al., 2007). The challenge is to create personas that people can relate to and that covers the majority of drivers. As mentioned in the results, 181 out of the 202 participants scored a 7 or higher as the highest score for the best matching persona, which implies that the majority of people could identify themselves with at least one of the personas. This suggests the number of personas that are developed and validated in this chapter cover the majority of the people. Also, the results indicate that all personas were selected as best matching persona by at least 5% of the respondents. These results suggests that no persona is superfluous.

The results indicate a difference in matching personas between females and males. According to the literature, male drivers are more likely to engage in undesirable driving behavior (Starkey & Isler, 2016), and self-report higher on reckless and angry driving styles, while females score higher on anxious and careful driving (Taubman-Ben-Ari & Yehiel, 2012). The findings discussed in this chapter are in agreement with these previous studies, as in this study the personas related to careful driving (Finn / Lotte and Jan / Kelly) as well as the persona related to more anxious driving (Matt / Sandra) were the most chosen ones among females. Male participants chose the risky persona (Mark / Lexi) significantly more often in comparison to females.

It should be kept in mind that questionnaires may be sensitive to biases such as social desirability or overestimating one's own skills compared to the skills of other drivers (Delhomme, 1991; Freund et al., 2005) and that this may influence the decision of people as to what is the best matching persona. For instance, the persona most respondents (38%) could identify with was Jan / Kelly. As this represents a careful driver who is aware of the consequences of his or her actions and is intrinsically motivated, this is perhaps also the most socially desirable persona.

As mentioned at the beginning of this chapter, the aim is to explore the design potential for in-car applications to increase the overall acceptance of intelligent systems by different types of drivers through the use of more personalized persuasive technologies. In the next section, design guidelines are provided according to the different quadrants of the framework.

Design Opportunities

As the drivers in the different spaces differ in characteristics and needs, selecting the most suitable persuasion strategy for each space may benefit the overall acceptance of intelligent systems. Fogg mentioned that to positively influence behavior, persuasive technologies may either act as a tool, media or social actor (Fogg, 2003), resulting in different strategies that can be defined to personalize persuasion for the eight different spaces of the framework proposed in this chapter. According to Fogg (Fogg, 2003) the goal of a computer as a tool is to persuade people through support. The computer will provide support to the user in order to make tasks or activities easier to do, such as calculating the optimal route to reach the end destination or leading the driver through the process of finding the correct route. Computers as media can provide stimulating experiences through information, allowing the user to explore the cause-and-effect relation (Fogg, 2003). The computer will provide feedback when needed, for example, when unacceptable behavior occurs such as speeding or tailgating. Lastly, a computer can act as a social actor by providing feedback and social support (Fogg, 2003). Providing rewarding feedback and social support can motivate people to interact with the system. Within each of the three different roles various ways can be defined to persuade people (See Figure 5).

Drivers who, according to the framework, are categorized as careful drivers, aware of the consequences of their driving behavior and extrinsically motivated (Finn / Lotte), mainly focus on the benefits accompanied with sustainable driving. They see sustainable driving sometimes even as a game. This happens perhaps most often when the driver has no pressure or perhaps is even becoming bored when driving. To prevent these drivers from disabling automated driving systems, persuasion through information may increase acceptance of intelligent systems. Information about the benefits accompanied with the driving behavior may encourage the driver to maintain sustainable driving even when more pressure is perceived. The use of game elements in persuasive systems may also encourage the continued use of ADAS.

Drivers who, according to the framework, are categorized as careful drivers, aware of the consequences to their driving behavior and intrinsically motivated (Jan / Kelly), tend to drive in a way that they may perceive as relaxing and comfortable. They have the feeling of being in full control and are aware of all the circumstances. For those drivers, persuasion through experience may support a comfortable experience that also provides ambient information about, for example, the driven speed. This may increase the acceptance of ADAS as it will support the feeling of being in control and situation awareness. This may be achieved through a LED strip mounted along the A-pillar of the vehicle through which light will move to provide ambient feedback about the driven speed (Meschtscherjakov, Döttlinger, Rödel, & Tscheligi, 2015).

Drivers who, according to the framework, are categorized as careful drivers, unaware of the consequences of their driving behavior and extrinsically motivated (Sam / Sabine), are more confident in driving. However, these drivers are not really fond of driving (Lajunen & Summala, 1995), which may result in boredom while driving. To compensate, they may try to do something else (Schroeter, Oxtoby, & Johnson, 2014), for example, singing along with the radio or having a conversation. People who are, for example, chatting with others while driving can be more cognitively distracted, influencing the driver's workload (Kaber, Liang, Zhang, Rogers, & Gangakhedkar, 2012). A higher workload may result in a decision to reduce the complexity of a task through, for example, slowing down. Persuasion through *correction* may support this type of drivers to encourage them, for example, to speed up when they are driving 10 km/h under the speed limit. The aim of the system is to support them in their driving tasks to create awareness about their driving behavior.

Drivers who, according to the framework, are categorized as careful drivers, unaware of the consequences of their driving behavior and intrinsically motivated (Matt / Sandra), have often less experience with driving and are therefore less confident (Lajunen & Summala, 1995). This group may also be referred to as cautious drivers who tend to be more anxious, resulting in avoidance of more tricky situations. In order for ADAS to effectively support this type of drivers, it is important that they trust the system. For those drivers, persuasion through support may increase the acceptance of ADAS by providing support for some of the driving tasks. For example, by creating a haptic guidance that will support the driver in maintaining the correct position in a lane.

Drivers who, according to the framework, are categorized as risky drivers, aware of the consequences of their driving behavior and extrinsically motivated (John / Sarah), are mainly focused on pursuing their goal, as for example, reaching their destination as fast as possible. This may result in more frustrated and angry driving behavior through for example tailgating and /or disregarding speed limits. ADAS may be a mismatch when the driver may not believe that the benefits of this type of systems can have a positive effect on their own goal. For those drivers, persuasion through information may increase the acceptance as these drivers do not drive because of the sensation but because of the perceived benefits when moving faster through traffic. For example, informing the driver of both the gains and losses of their preferred way of driving compared to more sustainable driving. The information lets them know that their behavior does not have a large benefit time-wise but has quite some negative results on safety and fuel consumption.

Drivers who, according to the framework, are categorized as risky drivers, aware of the consequences of their driving behavior and intrinsically motivated (Mark / Lexi), mainly want to maintain a preferred level of arousal that is most of the time related to higher speed. If ADAS in vehicles aim to induce a more careful driving style, it may create a mismatch with this type of driver. Persuasion through experience may support the acceptance for this type of driver as a system could be designed creating an experience that substitutes the experience of risky driving. For example, creating a light beam in the vehicle through which light will move at a faster rate than the vehicle driven speed. This may produce a feeling of speeding that may increase the acceptance for this type of drivers.

Drivers who, according to the framework, are categorized as risky drivers, unaware of the consequences of their driving behavior and extrinsically motivated (Tom / Kate), mainly see driving as a waste of time and look for secondary tasks to spend the driving time more usefully (Lajunen & Summala, 1995; Schroeter et al., 2014). As they do not see the joy in driving, they often also do not pay attention to how well they are driving, resulting in a more risky driving style (Schroeter et al., 2014). Secondary tasks mostly enhance jerky driving, creating more dangerous driving behaviors (Fuller, 2005). For those drivers, persuasion through correction may support them in maintaining a more safe and careful driving style. Corrections of driving behavior induced by the system should be noticeable by the driver; this can, for example, be done through a change in feedback force of the steering wheel or gas pedal.

Drivers who, according to the framework, are categorized as risky drivers, unaware of the consequences of their driving behavior and intrinsically motivated (Seth / Melissa), seem to be overconfident in their driving, resulting in a false judgment of their own driving skills and the safety boundaries of certain situations and road conditions (Fuller, 2005; Montella et al., 2011). As these drivers are over-confident about their own skills, this over-confidence may create mistrust in ADAS as they prefer more assertive driving and are not aware that their behavior creates dangerous situations. Persuasion through support may increase the acceptance for this type of drivers as a system should support the driver where s/he does not show appropriate behavior according to the road conditions and circumstances; next to this, the system should still provide some experience of assertive driving to satisfy the preferred way of driving.

Conclusion

In this chapter, eight different personas that were developed according to the three-dimensional framework are discussed and validated through an online questionnaire. Two hundred and two respondents rated the extent to which they identified themselves with each persona (rating from one to ten for each persona), taking a typical driving trip in mind. The results revealed that all personas were selected by at least five of the respondents and that the majority of the participants scored a 7 or higher as the highest score for their best matching persona. This implies that all eight of the personas are needed in order to cover the majority of the drivers and that there is no need to extend the number of personas. However, it should be taken into consideration that this does not necessarily mean that every aspect of an individual driver is covered by these eight personas. But it can be concluded that these personas are a good representation of the majority of drivers and can be used as a method to distinguish different types of drivers. Next, these personas can also benefit the selection process for the correct persuasion method in order to increase the willingness to use ADS.

The Pearson correlations indicate that there is a relationship between the number of shared characteristics and the correlations between the scores for personas, as more shared characteristics resulted in an overall higher correlation. From this, we conclude that the current results support the framework. Finally, the pattern of correlations suggests that all characteristics are approximately of equal importance. Discussing the different design opportunities, different studies need to be performed in order to investigate the influence of different persuasion strategies on the experience in a vehicle, with the aim to positively influence the willingness of drivers to use intelligent systems in vehicles.

In the next part of this thesis, ambient light and sound are explored as means to alter the experience within a vehicle.

Part 3

5

Ambient Light and its Influence on Driving Experience

Abstract

In modern traffic, measures are implemented to regulate speeding, which may annoy drivers who pursue an exciting driving experience and make them exceed speed limits. Others prefer a more relaxing experience resulting in socially desired driving behavior. This chapter presents a study investigating the capacity of ambient light to alter the perception of speed and therefore influence the driving experience. The aim of this study was to determine how different drivers experience the concept of an ambient light moving along the A-pillar inside the vehicle. In different conditions, the light moved at different speeds. The outcomes of the study show that overall the ambient light used in this study had a positive effect on the driving experience but that the attitude towards the ambient light was highly individual. The majority indicated a preference towards the ambient light while some saw it more as a distraction or even inducing more stress.

THIS CHAPTER IS BASED ON:

Hooft van Huysduynen, H., Terken, J.M.B., Meschtscherjakov, A., Eggen, J.H. & Tscheligi, M. (2017). *Ambient light and its influence on driving experience*. AutomotiveUI '17 Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, 24-27 September 2017, Oldenburg, Germany (pp. 293-301). New York: Association for Computing Machinery, Inc.

Introduction

As ADS are developed with a strong focus on safety, the behavior of highly autonomous vehicles is expected to be cautious and defensive. Taking a closer look at drivers, their driving behavior, needs, and motivations, it can be noted that drivers differ in their driving styles as already mentioned in the previous chapters. As a result, the behavior performed by an ADS may deviate from the behavior as preferred by the driver; this applies in particular to the risky drivers mentioned in the framework proposed in the previous chapter as the behavior of automated vehicles is expected to be cautious and defensive. This may have a negative effect on people's willingness to use such systems. Another reason why drivers may decide to disregard the assistance provided by ADS is the changing role of the driver in autonomous vehicles and therefore the experience of driving. As the role of the driver will change from being the driver to being an observer, and ultimately to being a passenger, the driving experience will change along (Eckoldt et al., 2012).

The idea emerged that, in particular for drivers who pursue an exciting driving experience, the decline in the experience due to the cautiousness and defensiveness of autonomous vehicles can be compensated for by intensifying visual, tactile and/or auditory sensations (Petiot, Kristensen, & Maier, 2013). Similarly, Schroeter et al. (Schroeter et al., 2014) have argued that simulating risky driving or replacing risky driving triggers with alternative stimuli may reduce actual risky driving.

Figure 6. Ambient Light concept implemented on the A-pillar of the driving simulator. The greenish LED segment on the left is moving from the bottom to the top of the A-pillar and then past the driver, in the peripheral view of the driver.

The goal of the work described in the current chapter was to take a first step to investigate how ambient light in a vehicle is experienced by different drivers in terms of stimulation and attractiveness and to test whether ambient light may compensate for the reduced stimulation experienced. This was done through an exploratory study with the aim to probe the promise of personalized persuasive technology in vehicles as discussed in the previous chapter. The idea behind the ambient light used in this study was that the ambient light should provide the perception of velocity in the absence of actual velocity, by increasing the optical flow (see Figure 6). Take, for example, the lights in a tunnel or the stripes on the road. The speed at which these are passed when driving is dependent on two factors: the driving speed and the appearance of the objects (e.g. the length of objects and distance between different objects). So, if the lights or stripes start to pass faster, it is either due to an increase in speed of the vehicle or the decrease of the distance between different objects. In the latter case, the increased optical flow induces a higher perceived speed. Taking this to the digital domain, the use of ambient light to manipulate the optical flow may offer an opportunity to enhance the driving experience and therefore persuade drivers pursuing an exciting driving experience to make use of ADS even if the ADS displays cautious and defensive behavior. On the other hand, in-vehicle technology that enhances the sensation of drivers pursuing an exciting driving experience may be disliked by more sedate of calm drivers and actually result in disuse of ADS.

The idea that concepts intended to persuade people to use certain technologies may not have the same effect on different types of users receives some support from the literature. In (Kaptein et al., 2012) personalized persuasion was designed by creating tailored persuasive messages to influence people's behavior, making use of the strategies defined by Cialdini (Cialdini, 2001). It was found that tailored, more personalized persuasion is more effective in motivating behavior change.

Likewise, we expect that the willingness to use intelligent systems in vehicles may be increased by means of personalized persuasive technologies. Since there are differences between drivers such as their driving style, strategies that are intended to persuade one type of driver to use intelligent systems may have no or even a negative influence on other types of drivers (Taubman-Ben-Ari & Yehiel, 2012). For example, when a careful driver receives an advice to slow down to create a gap for another vehicle, s/he will likely comply with this advice, while a risky driver may just neglect this advice and speed up to close the gap

The study presented in this chapter investigates the influence of ambient light on the driving experience, exploring the capacity of ambient light to alter the perception of speed. The aim of this study was to determine how different drivers experience the concept of an ambient light moving along the A-pillar inside the vehicle.

Related Work

Apart from legislation and regulation, several external measures are taken to regulate the speed of drivers including the changes of the physical environment such as roundabouts, speed bumps, and speed signs (Manser & Hancock, 2007). Road surface changes also appear to be effective in reducing speed (de Waard, Jessurun, Steyvers, Reggatt, & Brookhuis, 1995). Manser and Hancock (Manser & Hancock, 2007) investigated whether visual patterns and presence of texture used on walls of a tunnel differentially affect the driven speed. Their results showed that the overall driving speed decreased when drivers were exposed to visualization of vertical segments that decreased in width, creating smaller segments closer to each other. In contrast, when the drivers were exposed to vertical segments that became broader in combination with wider distances between the segments, the driving speed increased. Thus the perceived speed was influenced by the visual patterns outside the vehicle.

More intelligent systems are introduced in the vehicle to support the driver with the driving tasks. At times, these systems demand the attention of the driver which may elevate the driver's workload (Hancock & Parasuraman, 1992). Ambient displays may allow the user to be aware of the information while engaging in different activities (Matthews, Dey, Mankoff, Carter, & Rattenbury, 2004), by displaying non-critical information in the periphery of the driver's attention, without elevating the driver's workload. The use of ambient light as a means to convey information to a user and the influence on the user experience has been researched intensively in the HCI community. Löcken et al. (Löcken, Müller, Heuten, & Boll, 2014) identified several properties of the design space for ambient light displays such as the behavior of the LEDs, distance, and direction of movement. In the automotive context, ambient light has been used for turn-by-turn navigation (Matviienko, Löcken, El Ali, Heuten, & Boll, 2016) or to support lane change decisions (Löcken, Heuten, & Boll, 2015).

Meschtscherjakov et al. (Meschtscherjakov et al., 2015) made use of ambient visualizations to help drivers obtain awareness of the driving speed without the need to monitor the speedometer. Their aim was to support drivers to maintain a predefined driving speed. This was based on the simple idea that drivers perceive their speed differently when driving

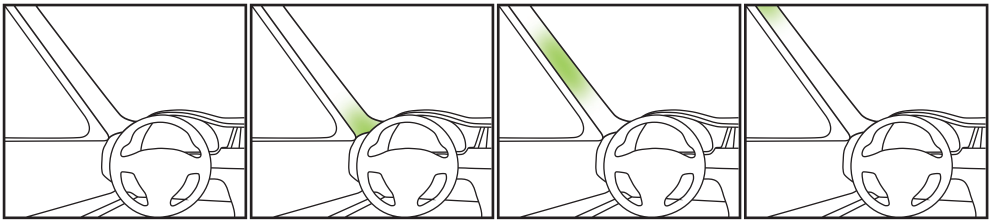


Figure 7. Ambient Light concept. The greenish LED segment on the left is moving backwards in the peripheral view of the driver.

on a broad U.S. highway with five lanes compared to driving at the same speed through a narrow Italian alley, reflecting that perceived speed also depends on environmental factors (Meschtscherjakov et al., 2015). In their study, participants had to drive in three different conditions, with three different types of ambient light feedback, in which the speedometer was not shown. They used a LED strip mounted to the A-pillar of a vehicle as an ambient visualization of the speed (See Figure 7) where the illusion of a moving light was created by switching the LEDs on and off sequentially. The three conditions were driving with ambient light moving at a constant speed, at a proportional speed (related to the speed of the vehicle itself), and at an adaptive speed (light moves faster when the speed deviated further from the appropriate speed). Their study revealed that the speed of the ambient light had a significant influence on the realized vehicle speed. Their data showed that the drivers drove significantly slower when the light moved according to the driven speed and that the target speed was better maintained in the adaptive speed setting. A critical aspect of these results is, that the ambient light was the only feedback on driven speed and the speedometer was not shown, which may raise a question regarding the ecological validity of their results, as in normal vehicles drivers always have the speedometer at their disposal.

The Ambient Light Concept

While in the study by Meschtscherjakov et al. (Meschtscherjakov et al., 2015) the aim of the ambient light was to give feedback to drivers on the realized speed in order to better maintain a target speed, in our study the aim of the Ambient Light concept was to increase the perceived speed, in order to positively influence the driving experience. We also decided to visualize the speedometer all the time to provide some objective feedback on the speed while driving.

Our Ambient Light concept consists of an LED strip that is placed along the A-pillar to the left of the driver, placing the light in the peripheral area of the driver's visual field (see Figure 7). By switching the LEDs on and off sequentially, the impression of a light that is moving through the LED array is created. The light moves past the driver, moving from the front to the back as if it passes by while driving. The LED stripe is 132 cm long and consists out of 190 RGB LEDs. Similar to one of the setups of Meschtscherjakov et al. (Meschtscherjakov et al., 2015), the light in our study moved at a speed proportional to the driving speed, meaning that the ambient light was moving faster as the vehicle accelerated.

In the Ambient Light concept, the light is made to move at a higher speed compared to the driven speed, increasing the optical flow. Assuming that careful and cautious drivers want to keep the optical flow at a comfortable level, the expected consequence is that drivers who are more cautious reduce the actual speed. In contrast, drivers who prefer more sensation maintain the current speed or will even increase the speed. Otherwise said, if the actual speed is lower, the Ambient Light creates the illusion that the vehicle is actually driving at a higher speed, therewith enhancing the driving experience for people who prefer the sensation of driving at a higher speed.

User Study

The aim of the study was to investigate how the Ambient Light concept was experienced and to see whether there were differences between participants. The experience was operationalized in terms of attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. We were interested to see if this study supported the notion that driver's attitude towards ambient light is dependent on their driving style. Drivers who prefer more sensation while driving may appreciate the concept while more anxious drivers experience it as more frustrating and demanding. The targeted influence of the Ambient Light concept on speed was also investigated. The following research questions were investigated.

- Does the use of the Ambient Light (resembling the idea of the stripes on the road passing by) have an influence on the driving experience?
- Does the experience when using an ambient light pattern differ between drivers and what are reasons for those different attitudes towards those ambient light patterns?
- Does an increase in speed of the ambient light influence the actual speed driven, resulting in a lower average driven speed compared to the setting with a lower speed for the ambient light?

We expect that driving with the Ambient Light concept will be experienced as more stimulating and attractive compared to driving without the Ambient Light concept. In addition, we expect that driving style determines the attitude towards the Ambient Light concept. The appreciation of the concept will be dependent on their driving style, as drivers who are more anxious while driving find it more stressful and distracting while others who prefer more sensation when driving appreciate the concept as being more pleasant or useful. Finally, we may assume that the speed of the Ambient Light will have an influence on the actual driven speed. When driving with the light moving at the same or higher speed compared to the driving speed, the driven speed will be lower compared to a baseline without the use of the moving light.

Next to investigating the influence of ambient light on the experience and perceived speed a more explorative part was conducted to investigate if there are differences between how drivers experience the driving when the light is related to the driving speed and when drivers are free to choose the speed of the light themselves and do not have (fully) monitor the speed of the vehicle through the use of cruise control (CC). What would the speed of the Ambient Light be if they are able to choose it themselves, or would they even turn it off?

Conditions

Based on previous research (Manser & Hancock, 2007; Meschtscherjakov et al., 2015) and the research questions, three different conditions were implemented, creating different settings for the Ambient Light concept. In the first condition, the light moves proportionally to the speed of the vehicle (explained further below). In the second condition, the light moves at a proportionally higher speed, having an offset of 10 km/h. These two conditions were chosen to evaluate the compensatory effects of the Ambient Light concept. In the last condition, the speed of the light is disconnected from the driving speed, allowing the participants to choose their own preferred speed of the light. This condition was chosen to explore which speed of the Ambient Light they will set themselves and how this compares to the speeds in conditions C1 and C2.

All three conditions make use of the setup of the Ambient Light concept explained before. The three conditions used in this study, proportional speed, proportional higher speed and disconnected speed, are described in the following part.

C1. Proportional Speed

The speed of the light is directly connected to the speed of the vehicle in this condition. This means that the movement of the light will be dependent on the driving speed. When the vehicle is driving 70 km/h the light moves as if the vehicle would drive 70 km/h. As used in the study by Meschtscherjakov et al. (Meschtscherjakov et al., 2015) the speed of the light is calculated with the formula (v) x 3 pixel/s, where v is the actual speed. Driving 50 km/h results in a speed of the ambient light of 150 pixels per second corresponding to one moving light per 1.27 seconds thought the length of the LED strip (190 RGB LEDs / 150 pixels per second).

C2. Proportional Higher Speed

The speed of the light is directly connected to the vehicle speed, however, the movement of the light is proportionally higher compared to the driven speed in this condition. This means that the movement of the light will be dependent on the driven speed with an offset of 10 km/h. When the vehicle is driving 70 km/h the light moves as if the vehicle would drive 80 km/h. In this condition, the speed of the light is calculated with the formula (v + 10 km/h) x 3 pixel/s, where v is the actual speed. Corresponding to light moving each (190 pixels / ((v + 10 km/h) x 3 pixel)) second. When driving 50 km/h in this condition a new light appears every 1.06 second (as compared to 1.27 s in condition 1). The difference between the two conditions in terms of the speed of the moving light is 19,8%.

C3. Disconnected Speed

In this condition, the driver is free to change the speed of the light according to his/her own preferences by turning a knob implemented in the vehicle while driving. The light will start moving at the start of this condition with a constant speed of 150 pixels/s, which is equal to driving 50 km/h in the proportional speed setting and can be adjusted to either increase or decrease the speed of the light.

Next to the three conditions, one baseline condition before the start of the conditions (BL1) and one after the three conditions (BL2) were implemented in which the Ambient Light concept was not activated. The average of these two baselines would be taken to balance out any learning effects. This because the same driving scenario was used for each of the different conditions and baselines.

Method

The study was conducted in a driving simulator. The Ambient Light concept was implemented through a LED array matching the green color of the surrounding grass in the scenarios (See Figure 6) to integrate the LED light with the surroundings.

In order to learn how the different conditions were experienced by the each type of driver, each participant experienced all three conditions (within-subject design). After each of the three conditions, participants were asked to answer questions related to the user experience of the driving trip.

Participants

Twenty-eight participants volunteered to participate in this study, sixteen males (57%) and twelve females (47%) aging between 18 and 64 years (*M=30.57, SD=8.57*) and possessing a driver's license for an average of 12 twelve years (*SD=8.46*). The participants received €10,- as a compensation for their time.

Procedure and Measure

First, participants signed the informed consent form and completed the first questionnaire containing questions about demographic data and thirteen statements related to their driving behavior when driving on a highway outside rush hour. The thirteen statements should be rated on a uni-polar seven-point scale ("not at all" to "very much"). With statements as "I feel I have control over driving", "I enjoy the sensation of driving on the speed limit", "I feel frightened while driving" and "I am calm while driving". Next, participants were asked to take a seat in the driving simulator. The simulator was a fixed base car mock-up with a projection of the OpenDS simulator software ("OpenDS - Home," n.d.) on a 3.28 x 1.85-meter screen with 1920 x 1080 pixel resolution (see Figure 6). In none of the conditions manual gear shifting was needed and in the condition requiring the system to maintain the speed of the vehicle (C3), the simulator made use of cruise control (CC) that could be activated and deactivated by the participant by pressing a button on the steering wheel. CC was used in C3 as CC is a common feature in modern cars and related to the aim of future autonomous vehicles in which the driver does not (fully) control the vehicle. CC can be seen as a step towards autonomous driving. It is interesting to know whether the Ambient Light has an influence on the perceived speed when the vehicle is driving with a constant speed, but as in modern cars, participants were able to deactivate the CC as we did not want to force people to use it.

The participants started their driving task with a training phase, allowing them to get used to the simulator and its behavior. To familiarize, they drove one round of around five minutes on a gray two-lane street with lanes separated by white lane markings with no traffic, creating none stimulating situation inducing more sensation seeking behavior. The scenario contained several soft corners and small differences in height requiring participants to maintain their focus on the driving task and their speed. The surroundings were flat and green with no objects beside the road except for the roadside poles. The same scenario was also used for the rest of the study to reduce contextual variation due to different environments and situations and to control the confounding factors. After the familiarization round, they drove another round of five minutes to set the first baseline.

Next, the participants drove one round of five minutes for each condition (the order of conditions C1, C2, C3 was randomized across participants to balance learning effects), ending with another round of five minutes for the second baseline condition.

For C1 and C2, participants were asked to accelerate to the target speed of 70 km/h and to continue driving as they would normally drive in their own vehicle. They were not informed about the aim of the Ambient Light or how it differed between C1 and C2. After one round the condition was concluded, indicated by a stopping sign at the side of the road. The assignment for C3 was to accelerate to the target speed of 70 km/h, activate CC and to continue driving as they would normally drive in their own vehicle by setting the speed of the CC to the speed they would drive when driving themselves. In addition, in C3 they were requested to adjust the speed of the Ambient Light to their preference while driving and to keep it on that speed when they found their optimum. If they were not comfortable with the use of CC they were allowed to deactivate it, either through braking or pushing the CC button again. The activation/deactivation of the CC and how to adjust the speed of the ambient light was explained prior to the start of C3 and the speed of the Ambient Light they ended with was used for further analysis. After one round the condition was concluded, indicated by a stopping sign at the side of the road. During all the conditions the speedometer was visible.

After the first baseline and after each of the three conditions, the participants were asked to fill the User Experience Questionnaire (UEQ), as the UEQ considers user experiences in a broader perspective through the aspects of pragmatic and hedonic qualities (Laugwitz, Held, & Schrepp, 2008). This allows us to assess the perceived experience of the light system with respect to choosing the driving speed and the use of intelligent systems that maintain a predefined speed. At the end of the study, four open questions were asked about their attitude towards the light system:

1. Overall, how did the light system support your awareness of the driving speed?
2. In what terms was the use of the light system useful while driving?
3. What do you think of the use of the light system in combination with Cruise Control?
4. To what extent did you have the feeling that the light system influenced your speed perception?

In total, the experiment took around 45 minutes per participant.

Results

Subjective Results

Table 10 shows the means and standard deviations of the different scales of the UEQ with scores between -3, the most negative value and +3, the most positive value.

To evaluate the significance of differences in experience between the different conditions paired samples t-tests were conducted. Participants rated the condition proportional speed (C1) as having significantly less perspicuity compared to driving without the light system (BL), $t(27) = 2.35$, $p = 0.026$, $r = 0.41$. Proportional speed (C1) was rated as more stimulating ($t(27) = -4.31$, $p = 0.000$, $r = 0.64$) and novel ($t(27) = -5.59$, $p = 0.000$, $r = 0.73$).

	BL1	C1	C2	C3
Attractiveness	M = 0.31 SD = 1.13	M = 0.62 SD = 1.30	M = 0.36 SD = 0.37	M = 1.18 SD = 0.88
Perspicuity	M = 1.67 SD = 1.02	M = 1.00 SD = 1.27	M = 1.13 SD = 1.21	M = 1.66 SD = 0.88
Efficiency	M = 0.53 SD = 0.68	M = 0.42 SD = 0.80	M = 0.51 SD = 0.84	M = 0.56 SD = 0.67
Dependability	M = 0.85 SD = 0.88	M = 0.55 SD = 1.13	M = 0.43 SD = 0.99	M = 0.92 SD = 0.78
Stimulation	M = -0.44 SD = 1.27	M = 0.58 SD = 1.17	M = 0.33 SD = 1.11	M = 0.47 SD = 1.17
Novelty	M = -0.69 SD = 1.30	M = 0.90 SD = 1.13	M = 0.61 SD = 1.10	M = 0.90 SD = 1.18

Table 10. Results of the different scales of the UEQ per condition

A comparison of the proportional higher speed condition (C2) and the baseline condition revealed significant positive differences for both stimulation ($t(27) = -2.83$, $p = 0.009$, $r =$ 0,48) and novelty ($t(27) = -4.49$, $p = 0.000$, $r = 0.65$). There were no significant differences between the proportional higher speed condition (C2) and the condition proportional speed (C1).

The comparison between the disconnected speed condition (C3) and the baseline condition revealed significant positive differences for stimulation ($t(27) = -3.31$, $p = 0.003$, $r = 0.54$) and novelty($t(27) = -5.58$, $p = 0.000$, $r = 0.73$), and for attractiveness ($t(27) = -3.84$, $p = 0.001$, $r = 0.59$). The condition disconnected speed (C3) was also rated as significantly more attractive compared to proportional speed (C1) ($t(27) = -2.78$, $p = 0.010$, $r = 0.47$) and proportional higher speed (C2) ($t(27) = -3.84$, $p = 0.001$, $r = 0.59$). Disconnected speed (C3) was also rated as having significantly more perspicuity (easier to learn, understand) than proportional speed (C1) ($t(27) = 2.41$, $p = 0.023$, $r = 0.42$), and disconnected speed (C3) was significant more dependable (more secure) compared to proportional higher speed (C2) ($t(27) = -2.30$, $p = 0.029$, $r = 0.40$). The Ambient Light concept was seen as more stimulating. The third condition, the disconnected speed condition (C3), was also rated as more attractive.

Participants were also asked to answer four open-ended questions about the Ambient Light concept. The answers given were quite diverse, reflecting different opinions between participants. Twenty out of 28 participants indicated the light as pleasant, relaxing or amusing as it helped them in maintaining the driving speed better and making the somewhat boring scenario more exciting. Using the Ambient Light concept in combination with CC was indicated as a positive distraction by eight participants, making the trip less boring and more exciting, and supporting to keep the attention towards the driving task. On the other hand, five participants indicated that they experienced the light as distracting and/or stressful when driving. Four participants found the Ambient Light concept distracting, inducing a more sleepy or drowsy feeling. They experienced the Ambient Light concept as more negative. Two participants indicated that they experienced more difficulty in maintaining the correct speed in the last session where they had to drive again without the Ambient Light concept. Five participants indicated the Ambient Light concept as not useful but did not experience negative effects when using it.

The answers to the four open questions were compared to the answers on the thirteen statements relating to their driving behavior. One participant (P18) considered her driving style as being more anxious and experienced the Ambient Light as even more stressful. Another participant (P1), who felt frightened while driving, saw the Ambient Light as disturbing. Other participants (P2, P4, and P5), who mentioned to enjoy driving, experienced the Ambient Light as a nice addition to the otherwise boring scenery. One participant (P3), mentioned the rhythm of the light as stimulating. However, correlations between the driving style scores and the UEQ scores were generally insignificant, except for a few significant correlations with attractiveness.

Twelve out of 28 participants mentioned that the Ambient Light concept supported their awareness of speed as it stimulated them to adhere to the speed limit. One participant also mentioned that the rhythm felt unpleasantly hasty when driving towards the 80 km/h. Five participants explicitly mentioned that the Ambient Light concept supported them in maintaining the correct speed, as deviations in the driven speed and in the speed of the light were noticed sooner than when driving without the Ambient Light concept.

Objective Results

The average speed was calculated for each participant for each condition. The data of the first and last five seconds of each session were not incorporated to exclude the acceleration and deceleration at the beginning and end of each session. As a baseline value, the average of both baseline conditions (BL1 and BL2) was calculated for each participant resulting in MeanBL. The mean speed for the different conditions can be seen in Table 11. Disconnected speed condition (C3) was not included in this part of the analysis as participants were asked to use the cruise control at 70 km/h, by definition resulting in an adherence to the speed limit.

C1	C2	MeanBL
M=68.57	M=68.66	M=69.22
SD=4.02	SD=4.35	SD=4.12

Table 11. The mean speed in km/h and standard deviation within the different conditions

A within-subjects ANOVA was conducted comparing the mean speed in the different conditions. The test compared the mean baseline (MeanBL), proportional speed (C1) and proportional higher speed (C2). The results revealed no significant difference between mean baseline and proportional speed (C1) and proportional higher speed (C2). There was no significant difference between proportional speed (C1) and proportional higher speed (C2), indicating that overall participants did not drive slower when the light was moving proportionally faster compared to when the light was moving at the same speed of the vehicle.

C3	Ambient Light Speed
M=68.24	M=131.86
SD=3.08	SD=67.57

Table 12. The mean speed and the standard deviation in Disconnected Speed (C3) in km/h and the mean speed and standard deviation of the Ambient Light in Disconnected Speed (C3) in pixel per second.

For the disconnected speed condition (C3), the mean speed of the light chosen was 131.86 pixels per second which was equal to approximately 44 km/h with a standard deviation of 67.57 pixels per second or 23 km/h in speed (see Table 12). Some of the participants reduced the speed of the light to zero while others increased it. A couple of participants deactivated the CC when taking some of the corners, but all participants drove with CC on the parts where they were able to drive 70 km/h resulting in a mean speed of 68.24 km/h with a standard deviation of 3.08 km/h.

Discussion

In this chapter, the Ambient Light concept was used to investigate the influence of the use of a moving light inside a vehicle on the driving experience, the relation between driving style and attitude of different drivers and the ability to alter the perception of driving speed in a vehicle. Our study revealed that the driving experience was changed through the visualization, indicating that the Ambient Light concept was exciting and motivating. We also found major individual differences in terms of acceptance.

As the results indicate a difference in terms of experience and acceptance, measured by the UEQ and the four open questions, supporting the idea that to influence drivers requires multiple solutions as one size fits all solutions do not seem to work for different types of drivers and perhaps for some drivers even have a more negative influence. Twelve participants mentioned that they preferred the Ambient Light concept as it made them more aware of unintentional speeding compared to driving without the Ambient Light concept, allowing them to more quickly respond by reducing their speed. This indicates that the Ambient Light can be seen as a support system while driving for these type of drivers, enabling them to maintain a better awareness of the driven speed. On the other hand, five participants indicated that they did not like the Ambient Light concept as they experienced it as a distraction or creating more stress when driving. For these people the concept of the Ambient Light seems to induce a more negative driving experience. These people also indicated that they experience driving itself already as somewhat stressful. For these participants, the use of the light was seen as a negative contribution to their driving experience and driving behavior.

As the results showed that the Ambient Light concept had a positive effect on the driving experience for most of the participants, this suggests that the Ambient Light concept may compensate for the loss in driving experience induced by the more cautious behavior of an autonomous vehicle. The idea is that by making use of the Ambient Light the optical flow will be enhanced, resulting in a positive driving experience even when the driver does not (fully) control the vehicle.

The results also showed that most participants experienced the disconnected speed condition (C3), which allowed them to choose the preferred speed of the ambient light, as more attractive compared to the other conditions. The results of this part revealed that the Ambient Light concept has a positive influence on certain participants as they indicated the Ambient Light concept as supporting, pleasant or relaxing, while others experienced the Ambient Light concept as more distracting or inducing a sleepy feeling that may lead to more dangerous situations. This indicates that the attitude towards the Ambient Light concept was highly individual and endorses the need to take differences between drivers into consideration when designing systems that aim to induce more socially desired behavior. A system designed for one driver may induce negative behavior or experience for other drivers. Thus, as mentioned before, strategies that are intended to persuade one driver to use intelligent systems may have no or even a negative influence on other drivers (Taubman-Ben-Ari & Yehiel, 2012). Of course it is not meaningful to devise strategies for individual drivers and we propose to devise strategies for types of drivers as discussed in Chapter 4, but so far, from the current results, there is no clue yet on the basis of which characteristics to classify drivers into types of drivers.

The objective results of this study are not in line with the findings in a previous study performed by Meschtscherjakov et al. (Meschtscherjakov et al., 2015) as hypothesis 3 was rejected. In their study, participants were asked to drive at a given speed with only the ambient light as a visual feedback additionally to the driving simulation itself but without a speedometer. Their results show that participants drove significantly slower with a higher velocity of the ambient light. Our results suggest that the influence of the Ambient Light concept on the perceived speed is negligible compared to the objective measure of the speed gained through the speedometer, resulting in no significant difference in the actual speed driving within the conditions proportional speed (C1), proportional higher speed (C2) and the average of the two baselines.

The absence of significant differences in the average speed and the experience reported between the proportional speed condition (C1) and the proportional higher speed condition (C2) suggests that the participants are not consciously aware of the difference between the two conditions. Apparently, the difference of 10 km/h is subtle and not noticeable by most participants. The results of this study suggest that participants are able to distinguish changes in speed within one condition but not between conditions, indicating that the absolute speed of the Ambient Light concept itself is of less importance compared to the relative speed, the proportional aspect of used in this study.

Limitations

There are also several disadvantages of using a driving simulator as the fidelity of the simulator may affect the perceived speed. Therefore, we cannot extrapolate towards the influence of the Ambient Light concept on the user experience on the road. Also, having no traffic in the scenario may have had an influence on the results as other traffic may also have an influence on the perceived speed and therefore the driving experience. Thus, the influence of the Ambient Light should also be tested within an instrumented vehicle on the road in real traffic conditions or in scenarios with other traffic.

Conclusion

The results indicate that the ambient light can have a positive influence on the experience of users as some of the participants experienced the ambient light as pleasant, informative and/or counteracting boredom. Participants indicated that the light pattern of the Ambient Light concept counteracted the boredom induced by the use of Cruise Control. However, the results indicate that Ambient Light concept has a negligible effect on the perceived speed as driven speed without the use of the Ambient Light was not significantly different compared to the speed driven with the Ambient Light. A question that remains to be answered is how the driving experience will be affected when participants first have the possibility to set the preferred speed of the light of the Ambient Light concept and how their experience will be influenced if the chosen speed is taken as a base for the proportional speed condition used in this study.

Looking into the future the Ambient Light concept might also be applied in autonomous vehicles to enhance the driving experience for the driver when being driven. We believe that an ambient light system, as presented in this chapter could be utilized to influence driving experience in various ways for a variety of drivers. The Ambient Light can perhaps provide accurate information about the speed for drivers who prefer safe driving and adhere to the speed limits. On the other hand, the Ambient Light in a different setting can perhaps induce more the sensation of speeding for drivers who prefer driving at higher speeds and perhaps no Ambient Light is needed for drivers who experience driving already as somewhat stressful. Above that, the Ambient Light may be used to reduce motion sickness since it provides information about the speed in the peripheral vision of a person sitting in the autonomous vehicle reading a book.

As the results of this study indicate that the attitude towards the ambient light was highly individual, another step is to continue the idea of more personalized persuasion inside a vehicle to influence the experience of driving.

6

A Satisfying Experience for Autonomous Driving Through Personalized Soundscapes

Abstract

Autonomous driving is likely to result in degradation of the driving experience. However, as long as autonomous vehicles contain driving controls, it is up to the discretion of the driver to put the autopilot function on or off. To prevent drivers from taking over control when there is no need to do so, the degradation of experience may need to be compensated for. One way to do so may be by offering proper soundscapes. This chapter presents a study conducted in a driving simulator, in which the influence of two different soundscapes on the driving experience was investigated, one giving a more thrilling experience, the other giving a more relaxing experience. Forty-four participants representing two different driving styles, assertive/risky or calm/careful, drove in a simulated autonomous vehicle, where they could put the autopilot function on or off. When the autopilot was enabled, one of the two soundscapes designed for this study was played. The results did not provide a conclusive answer that soundscapes personalized according to participants' driving style influenced the willingness to use the autopilot. In the discussion, several possible explanations are considered and directions for future research are outlined.

THIS CHAPTER IS BASED ON:

Hooft van Huysduynen, H., le Blanc, J.J., Terken, J. M. B., & Eggen, J. H. (Submitted, Personal and Ubiquitous Computing 2018). *A Satisfying Experience for Autonomous Driving Through Personalized Soundscapes*

Introduction

It is predicted that the way vehicles are controlled by the driver as we know them nowadays, will disappear ("Drive Me – the self-driving car in action | Volvo Cars," n.d.; "Here's how Daimler is evolving its tiny Smart car for self-driving - The Verge," n.d.; "Waymo," n.d.). Intelligent systems will take over driving tasks like steering, accelerating, and braking, ultimately resulting in autonomous vehicles. However, as long as autonomous vehicles are not able to operate appropriately in all situations that the vehicle may encounter, the driver may have to regain control occasionally. To enable drivers to do so, vehicles will contain driving controls such as a steering wheel, throttle, and brake. This also provides the opportunity for the driver to regain control of the vehicle when the system does not explicitly require the driver to take the control back.

One reason why a driver may want to regain control may be that the behavior of the vehicle deviates from the desired driving behavior, therewith degrading the driving experience and influencing the willingness of the driver to let the vehicle drive autonomously (Eckoldt et al., 2012). This could be solved by allowing drivers to share control (Abbink & Mulder, 2010), for example, by allowing the driver to influence the acceleration of the vehicle. However, since automated systems are developed with the aim to increase safety, we would like to take measures that persuade people to use the automation as much as possible, without interfering with the behavior of the automated vehicle. Therefore, we might look for ways to compensate the driver for the degradation of experience.

Since people differ in their needs and interests, strategies that are intended to persuade one type of driver to use intelligent systems may have no or even a negative influence on other types of drivers (Taubman-Ben-Ari & Yehiel, 2012).It has been suggested that influencing drivers may be done in several ways, for instance by visual, tactile or auditory means (Petiot et al., 2013). In the current study, we explore whether the use of sounds in a vehicle may contribute to the willingness to use automated functions in a vehicle, in terms of keeping the automated functions enabled, as the use of sound is mentioned as one of the potential ways to compensate for the loss of driving experience (Petiot et al., 2013).

The current soundscape in a vehicle results from in-car sounds generated by the engine, tires and aerodynamic noise, as well as auditory displays, mostly in the form of discontinuous sounds such as warnings and alerts (Nees & Walker, 2011). The method of mapping and displaying data through non-speech audio is called sonification (Kramer, 1994), representing on-going information about a system and its changes through continuous soundscapes. The proper use of auditory displays is important, as more pleasant and sonically integrated displays may contribute significantly to the acceptance of systems making use of auditory displays (Kramer, 1994). Also, proper soundscapes that are in line with the driving profile of the driver may positively influence the willingness to use intelligent systems in vehicles.

This chapter investigates the influence of two different soundscapes on the driver's experience while driving when an autopilot is activated. Next, the experiences of different types of drivers are compared. The soundscapes provide on-going information about other traffic around the vehicle. One concept is designed for drivers with a calm/careful driving style, who prefer sustainable and safe driving. It provides the information in a relaxing and comfortable matter, operating in the periphery of the driver's attention. The other concept is designed for drivers with a risky/assertive driving style. It provides the same information in a more exciting manner, supporting the need for sensation and thrill while driving and is meant to prevent a need to adjust the behavior of the vehicle or take over control altogether.

Related Work

Decisions made during driving are dependent on multiple factors, including information about objects in the proximity and the state of the vehicle itself. This task-specific understanding of the situation is also known as situation awareness (Endsley, 1995) which is a necessity for manual driving (Stanton et al., 1997). One of the sources of information for building situation awareness is through the sounds of the vehicle and of the surrounding traffic (Walker, Stanton, & Young, 2006). However, as mentioned by Walker et al. (Walker et al., 2006) the trend in automotive design is towards diminishing the sound feedback, for instance through better sound insulation of the vehicle. Another factor reducing the situation awareness of drivers is the increasing automation of vehicles. These developments may lead to more dangerous situations, especially when the driver has to regain control of the vehicle. Furthermore, the increasing automation of the vehicle tends to lead to more engagement in non-driving related tasks by drivers, which may also negatively influence the situation awareness (de Winter et al., 2014). According to Walker et al. (Walker et al., 2006), auditory feedback can positively influence the situation awareness of drivers, creating safer situations when the driver has to regain control of the vehicle.

A related development is the introduction of electrical and hybrid vehicles. Here, traditional and familiar sounds created by the internal combustion engines are disappearing, resulting in quieter vehicles, which may have a negative impact on the driving behavior. For example, several studies indicated that in-car sound has an influence on the perceived and driven speed of a vehicle, resulting in driving at higher speeds when no or low in-car sounds are heard (Hellier, Naweed, Walker, Husband, & Edworthy, 2011; Walker et al., 2006; E. Y. Wang & Wang, 2012). Wang et al. (E. Y. Wang & Wang, 2012) indicated that a totally quiet cabin may lead to an incorrect judgment of the speed. Especially when driving 100 km/h or faster the speed was underestimated. Hellier et al. [8] demonstrated that the driving speed was higher when there was no engine noise feedback or low levels of sound feedback. As the number of hybrid and electric vehicles is increasing and these vehicles have lower to no in car-sounds, Beattie et al. (Beattie, Baillie, & Halvey, 2015) investigated the use of different types of sound cues for auditory displays replacing the sounds that disappear with the development of hybrid and electric vehicles. They investigated the difference in the effectiveness of the use of existing vehicle sounds, earcons, speech and auditory icons to represent different primary driving tasks. The results indicated that the use of earcons was as effective as the use of existing vehicle sounds. A prior study also indicated that spatialized sounds supported the feeling of control in autonomous driving and enhancement of awareness (Beattie, Baillie, Halvey, & McCall, 2014) that is needed when drivers need to regain control of the vehicle when the vehicle is not able to continue driving by itself. The sound produced by the vehicle enhances the situation awareness both of the driver and other road users such as pedestrians and cyclists, enhancing safety.

The sound of the vehicle is also often seen as a means of branding for car manufacturers through the use of sound signatures (Petiot et al., 2013), creating different driving experiences according to the sounds heard. Pursuing on this, a Swedish company created SoundRacer, a gadget that allows drivers to experience the sound of, for example, a Ferrari V12 engine while driving ("Ferrari V12 sounds in your standard car!," n.d.). Different soundscapes create different experiences while driving the same car.

A study that used sound to convey information through calm technology, allowing sounds to move between the center and the periphery of attention, indicated that sound information can effectively be perceived in the periphery of attention (Bakker, van den Hoven, & Eggen, 2010). The researchers also mentioned that the extent to which the participants experienced the sounds as informative or disturbing was related to the extent to which the conveyed information was relevant. This relevance depended on the context, experience, interest, and knowledge of the participants.

In this chapter, the use of two different soundscapes designed for either riskier or more careful drivers is explored in relation to the driving experience and the willingness to make use of the autopilot.

Concept

The sounds used in this study were designed as continuous soundscapes that correspond to the traffic situation around the vehicle. Elements of the soundscapes may be brought to the focus of the attention when desired and fade into the background or periphery when not needed. Both soundscapes used in the study were linked to the autopilot and are therefore only activated when the autopilot was engaged by the driver when driving in a driving simulator. Each of the soundscapes designed for this study was built upon a three-layer structure, consisting of vehicle sound layer (L1), a base ambiance layer (L2) and a layer of sound generated from surrounding traffic (L3) (see Figure 8). The vehicle sound layer (L1) was the same for both concepts and consisted of combined field recordings from both inside and outside of the vehicle, balanced and equalized to mimic a realistic 'inside of a car' auditory feel. The sounds were recordings of an engine, tires, and wind while driving. The engine sound gradually changed in pitch and tempo in relation to the rpm of the motor, using a seamlessly looped sound sample of a running engine at 2000 rpm. The tire and wind sounds increased in volume relative to the speed of 80 km/h and higher. The electronically generated sounds for the base ambient sound layer (L2) and electronically generated real-time controlled sounds for the third layer (L3) were different for the two concepts, as detailed below.

Concept A

For the careful driver, the soundscape was designed to create a sense of comfort and an overall unobtrusive auditory experience when the autopilot was activated, as if their vehicle was enclosed in a safe 'bubble'. The second layer (L2) of sound for the careful

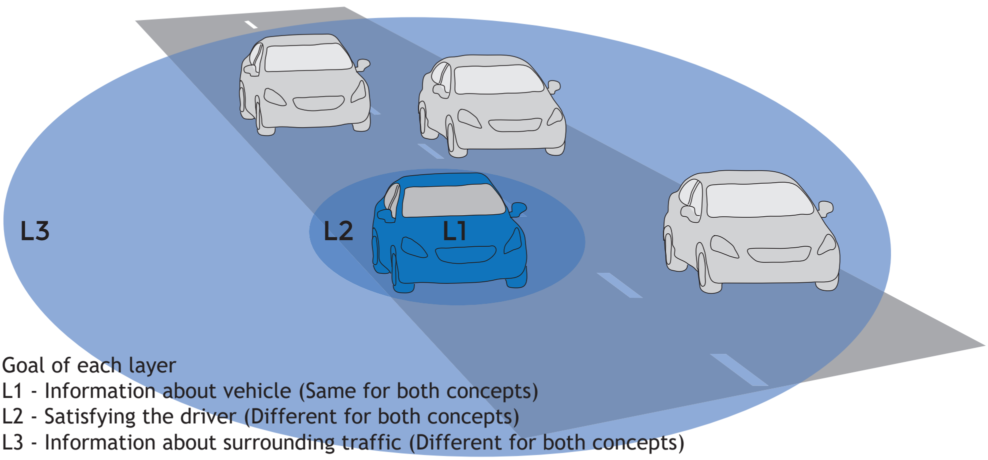


Figure 8. Sound Layers

driver consisted of a continuous frequency modulated sine-wave of a very low frequency, which functioned as a subtle background sound when the autopilot was engaged. For the third layer (L3), different sets of sounds were explored in a pilot study. The final sound set for the third layer (L3) consisted of rhythmic variations of drone sounds representing the surrounding traffic with a periodical increase and decrease in their overall amplitude. Every vehicle on the road that entered the sensor range of the autonomous car was translated into an additional harmonic sound in the soundscape. Real-time low-pass filtering was applied to the sounds to enhance the feeling of a safe enclosure. The sounds faded in, in combination with a slight raise of the low-pass filter cutoff frequency. This brought the sound slightly more to the foreground when a vehicle came closer. The sounds were overall seen as enjoyable, motivating and exciting by the five participants in the pilot study.

Concept B

For the second concept, the soundscape was designed to stimulate a feeling of arousal, simulating quick maneuvers and overall a more risky driving style. The sound for L2 was designed to sound like a deep heartbeat sound that pitched very slightly when the autopilot speeded up beyond 80 km/h. The same as for L3 in concept A, the sounds in L3 for the risky driver corresponded to the number of vehicles surrounding the car. Different sound designs were studied during a pilot study. The final sound for the third layer (L3) consisted of a non-rhythmic soundscape featuring more disconnected sounds that were less coherent when played together, creating more unexpected auditory combinations when the driver encountered other traffic. An algorithm was used to increase the playback speed when the distance to the other vehicles decreased, creating a rising pitch of the sound. In the pilot study, the non-rhythmic version was perceived as unpredictable and therefore more complex, leading towards a higher demand of attention. Overall the non-rhythmic sound was experienced as thrilling and fast by the five participants in the pilot study.

Indicator sound

The sound sample for the indicator was a custom sound for both the risky driver and the careful driver. The indicator sound was directional, meaning that it was heard from the front right or front left speaker depending on which indicator was activated.

Method

Driving Simulator

The simulator used in this study was a medium-fidelity fixed base simulator designed and manufactured by the Dutch company Green Dino BV (see Figure 9). The simulator consisted

Figure 9. Driving Simulator

of a car seat, a Ford steering wheel, indicators, ignition key, pedals, a gear lever and a handbrake. The renderings were visualized on three 32 inch screens and the mirrors and dashboard were part of the 3D renderings. The driven speed and activation of the autopilot were logged by the simulator at 20 Hertz. It this study the vehicle contained automatic gearing.

The scenario consisted of a two-lane highway with mixed traffic, where, at certain moments, the traffic was a little crowded but there were no congestions. The vehicle used in this scenario had the ability to drive autonomously through the use of an autopilot. The autopilot function could be turned on or off by pressing a button located next to the handbrake, and it could also be deactivated by hitting the brake. When the autopilot was activated, the vehicle took over the task of driving, leaving the driver to only monitor the system. In the autopilot setting the vehicle controlled all aspects of driving including changing lanes and overtaking other vehicles. The steering wheel moved along with the movements of the vehicle. At certain moments the autopilot reduced the speed of the vehicle to around 80 to 90 km/h in order to anticipate upcoming events. According to the SAE automation taxonomy (SAE International, n.d.), intelligent systems that correspond to level 2 of automation, also known as partial automation, still require full attention throughout the driving task. Here, the driver is responsible for identifying situations where the system runs into its limitations. The autopilot function used in this scenario can be categorized as level 2 of the SAE classification (SAE International, n.d.) as participants were required to keep their attention focused on the driving task, and to continuously monitor the system and the surroundings. This level is typical for currently available autopilot functions in vehicles such as the Tesla. As it is level 2 automation, the autopilot function is not completely perfect and therefore requires the full attention of the driver to intervene when needed. At certain moments the autopilot reduced the speed of the vehicle to around 80 to 90 km/h in order to give phantom traffic jams building up further down the road the opportunity to dissolve (Schakel et al., 2010). This could happen at moments when a minimum amount of traffic was around; no reason for the adjustment was communicated to the driver. Also, the behavior of the autopilot was more conservative resulted in the vehicle always trying to go back to the right lane even when approaching a truck in the right lane. As a consequence, when approaching a truck in the same lane the speed of the vehicle would first be reduced before the vehicle would change to the left lane to overtake the truck.

Audio

The sound system of the driving simulator included four Genelec 8030 speakers and a Genelec 7040a subwoofer. These speakers were connected to an external sound card that was connected to an external computer. This computer was connected to the simulator computer via Ethernet allowing TCP/IP communication between two computers. Sounds in the third layer of the two concepts were positioned in 3D space in Max/MSP and displayed on the four individually assignable speakers positioned around the driver, as well as the subwoofer underneath the driver seat. The software Max/MSP was used to translate different parameters sent by the Unity software into different sounds by using Processing software as a bridge.

Study Set-Up

A between-subjects user study was conducted to evaluate the effects of the different soundscapes on the willingness to use the autopilot function. People were asked to participate in a driving simulator study related to autonomous driving and completed a pre-evaluation questionnaire. This pre-evaluation questionnaire asked for demographic data and provided eight different personas, explained in chapter four, representing different driving styles, as explained in Chapter 4, four of the personas representing calm/careful driving styles and four of them representing risky assertive driving styles. Respondents were asked to imagine that it was a Thursday morning and they were in their vehicle driving to work. They were driving on the highway in mixed traffic, it was a busy road but there were no congestions. Then they were asked with which of the eight personas they identified themselves most for the given scenario.

The results of the pre-evaluation questionnaire were used to assign participants to one of the two driving styles, one the more assertive/risky driving style and the other the more calm/careful driving style. After participants were assigned to one of the two groups, they received an invitation to the driving simulator. Within each group, the participants were pseudo-randomly assigned to condition A or B, such that half perceived condition A and the other half condition B. In condition A, concept A was played, while in condition B, concept B was played.

Participants

Forty-four participants who were in possession of a driving license participated in the study, forty males (90.91%) and four females (9.09%), aging between 18 and 59 years (M=26.32, SD=6.92). The participants received a €10 gift card as a compensation for their time. Of the 44 people participating in this study, 28 participants (of whom two were women) were categorized as careful drivers and 16 participants were categorized as risky drivers.

Procedure and Measure

After signing the informed consent form participants were asked to take a seat in the driving simulator. The first part of the session was the training phase that allowed participants to become familiar with the simulator and its behavior as well as the use of the autopilot function which took over all the control of the vehicle till the function was disabled by the driver. The aim of this part was that the participants understood how the simulator worked in combination with the assigned sound concept, so they had to drive both with and without the autopilot enabled. The participants were instructed that an autopilot system was implemented, allowing the vehicle to drive by itself when the autopilot was activated. It was mentioned that the autopilot could be activated and deactivated through a small button next to the handbrake and through hitting the break the autopilot would also be deactivated. This part took around twenty minutes on a four-lane highway with mixed traffic (See Figure 9).

Before the start of the main part of this study, the participants had a five-minute break in which the system was reset and a brief explanation was provided to the participants. They were told to imagine they were sitting in their vehicle on a typical morning driving to their work. The participants were asked to drive in the simulator as if it was their own vehicle they use to go to work but now also making use of the autopilot function. They were told that the traffic rules were in line with the traffic rules as they apply on a typical highway in the Netherlands, including a speed limit of 120 km/h. The task was to monitor the system and the situation around the vehicle during the trip. Participants were allowed to disable the autopilot function when they did not agree with the behavior of the autopilot or felt uncomfortable, frustrated or not safe by using it. As the system had some minor issues with changing lanes, participants were instructed to ignore these issues by not letting these issues influence their decision to disable the autopilot. The trip on the highway took 20 minutes after which an alarm would ring indicating that they could disable the autopilot if it had not already been disabled, and bring the car to the side of the road to make a safe stop. After this, the participants were asked to fill in the User Experience Questionnaire (UEQ) (Laugwitz et al., 2008), providing a comprehensive impression of user experience , addressing both usability aspects (efficiency, perspicuity, dependability) and user experience aspects (originality, stimulation). Unified Theory of Acceptance and Use of Technology questionnaire (UTAUT) (Venkatesh et al., 2003), assessing the four constructs related to accepting new technologies or intelligent systems and an open question in which they were asked to clarify what they thought of the soundscape connected to the autopilot. The total length of the session was approximately one hour.

It was hypothesized that participants in the compatible conditions (careful drivers who received concept A and risky drivers who received concept B) would score higher on the different categories of both the UEQ and UTAUT questionnaire compared to participants in the incompatible conditions (careful drivers who received concept B and risky drivers receiving concept A). Next, it was also hypothesized that the group in the compatible conditions would have more positive opinions about the soundscape compared to the incompatible conditions. Careful drivers who received concept B and risky drivers receiving concept A were expected to provide more negative opinions about the soundscapes.

Results

	Concept A	Concept B
Careful drivers	14	14
Risky drivers	8	8

Table 13. Distribution of the participants among the concepts

Of the 44 people participating in this study, 28 participants were categorized as careful drivers and 16 participants were categorized as risky drivers. In total 22 people heard concept A when they activated the autopilot and the other 22 people heard concept B when the autopilot was activated (see Table 13).

	Concept A	Concept B
Careful drivers	M = 5.36 SD = 2.88 Min = 1 Max = 10	M = 5.88 SD = 3.80 Min = 1 Max = 13
Risky drivers	M = 4.29 SD = 1.94 Min = 2 Max = 9	M = 5.38 SD = 3.25 Min = 0 Max = 9

Table 14. Number of times the autopilot was disabled

The autopilot was disabled on average five times per participant with a minimum of zero to a maximum of 13 times during the session (see Table 14). The number of times that the autopilot was disabled did not show a relation to the distinction of whether the concept was compatible with the driving style or not.

	Careful A	Careful B	Risky A	Risky B
Attractiveness	M = 0.63 SD = 1.12	M = 0.96 SD = 1.18	M = 0.74 SD = 0.65	M = 0.85 SD = 1.44
Perspicuity	M = 1.27 SD = 1.18	M = 1.54 SD = 1.36	M = 1.39 SD = 0.97	M = 1.19 SD = 0.80
Efficiency	M = 0.68 SD = 0.84	M = 0.79 SD = 1.10	M = 0.79 SD = 1.10	M = 0.25 SD = 0.88
Dependability	M = 1.05 SD = 1.04	M = 1.00 SD = 1.21	M = 0.68 SD = 1.27	M = 0.72 SD = 1.51
Stimulation	M = 0.26 SD = 0.89	M = 0.32 SD = 1.11	M = 0.57 SD = 0.86	M = -0.70 SD = 1.63
Novelty	M = 0.05 SD = 1.17	M = 0.36 SD = 1.18	M = 0.18 SD = 1.03	M = 0.09 SD = 1.76

Table 15. Results of the different scales of the UEQ per condition

Table 15 shows the means and standard deviations of the different scales of the UEQ with scores between -3, the most negative value and +3, the most positive value. As mentioned before, careful drivers exposed to concept A and risky drivers exposed to concept B were expected to give more positive judgments than careful drivers exposed to concept B and risky drivers exposed to concept A, respectively.

To evaluate the significance of differences in experience between the different conditions two-way between – subjects ANOVAs were conducted, with driving styles and concepts as fixed factors. The results revealed no significant interactions nor significant effects of the fixed factors.

Table 16 shows the means and standard deviations of the different scales of the UTAUT with scores between 1, the most negative value, and 7, the most positive value. Again, careful drivers exposed to concept A and risky drivers exposed to concept B were expected to give more positive judgments than careful drivers exposed to concept B and risky drivers exposed to concept A, respectively.

	Careful A	**Careful B**	**Risky A**	**Risky B**
Behavioral Intention	M = 4.36 SD = 1.73	M = 4.83 SD = 1.70	M = 4.75 SD = 1.94	M = 3.88 SD = 1.88
Performance Expectancy	M = 4.17 SD = 1.10	M = 4.11 SD = 1.41	M = 4.31 SD = 0.92	M = 3.73 SD = 2.06
Effort Expectancy	M = 5.75 SD = 0.89	M = 5.66 SD = 1.25	M = 5.81 SD = 1.17	M = 5.81 SD = 0.70
Social Influence	M = 4.05 SD = 1.24	M = 4.48 SD = 1.25	M = 4.97 SD = 0.90	M = 4.69 SD = 1.02

Table 16. Results of the different scales of the UTAUT per condition

To evaluate the significance of differences in acceptance two-way between – subjects ANOVAs were conducted, with driving styles and concepts as fixed factors. The results revealed no significant effects of the fixed factors nor significant interactions.

Next to the quantitative results of the two questionnaires, a third analysis was performed on the qualitative data gained from the open question in which participants were asked to reflect on the soundscape connected to the autopilot. The answers describing the opinions about the soundscape they heard while driving with the autopilot were documented and categorized into reoccurring themes. When reflections of participants contained elements related to different themes, they were split up and used separately in the analysis. The analysis was done through affinity diagramming with colleagues who were involved with this study (Martin & Hanington, 2012). The 64 opinions provided by the 44 participants were clustered over six reoccurring themes: Perceptual, Positive and Negative Functionality, Positive and Negative Ambience, and Onset of Boredom or Sleepiness. Again, it was expected that careful drivers exposed to concept A and risky drivers exposed to concept B would give more positive judgments than careful drivers exposed to concept B and risky drivers exposed to concept A, respectively. In contrast, careful drivers exposed to concept B and risky drivers exposed to concept A were expected to give more negative judgments than careful drivers exposed to concept A and risky drivers exposed to concept B, respectively.

	Careful A	Careful B	Risky A	Risky B
Perceptual	1	3	1	1
Positive Functionality	5	4	3	4
Positive Ambience	5	6	2	5
Negative Functionality	5	1	2	-
Negative Ambience	4	4	-	-
Onset of Boredom or Sleepiness	2	2	2	2

Table 17. Distribution of the opinions among the six categories

Perceptual

In total six participants mentioned that they were not aware of the soundscape played or could not relate to the sound at all.

"I did not hear anything, did not notice." (P6, Risky A). "I would like it to be a lot louder …" (P7, Careful B). "Did not really notice, when working …" (P21, Careful A) "I did not realize it." (P27, Careful B).

Positive Opinions

Positive Functionality

Positive opinions expressing function-related benefits of the soundscape were categorized as positive functionality. In total sixteen participants mentioned different function-related benefits gained when listening to the soundscape when the autopilot was activated.

"It helps you to pay attention to the road …" (P1, Careful A). I think it is realistic to what you would actually hear while driving." (P16, Risky A). "The sound system connected to the

autopilot helps the driver to have a quick response …" (P32, Careful B). "... It adds to my trust in the system because it communicates in a very friendly but efficient way that it is aware of its surroundings and its intentions…" (P44, Risky B).

Positive Ambience

Positive emotions provoked by the soundscape were categorized as positive ambiance. In total, eighteen participants mentioned positive feelings/emotions towards the soundscape they heard.

"… like if I entered a protected bubble and I could feel somehow protected and safe …" (P4, Careful A). "It is nice to hear …" (P8, Careful B). "It is interesting …" (P25, Risky A). "I think it has a positive influence ..." (P39, Risky B).

Negative Opinions

Negative Functionality

Negative opinions expressing function-related negative consequences of the soundscape were categorized as negative functionality. Eight participants responded to the question of what they thought of the soundscape associated with the autopilot as not useful, decreasing faith or losing the connection with the surroundings.

"… but the sound also made me feel isolated from the road …" (P4, Careful A). "… it felt like I was losing the surrounding sounds, which I think is important." (P13, Careful A). "Honestly, it was just white noise. It did not do anything to influence my behavior …" (P43, Risky A).

Negative Ambience

Opinions expressing negative emotions were categorized as negative ambience. Eight participants mentioned negative feelings towards the soundscape they heard.

"Sound is not very pleasant …" (P17, Careful A). "Sounded ominous most of the time." (P20, Careful B). "It sounds dangerous. Activating the soundscape made it sound like I was in danger, or going to be in danger soon …" (P30, Careful A). "I felt like it was unnerving as it created a sense of threat when I felt I had good control…" (P38, Careful A).

Onset of Boredom or Sleepiness

Eight participants explicitly mentioned that they felt that the soundscape induced feelings of boredom and sleepiness, and those opinions were treated as a separate category.

"…could have the potential to put the driver to sleep (as it is repetitive and monotonous)…"

(P3, Thill A). "… It is like white noise which was making me sleepy." (P16, Risky A). "A bit dull, it made me bored and inattentive at some point." (P22, Careful A) "… The sound made me even more relaxed while already bored and I felt like it was becoming easy for me to fall asleep." (P28, Risky B).

Overall, the differences in qualitative responses of the participants, divided among the six categories, did not show conclusive results that the compatible conditions had a more positive influence on the experience and the willingness to use the autopilot compared to the incompatible condition (See Table 16). The distribution of opinions over the six categories did not show a clear relation to the driving styles indicated by the questionnaire filled in beforehand and the difference in soundscape they heard when the autopilot was activated. There is a slight indication that, as hypothesized, risky drivers exposed to concept B (N = 8) were more positive about the soundscape than risky drivers receiving concept A (N = 8), and that risky drivers exposed to concept A were more negative about the soundscape than risky drivers receiving concept B. However, contrary to expectation, there was no similar trend for calm/careful drivers. Instead, the data in Table 4 suggest that careful drivers exposed to the compatible concept A (N = 14) were more negative about the soundscape than careful drivers receiving the incompatible concept B (N = 14).

Discussion

The findings emerging from the current study do not provide conclusive evidence for the hypothesis that soundscapes that are compatible with people's driving style result in a better driving experience and result in more willingness to use the autopilot than soundscapes that are incompatible with people's driving style. This may either mean that the auditory soundscapes were not implemented adequately, or that the use of auditory stimuli is not a suitable solution for personalized persuasion, or that the use of personalized persuasion based on differences in driving style to influence the driving experience is not suitable, or that the preferred driving style while driving manually differs from sitting in an automated vehicle. In the next paragraphs, we will discuss these four possible explanations.

One reason why the results of this study are not conclusive might be that the soundscapes were not implemented adequately. In the first place, not all of the participants did not perceive the sounds played when the autopilot was activated. Secondly, perhaps the differences between the two soundscapes were not extreme enough, making it more difficult to measure a difference in experience. Next, it may be that the soundscape for careful drivers was not calm, relaxing or informative enough and on the other side, the soundscape for risky drivers was not sensational or upbeat enough. Finally, it may also be that the intention of the two soundscapes was not communicated clearly enough as not all the participants related the sounds to the vehicles surrounding their vehicle.

A second reason may be that the use of auditory stimuli, in general, may not be the most suitable solution to influence the experience of driving in an automated vehicle. In a previous study, explained in Chapter 5, that made use of ambient light it was found that overall the ambient light used in that study had a positive effect on the driving experience but that the attitude, positive or negative, towards the ambient light was highly individual. So perhaps a multi-modal approach of both visual and auditory stimuli has a stronger effect on driver's experience.

A third reason may be that the use of personalized persuasion based on differences in driving styles is not the most suitable solution. Instead, personal persuasion by means of soundscapes might be more effective if the choice is based on personality characteristics of the driver (for example, sensation seeking (Zuckerman & Neeb, 1980). Multiple studies looked into the relation between sensation seeking and risky driving. Jonah et al. (Jonah, 1997) examined 40 studies on sensation seeking as a direct influencer of risky driving and its consequences and as a moderator of the influence of other factors. This review showed a positive relation between sensation seeking and risky driving, making this explanation for the current findings less likely. This indicates that there is a positive relation between people's sensation seeking score and their driving style. However, it still may be that drivers' preferences for persuasion are also related to other characteristics. Kaptein (Kaptein et al., 2012) showed that personalized persuasion may be more effective by creating tailored persuasive messages to influence people's behavior, by making use of the strategies defined by Cialdini (Cialdini, 2001). These strategies are based on human preferences for automatic, shortcut responses to messages. For example, some people are more inclined to act on a request under social pressure, others are more inclined when asked by an authority figure. Possibly, persuasion strategies related to these differences between people might be more effective.

Lastly, the fourth reason may be that the driving style that people prefer while driving manually is not in line with the needs and motivations when the driving is automated. Multiple studies looked into the adoption of the user's driving style by autonomous vehicles (Basu, Yang, Hungerman, Singhal, & Dragan, 2017; Yusof et al., 2016) and found that drivers prefer a more defensive driving style compared to their own when being driven by an automated vehicle. The implication of this would be that drivers do not have to be compensated in different ways, depending on their driving style, when being driven in an autonomous vehicle.

Limitations

Another aspect that has to be taken into consideration is the use of a driving simulator. The fidelity of the simulator may have had an effect on the driving experience, and accordingly may have influenced how participants perceived the autopilot and the effect of the sound on the willingness to use the autopilot. In addition, the setting was artificial, so that the ride was not part of a real-life activity. Thus, it remains to be established that the same considerations will apply for use or disuse of the autopilot in combinations with the soundscapes in real-life situations.

Conclusion

This chapter investigated the influence of two different soundscapes on the driver's experience while driving automated through the use of an autopilot, separately for two different types of drivers, calm/careful drivers and assertive/risky drivers. The study reported in this chapter investigated the difference in experience and the different opinions participants had towards the soundscape they heard while driving with the autopilot. This study took place in a driving simulator. The participants drove in a partially-autonomous vehicle for 20 minutes on a two-lane highway with mixed traffic.

It was expected that participants in the compatible conditions (careful drivers who received concept A and risky drivers who received concept B) would score higher for the different dimensions of both the User Experience Questionnaire (UEQ) and the Unified Theory of Acceptance and use of Technology (UTAUT) questionnaire compared to the participants in the incompatible conditions (careful drivers who received concept B and risky drivers receiving concept A). The results of the UEQ and UTAUT questionnaire did not reveal any significant differences among the different testing groups. The qualitative data gained from the driving simulator study described in this chapter revealed six reoccurring themes among all given opinions: Perceptual, Positive and Negative Functionality, Positive and Negative Ambience, and Onset of Boredom or Sleepiness.

The opinions provided by the participants did not show a clear effect of compatibility. Therefore, it cannot be clearly stated that the two soundscapes A and B presented in this chapter are appreciated by careful drivers and risky drivers, respectively. This may be because the different auditory stimuli were not implemented appropriately, or because the use of auditory stimuli is not the most suitable solution, or because the use of personalized persuasion based on differences in driving style to influence the driving experience is not suitable, although in view of the literature the last explanation seems less likely.

As no conclusive answers were found that more personalized soundscapes influenced the willingness to use the autopilot, the next chapter will zoom out again and investigate alternative reasons why drivers may disengage the autopilot not related to the soundscape.

7
Why Disable the Autopilot

Abstract

The number of systems in commercially available vehicles that assist or automate driving tasks is rapidly increasing. At least for the next decade, using such systems remains up to the discretion of the user. This chapter focuses on autopilot systems and investigates different reasons why drivers may disengage the autopilot are investigated. This was done through a simulator study in which the system could drive fully automated, but where participants could also disengage the system. Qualitative data were collected about why participants disengaged the autopilot. The analysis of the data revealed six reoccurring themes covering the reasons why participants disabled the autopilot without the need to intervene: The speed maintained by the autopilot, The behavior of the autopilot in relation to overtaking other vehicles, Onset of boredom, Onset of sleepiness, Lack of trust in the autopilot and Enjoyment of manual driving. On the basis of the results, design opportunities are proposed to counteract the tendency to disuse automated driving systems.

THIS CHAPTER IS BASED ON:

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Introduction

As intelligent systems will take over activities such as steering, accelerating and braking, creating automated vehicles, the role of the driver will gradually change from an actuator to an operator, and ultimately to a passenger (Eckoldt et al., 2012). Ultimately, vehicles will be able to drive in all possible situations they may encounter, thus drive fully automated corresponding to level 5 of the SAE automation taxonomy (SAE International, n.d.). In such vehicles no driving controls will be available anymore and the driver will not be able to regain control.

The purpose of the development of automated vehicles is to increase the traffic flow, reduce traffic accidents as well as driver's workload, distraction, and drowsiness, to create safer driving environments and mobility for everyone, and enhance convenience and sustainability. As long as automated vehicles are not able to operate in all possible situations, the driver needs to regain control when the vehicle is not able to proceed by itself. According to the SAE automation taxonomy (SAE International, n.d.), intelligent systems that correspond to level 2 of automation, also known as partial automation, still require full attention throughout the driving task. Here, the driver is responsible for identifying situations where the system runs into its limitations. Level 3 automated vehicles do not require supervision. When the system runs into its limitations, it will issue a request to the driver to regain control. Given that the vehicles in either of those two levels still contain driving controls such as a steering wheel, throttle, and brake, the driver also has the possibility to regain control of the vehicle when the behavior of the systems in the vehicle deviates from the desired driving behavior, even if the system does not run into the boundaries of the technology. The behavior of the intelligent systems may, therefore, influence the willingness of the driver to use the autopilot. Therefore, the targeted benefits may be jeopardized when an autopilot is not accepted by drivers. This may not only affect the driver him/ herself but also other road users as well as the development of these type of systems in general. Knowing the reasons why people do not accept the automation may help to design the technology such that this tendency is suppressed.

In the remainder of this chapter, we will use the term 'autopilot' specifically to refer to intelligent systems that still require full attention throughout the driving task (level 2). Most vehicles with assisted and automated functions that are commercially available nowadays are partially automated vehicles, demanding continuous attention and requiring human intervention if needed. In this chapter, reasons for drivers to disable the autopilot and regaining control without an objective need to take the control back are investigated. This is done through the analysis of qualitative research data gathered during a driving simulator study in which people drove in a vehicle that was able to drive automated but required the driver to continuously monitor the system and surroundings. The aim of this chapter is to create a better understanding of possible reasons why drivers may disable the autopilot function without there being a clear need to do so, so that the autopilot function can be improved and the users' willingness to use it may increase.

Related Work

Levels of Automation

The Society of Automotive Engineers (SAE) (SAE International, n.d.), has defined six Levels of Automation (LOA), ranging from 0 to 5, based on technological aspects of (a combination of) intelligent systems in vehicles.

Level 0 is defined as no automation as the driver controls the entire driving task, perhaps with the help of supportive functions as, for example, ABS. Most of the vehicles that are on the roads today can be categorized into this level. However, advanced driver-assist technologies, corresponding to level 1, driver assistance, are becoming more common. This level of automation involves one specific function that either, for example, keeps the vehicle in the lane or maintains a safe distance from other vehicles. Taking it one step further to level 2, partial automation, at least two primary control functions are working in unison, controlling, for example, both the position of the vehicle within the lane and the distance towards other vehicles. Perhaps the best known example of a vehicle at level 2 is the Tesla Model S. The autopilot of the Tesla Model S ("Autopilot | Tesla," n.d.) makes use of multiple control functions, using adaptive cruise control to maintain the correct distance and an auto-steer function to stay within the lane in combination with assisted lane-change function to change lanes when the indicator is activated and it is safe to change lanes. When using the Tesla's 'autopilot' the driver must continuously monitor the situation and be prepared to regain control at any moment. This is the key characteristic of level 2. Vehicles categorized as level 3, conditional automation, enable the driver to delegate full control to the vehicle within specific driving conditions or environments without the need to continue monitoring the system and surroundings until the system requests to intervene. Audi introduced the first commercially available vehicle driving in level 3 ("The new Audi A8 – conditional automated at level 3 | Audi MediaCenter," n.d.). Volvo started the 'Drive Me' project ("Drive Me – the self-driving car in action | Volvo Cars," n.d.) in which customers use Volvo XC90s to drive autonomously on specific roads within Gothenburg without the need of supervision, corresponding to level 4, high automation. If the system requests an intervention and no response is recorded, the system should be able to handle critical situations without compromising safety. At the highest level, level 5, full automation, vehicles should be able to fully control all the primary functions of driving for an entire trip. Examples are the Waymo's car ("Waymo," n.d.) and the Daimler Smart EQ concept ("Here's how Daimler is evolving its tiny Smart car for self-driving - The Verge," n.d.), which are fully automated vehicles in which a driver is no longer needed.

Challenges and Troubles Using Partially Automated Vehicles

As mentioned by Casner et al (Casner, Hutchins, & Norman, 2016) the transition towards fully automated vehicles will be difficult for drivers, especially for partially automated vehicles in which automation is both incomplete and imperfect, requiring the driver to continuously monitor the system to be able to intervene and regain control. The driver will have to cope with different types of challenges when driving a partially automated vehicle, such as inattention, as drivers are more tempted to engage in secondary tasks (de Winter et al., 2014; Llaneras et al., 2013). These challenges may have an influence on the willingness of drivers to use automated systems and can provide reasons for drivers to disable these type of systems.

Driving manually contributes to a better task-specific understanding (Stanton et al., 1997) of the situation that is also known as situation awareness (Endsley, 1995). Engaging in secondary tasks may result in lower situation awareness compared to drivers who drive manually, which may lead to more difficulty in regaining control and maintaining safe driving. Strand et al. (Strand et al., 2014) conducted a driving simulator study supporting the notion that driver performance degrades when the level of automation increases. A meta-analysis done by de Winter et al. (de Winter et al., 2014), showed that drivers who are engaged in secondary tasks when driving in highly automated settings have lower situation awareness compared to drivers who drive manually, which may create difficulties when the driver needs to regain control of the vehicle, and therefore may provide a reasons to disengage automated systems. Having lower situation awareness may affect the willingness to intelligent systems.

The willingness to use new technologies or systems in vehicles depends on other aspects as well. A commonly mentioned aspect is trust. Drivers who gain more experience with an automated system will also gain more trust in the usage of that system (Parasuraman & Riley, 1997) and therefore trust will positively influence the willingness to use intelligent systems in vehicles. However, as drivers' trust in the automation increases due to longer periods of impeccable performance, this may result in a decrease of attentional resources when driving a partially automated vehicle (Casner et al., 2016). As trust influences the willingness to use automation and may provide a reason to disable automated systems, the large individual differences between drivers make predictions about the use more difficult (Parasuraman & Riley, 1997).

Multiple studies looked into the transition between automated driving and manual driving and how to maintain driver availability for regaining control when needed (Blommer et al., 2015; Johns et al., 2016; Mok, Johns, Miller, & Ju, 2017) that may support drivers to continue using automated systems. Mok et al. (Mok et al., 2017) investigated the time needed to regain control of a vehicle when being engaged in the secondary task of playing a game on a tablet during automated driving. They found that the majority of the drivers needed 5 or 8 seconds to regain control in order to proceed safely. Johns et al. (Johns et al., 2016) looked into the idea of shared control using haptic feedback through the steering wheel. Correct support for transition between manual and automated driving may support drivers to continue using automated systems.

Brown and Laurier (Brown & Laurier, 2017) analyzed multiple recordings of Tesla's 'autopilot' indicating some of the troubles drivers may encounter when using the autopilot. An example

Figure 10. Driving Simulator

is that a driver had to intervene as the autopilot followed the edge-markings resulting in taking the exit instead of driving the intended route. The troubles with the Tesla's 'autopilot' mentioned by Brown and Laurier (Brown & Laurier, 2017) are related to the technical limitations of the system, requiring drivers to regain full control over the driving tasks. In the current chapter, the human perspective is explored, investigating the different reasons drivers may have to disable an autopilot function in their vehicle when the situation does not require them to regain full control over the driving tasks.

The current study focuses on Risky / Thrill Seeking and Careful / Calm driving style, with the goal to investigate whether and why people with different driving styles disable the autopilot when there is no objective necessity to regain control.

Method

A study was conducted in a driving simulator. The simulator used in this study is a medium-fidelity fixed based simulator designed and manufactured by the Dutch company Green Dino BV. The simulator consists of a car seat, a Ford steering wheel, indicators, ignition key, pedals, a gear lever and a handbrake. The renderings are visualized on three 32 inch screens and the mirrors and dashboard are part of the 3D renderings. The driven speed and activation of the autopilot are logged by the simulator at 20 Hertz. It this study the vehicle contained automatic gearing.

The scenario (see Figure 10) consisted of a two-lane highway with mixed traffic, where, at certain moments, the traffic was a little crowded but there were no congestions. The vehicle used in this scenario had the ability to drive partially-automated through the use of the autopilot. The autopilot function could be turned on or off by pressing a button located next to the handbrake, and it could also be deactivated by hitting the brake. When the autopilot was activated, the vehicle took over the task of driving, leaving the driver to only monitor the system. In the autopilot setting the vehicle controlled all aspects of driving including changing lanes and overtaking other vehicles. In this mode, the steering wheel moved along with the movements of the vehicle. The autopilot function used in this scenario can be categorized as level 2 of the SAE classification as participants were required to keep their attention focused on the driving task and to continuously monitor the system and the surroundings. This level is typical for currently available autopilot functions in vehicles such as the Tesla. As it is level 2 automation, the autopilot function is not completely perfect and therefore requires the full attention of the driver to intervene when needed. At certain moments the autopilot reduced the speed of the vehicle to around 80 to 90 km/h in order to give phantom traffic jams building up further down the road the opportunity to dissolve (Schakel et al., 2010). This could happen at moments when a minimum amount of traffic was around; no reason for the adjustment was communicated to the driver.

The data for the current analysis were collected in the context of the study that aimed to investigate the effect of personalized soundscapes on participants' willingness to use automation (See Chapter 6). These soundscapes were activated when the autopilot was enabled. As no conclusive answers were found that more personalized soundscapes influenced the willingness to use the autopilot, the current analysis zoomed out again and investigated alternative reasons why drivers may disengage the autopilot not related to the soundscape.

Participants

People were asked to participate in a driving simulator study concerning automated driving by completing a pre-evaluation questionnaire. This pre-evaluation questionnaire asked for demographic data and described a concrete scenario and eight different personas representing different driving styles explained in Chapter 4, four of them representing calm/careful driving styles and four of them representing risky assertive driving styles. Respondents were asked to imagine that it was a Thursday morning and they were in their vehicle driving to work. They were driving on the highway in mixed traffic, it was a busy road but there were no congestions. Then they were asked with which of the eight personas they identified themselves most for the given scenario.

The results of the pre-evaluation questionnaire were used to assign participants to one of the two driving styles, one the more assertive/risky driving style and the other the more calm/careful driving style.

Forty-four participants participated in the study, forty males (90.91%) and four females (9.09%), aging between 18 and 59 years (M=26.32, SD=6.92). The participants received a €10 gift card as a compensation for their time. Of the 44 people participating in this study, 28 participants (of whom two were women) were categorized as calm drivers and 16 participants were categorized as risky drivers.

Procedure and Measure

After signing the informed consent form participants were asked to take a seat in the driving simulator. The first part of the session was a training phase that allowed the participants to get familiarized with the simulator and its behavior as well as the use of the autopilot function, which controlled the vehicle until the function would be disabled by the driver. The aim of this part was that the participants would create a full understanding of how the simulator works, meaning that they had to drive both with and without the autopilot enabled. The participants were instructed that an autopilot system was implemented, allowing the vehicle to drive by itself when the autopilot was activated. It was mentioned that the autopilot could be activated and deactivated through a small button next to the handbrake and through hitting the brake the autopilot would also be deactivated. This session took around twenty minutes on a two-lane highway with mixed traffic (See Figure 10.)

Before the start of the main part of this study, the participants had a five-minute break in which the system was reset and a brief explanation was provided to the participants. They were told to imagine they were sitting in their vehicle on a typical morning driving to their work. The participants were asked to drive in the simulator as if it was their own vehicle they use to go to work but now also making use of the autopilot function. They were told that the traffic rules were in line with the traffic rules as they apply on a typical highway in the Netherlands, including a speed limit of 120 km/h. The task was to monitor the system and the situation around the vehicle during the trip. Participants were allowed to disable the autopilot function when they did not agree with the behavior of the autopilot or felt uncomfortable, frustrated or not safe by using it. As the system had some minor issues with the trajectory for executing changing lanes, participants were instructed to ignore these issues by not letting them influence their decision to disable the autopilot. The trip on the highway took 20 minutes after which an alarm would ring, indicating that they could disable the autopilot if it was not already disabled and bring the car to the side of the road to make a safe stop. After this, the participants were asked to clarify the moments the autopilot was disabled during the session. They could do so by shortly describing the reasons why they disabled the autopilot function during the study (if they did) on a piece of paper.

The answers describing the reasons why they disabled the autopilot function during the study were documented and subjected to thematic analysis by means of affinity diagramming (Martin & Hanington, 2012): The different statements provided by the participants were repeatedly clustered by the authors based on similarity and the resulting clusters were labeled as themes.

Findings

The autopilot was disabled on average five times per participant with a minimum of zero to a maximum of 13 times during the session. Sixty-four reasons were provided by the 44 participants why they disabled the autopilot during the trip. The reasons why participants disabled the autopilot function while driving were divided over six themes: The speed

	Calm (N=28)	Risky (N=16)	Total
The speed maintained by the autopilot	9	9	18
The behavior of the autopilot	10	8	18
Onset of boredom	6	5	11
Onset of sleepiness	3	1	4
Lack of trust in the autopilot	9	1	10
Enjoyment of manual driving	3	0	3
	40	24	64

Table 18: Distribution reasons among driving styles

maintained by the autopilot, The behavior of the autopilot in relation to overtaking other vehicles, Onset of boredom, Onset of sleepiness, Lack of trust in the autopilot, and Enjoyment of manual driving. Table 18 shows the distribution of instances where the autopilot was disengaged over the different themes, as a function of the participants' driving style.

The themes will be elaborated further in the next part of this chapter. For each theme, we present the number of participants mentioning that type of reason, some quotes, the relation between the theme and the scenario, the relation to the literature, and how to design for that reason.

The Speed Maintained By the Autopilot

In total, eighteen participants mentioned the drop in speed below the maximum allowed speed without an obvious need, when the autopilot was activated as one of the reasons to disable the autopilot. This was done to momentarily drive manually in order to increase the driving speed.

"It was too slow… There was a possibility to go faster" (P6). "It went below the speed limit slowing down my journey." (P22). "… slowed down for no reason." (P36) "I felt like the system was either driving too slow ….”(P38)

These remarks concerned cases where the speed of the vehicle was sometimes reduced to 80 to 90 km/h by the autopilot while the maximum speed was still 120 km/h. As explained in the Method section, this happened because the autopilot adjusted its speed in anticipation of a phantom traffic jam building up further down the road. However, this happened without providing an explanation to the drivers why the speed dropped.

Looking at the future, one of the ideas behind the use of the autopilot is that vehicles are able to communicate information such as direction, location, speed, deceleration and acceleration to other vehicles and the infrastructure. Communicating these aspects to other vehicles and the infrastructure allows vehicles to anticipate imminent traffic situations and subsequently adjust their own behavior and negotiate their actions with other agents (whether human or automated). This may, for example, result in reducing the vehicle speed in advance to prevent or diminish congestion further down the road. An example of such a system is an advanced version of Adaptive Cruise Control called Cooperative Adaptive Cruise Control (CACC) that is able to communicate between vehicles (Schakel et al., 2010). Schakel et al. (Schakel et al., 2010) mention that CACC may reduce shockwaves improving the traffic flow stability by reducing the speed. This may lead to a reduction of the speed without an obvious explanation. Lajunen et al. (Lajunen & Summala, 1995) indicate that skill-oriented drivers may get irritated and aggressive when certain traffic situations do not satisfy their expectations, which may lead to disabling the autopilot.

With respect to opportunities for design, providing information about why the system behaves in a certain way may increase the willingness to use driver support systems (Lee & See, 2004). For example, one might just explain the reasons why the speed of the vehicle is reduced. Or one might inform the driver about the gains and losses of their preferred way of driving compared to more adaptive driving in combination with information about the performed driving behavior. This can be done by showing that their behavior does not have a large benefit time-wise but may lead to worsening the traffic conditions. Another solution may be the use of illumination and/or haptic feedback to support situation awareness in situations which the role of the driver is changing towards supervisory control (van den Beukel, van der Voort, & Eger, 2016)

The Behavior of the Autopilot In Relation To Overtaking Other Vehicles

Eighteen participants mentioned that they disabled the autopilot because of the conservative behavior of the autopilot by reducing speed before overtaking trucks. Some mentioned explicitly that they disabled the autopilot to change lanes themselves in order to maintain the flow of driving and the driven speed. After overtaking the truck and changing back to the right lane the autopilot would be enabled again.

“If I saw the autopilot was very slow but I had the opportunity to overtake the vehicle in front” (P7). “Sometimes (in my opinion) taking over could have been done earlier so I would not get stuck behind a truck for a while because the autopilot only switches lanes when the approaching car is far away.” (P8). “When overtaking trucks, the autopilot reduced speed while there was enough space between the vehicle and vehicles behind to overtake the truck” (P23). “When trucks are in the right lane, the autopilot did not overtake and drove below 80 km/h. During this time I took control of the vehicle” (P41).

During the study, the behavior of the autopilot could be experienced as unduly conservative by participants. The conservative behavior resulted in the vehicle always trying to go back to the right lane even when approaching a truck in the right lane. As a consequence, when approaching a truck in the same lane the speed of the vehicle would first be reduced before the vehicle would change to the left lane to overtake that truck.

Whereas human drivers drive their vehicles on the basis of their emotions and motivations (Summala, 2007), systems that take over parts of the driving tasks can be seen as sophisticated robots that maximize safety based on optimized logic (Yusof et al., 2016). However, the situation depicted here resembles the situation where a human driver using Adaptive Cruise Control (ACC) would not look ahead sufficiently, resulting in the ACC slowing down the speed before initiating the take-over maneuver. Currently, it is still unclear whether automated systems will be equipped with sufficient look-ahead capabilities to handle these situations satisfactorily. They are developed primarily with the aim to increase driver safety (van Arem, van Driel, & Visser, 2006).

With respect to opportunities for design, a solution to overcome the gap between the behavior of intelligent systems in vehicles and drivers is the use of shared control. The control authority of the vehicle is, in this case, shared between the intelligent systems and the driver (Abbink & Mulder, 2010), allowing the driver, for example, to influence the acceleration of the vehicle. Another example of shared control is the use of haptic torque feedback on the steering wheel that can convey intent (Johns et al., 2016). Shared control can provide the opportunity to improve safety as both the driver and the system can supervise (Johns et al., 2016). An alternative to overcome the gap between the behavior of intelligent systems and drivers is to change the behavior of the system. For example, Volvo has an overtaking assistance with their adaptive cruise control (ACC). When the driver expresses the intention to overtake another vehicle through activation of the indicator, the ACC helps in accelerating the vehicle before changing lanes (Volvo, n.d.).

Onset of Boredom

Eleven participants mentioned that the use of the autopilot resulted in feeling bored at some point. This resulted in disabling the autopilot as a way to counteract the boredom of just monitoring the system.

"Sometimes it is boring, by sitting and doing nothing in the car." (P5). "I felt bored at times, to sit idle. That's the one reason why I disabled the autopilot" (P18). "When I felt bored sitting and just watching …" (P29). "Sometimes I felt bored and I wanted to do something." (P40).

The autopilot used in this study performed most of the driving tasks, leaving the participant to only monitor the system and surroundings. This required participants to maintain their attention to the driving tasks without the need to perform any of these tasks.

Boredom can be defined as "a state of relatively low arousal and dissatisfaction, which is attributed to an inadequately stimulating situation." (Mikulas & Vodanovich, 1993, p. 3). In the context of driving, as the autopilot controls both the lane position and speed of the vehicle and drivers are still required to fully monitor the system, driving may be experienced as monotonous, with fewer tasks and lower workload (Mkrtchyan, Macbeth, Solovey, Ryan, & Cummings, 2012). Over time, this may reduce the willingness to monitor the systems and may lead to seeking other stimuli to reduce boredom and creating motivations to engage in secondary tasks like using a cell phone.

With respect to opportunities for design, Diewald et al. (Diewald, Möller, Roalter, Stockinger, & Kranz, 2013) propose multiple eco-driving applications that make use of gamification. The game elements in these persuasive systems may increase the motivation of drivers to use intelligent systems that support the driving tasks, as they provide additional tasks next to monitoring the system and surroundings. Mkrtchyan et al. (Mkrtchyan et al., 2012) suggest that the use of alerts may be useful to sustain attention and thus counteract consequences of boredom.

Onset of Sleepiness

Four participants mentioned that the use of the autopilot induced sleepiness, leading them to disable the autopilot to increase the number of tasks to perform and thus their mental workload. By disabling the autopilot, participants avoided running the risk of falling asleep and getting involved in an accident.

"I felt that I was relaxed about the autopilot driving the car but I did not like the feeling

of falling asleep and I preferred to not take such a risk and rather drive." (P4) "Once I felt sleepy with the autopilot. So I switched to manual to wake myself" (P13). "… It was actually making me sleepy" (P14) "…sometimes I almost fell asleep" (P42).

As already mentioned before, when the autopilot was activated during the study, the vehicle took over all driving tasks, leaving the driver to only monitor the system and surroundings.

When ADAS controls both the position of the vehicle within the lane and the speed in combination with the distance towards other vehicles, the driver's workload will be reduced. Reducing tasks for the driver to only monitoring the system may result in drowsiness or fatigue, which can be split into sleep-related and task-related fatigue (May & Baldwin, 2009). Task-related fatigue can either be active or passive task-related fatigue. Active task-related fatigue is related to mental overload. Passive task-related fatigue can be related to mental underload (Gimeno, Cerezuela, & Montanes, 2006) when, for example, the driving task is predictable or monotonous. Having the sole task of monitoring the system can be quite monotonous and as this reduces the workload, it can induce fatigue and decrease the performance of the driver in maintaining situation awareness (May & Baldwin, 2009).

With respect to opportunities for design, Miller et al. (Miller et al., 2015) indicated that drivers who were engaged in activities as watching a video or reading were less likely to exhibit drowsiness compared to drivers who only had to oversee the automated system. Several countermeasures can be implemented in vehicles against passive task-related fatigue. Gimeno et al (Gimeno et al., 2006) classified several empirical studies that evaluated possible countermeasures. One of the countermeasures to prevent drowsiness, fatigue or inattention is the use of stimulation. This indicates that drivers might be stimulated through, for example, light, sound, cold air, music or games to reduce fatigue while driving. Also, automated systems that share the control with the human driver may reduce driving fatigue and provide the opportunity to improve safety (Johns et al., 2016).

Lack of Trust in the Autopilot

In total nine participants, almost exclusively Calm drivers, reported reasons to disable the autopilot relating to trust or lack of trust in the autopilot.

"… Traffic was too dense and unpredictable at times, so I was unsure it would handle it" (P1). "Sometimes a car behind was too close." (P13). "There was a car approaching from the back very fast and getting close" (P19). "… I did not trust it enough to handle certain situations" (P38).

The behavior of other traffic in the scenario was not always predictable, similar to the behavior of drivers in real life. This was a reason mentioned by one participant to disable the autopilot. Another participant mentioned that a vehicle from behind was approaching at a higher speed and s/he was not sure how the autopilot would deal this, resulting in disabling the autopilot to make sure no accident would happen. One participant mentioned that another car came too close and therefore s/he disabled the autopilot. Three participants mentioned that they did not always trust the autopilot in handling certain situations and one participant was not comfortable when the vehicle was in a turn. Apparently, Calm drivers have a stricter interpretation of what is safe than Risky drivers.

For two participants the autopilot sufficiently fulfilled the expected driving dynamics as they did not disable the autopilot. They, therefore, trusted the autopilot to cope with tasks of driving by itself.

Trust is mentioned as one of the aspects of adapting and accepting automated technologies in vehicles by drivers as mentioned by Lee and See (Lee & See, 2004). People tend to rely more on automation when they trust it and will more often reject the automation if they do not. Even if people do not trust the technology at first, by gaining experience with a new system that is reliable, users tend to gain more trust in the system (Parasuraman & Riley, 1997). People can also misuse or disuse automation (Parasuraman & Riley, 1997). Some people over-trust a system despite the system's inability to cope with the situation. This can result in misuse of the system creating unwanted or dangerous settings. Ignoring the capabilities and support of systems can be referred to a disuse of the system.

With respect to opportunities for design, the amount of appropriate trust and reliance a driver may have on the system is influenced by how well the capabilities of driver support systems are communicated to the driver (Lee & See, 2004). Communicating the system's uncertainty may have a positive influence on the trust of drivers and the acceptance towards automation (Beller, Heesen, & Vollrath, 2013) as well as on situation awareness (Stockert, Richardson, & Lienkamp, 2015). Verberne et al. (Verberne, Ham, & Midden, 2012) indicate that systems that share the driving goals of the driver and provide information are judged as more trustworthy and acceptable. Also, drivers who gain more experience with an automated system will most likely gain more trust in the usage of that system (Parasuraman & Riley, 1997). Next, it appears that Calm drivers have a different opinion about what is safe than Risky drivers. Taking into consideration the variety of driver's opinions about what is safe may also help to increase the acceptance.

Enjoyment of Manual Driving

Two participants mentioned explicitly that they disabled the autopilot to experience the thrill and enjoyment of driving related to manual driving, and a third participant wanted to make the driving more interesting again.

“To make driving more interesting” (P20). “… when I could enjoy the thrill of driving” (P29). “To experience the manual driving (enjoy driving yourself)” (P32).

These participants were all Calm drivers. However, the number is too small to conclude reliably that Calm drivers have a stronger desire for enjoying manual driving than Risky drivers.

As mentioned by Nordhoff et al. (Nordhoff, van Arem, & Happee, 2016) it is challenging to gain the wow factor within driving when being driven by an onboard computer. Next to this, results of a questionnaire conducted by Kyriakidis et al. (Kyriakidis, Happee, & de Winter, 2015) showed that on average, their participants considered manual driving as most enjoyable. As the notion of autonomy is changing, the driving experience is changing along. During a study that explored how Adaptive Cruise Control (ACC) impacts people’s driving experience (Eckoldt et al., 2012), one of their participants said: “*… it feels like sitting on the neck (of a cat) just watching …*”. This is in contrast to the experience when driving manually “*… a cat lying in the wait … when I drive the car, I become the cat to some extent …*”. Another participant mentioned holding the steering wheel more tightly compared to manual driving as this releases the tension of not using the pedals (Eckoldt et al., 2012). This study revealed that ACC creates a distance, a gap between the driver and the car. When driving with ACC activated the driving experience will change, which might be satisfactory for some but not for others.

With respect to opportunities for design, for drivers who pursue an exciting driving experience, the use of driver support system increases the decline in the experience due to the cautiousness and defensiveness of automated vehicles. This may be compensated for by intensifying visual, tactile and/or auditory sensations (Petiot et al., 2013). Schroeter et al. (Schroeter et al., 2014) argued that simulating risky driving or replacing risky driving triggers with alternative stimuli may reduce actual risky driving. Frison et al. (Frison, Wintersberger, Riener, & Schartmüller, 2017) mentioned that automated driving lacks in provisioning joy of driving and proposes a hybrid interface combing the advantages of both manual and automated driving. In Chapter 5 and 6 both visual and auditory stimuli are proposed as a mean to counteract the change in experience in automated vehicles.

Discussion

As discussed in the findings, previous studies have already delivered several insights regarding various aspects of the driving experience in combination with driver support systems. These studies independently modified specific attributes of the experience that led to specific findings. In contrast, in this study, these insights emerged from a general realistic driving task without focusing on any specific limitation of an autopilot system. This makes the current findings a relevant contribution to understanding the factors that influence users' interactions with the system and why they would disable the autopilot function even when it is not required by the limitations of the system.

As mentioned in this chapter, some of the participants experienced the autopilot function as boring while for others it induced a more sleepy feeling. Both boredom and fatigue result in more inattentiveness which may cause problems when the system requires the driver to immediately regain control. Also, an increase in trust of the system can result in a decrease in attention towards the system, as the attention of the driver may shift towards secondary activities. This may cause dangerous situations when the driver is not fully aware of the system's status and the situation around the vehicle and has to drive manually again. Another aspect of level 2 automation is that these systems are perhaps both incomplete and imperfect, which requires drivers to sometimes intervene. When their attention is lower or shifted, this may result in situations in which the vehicle makes an error that is not corrected by the driver, possibly resulting in a crash. Take for example the Tesla 'autopilot' that a driver uses on the highway, which correctly follows the road markings for quite some time. The driver gains more trust and starts to shift his or her attention to non-driving related activities, not noticing the construction works ahead. At some point, yellow road markings appear which are not recognized by the autopilot and the system keeps following the original white road marking, resulting in a crash into the Jersey barrier (road divider). These considerations raise the question whether level 2 of automation is an appropriate level to implement in commercially available vehicles on a wider scale. A way out might consist of the different countermeasures discussed in this chapter.

Limitations

It has to be taken into consideration that a driving simulator was used in this study. The fidelity of the simulator may have had an effect on the driving experience, and accordingly may have influenced how participants perceived the autopilot. In addition, the setting was artificial, so that the ride was not part of a real-life activity. Thus, it remains to be established that the same considerations will apply for use or disuse of the autopilot in real-life situations.

Conclusion

The number of driver support systems that are developed to increase safety and efficiency is increasing. These systems provide the opportunity to assign more and more driving tasks to the vehicle itself. The transition from manually driven vehicles towards fully automated vehicles will be accompanied by challenges and obstacles. The study described in this chapter reported different reasons why participants disabled the autopilot function that was implemented in a vehicle in a driving simulator. The participants drove in a partially-automated vehicle for 20 minutes on a two-lane highway with mixed traffic. The different reasons why drivers would disengage the autopilot function categorized as level 2 of the SAE taxonomy were classified. The qualitative data gained from the driving simulator study described in this chapter revealed six reoccurring themes: The speed maintained by the autopilot, the behavior of the autopilot in relation to overtaking other vehicles, onset of boredom, onset of sleepiness, lack of trust in the autopilot and enjoyment of manual driving. The following part will summarize these six themes, what they mean and how to design for.

The speed maintained by the autopilot was at certain moments reduced to 80 to 90 km/h without giving an explanation to the driver. This resulted in some of the participants disabling the autopilot. Providing more information on the motivation of the system's behavior may support the willingness of drivers to keep the autopilot enabled (Lee & See, 2004)

The behavior of the autopilot in relation to overtaking other vehicles resulted in a decrease in speed when approaching a truck before changing lanes. This could be seen as more conservative driving behavior. Intelligent systems in vehicles try to maximize safety based on optimized logic (Yusof et al., 2016). Next, these systems also comply with traffic rules even if this is not motivated by safety perspectives. Developing systems with better look-ahead or allowing for shared control between the system and the driver may support the willingness to continue the use of the autopilot (Abbink & Mulder, 2010).

Onset of boredom occurs through the monotonous task of monitoring the system. Participants mentioned they disabled the autopilot to overcome the boredom as they were not allowed / able to perform other activities when the vehicle was driving by itself. Introducing gamification elements in the monitoring task may support the prevention of boredom when using automated systems (Diewald et al., 2013).

Onset of sleepiness was also mentioned, leading participants to disable the autopilot, therewith increasing the number of tasks. A countermeasure against fatigue can be the implementation of extra stimuli (Gimeno et al., 2006) while using the autopilot.

Lack of trust in the autopilot was another reason to disable the autopilot. Trust is one of the aspects influencing people's willingness to use automated systems in their vehicles. By communicating the automation uncertainty and by taking into consideration the driver's opinions about what is safe, the trust of drivers and the acceptance towards automation may increase (Lee & See, 2004).

Enjoyment of manual driving and experiencing the thrill of driving was another reason to disable the autopilot. Automation may decrease the driving experience for drivers. This may be compensated through intensifying different visual, tactile and/or auditory sensations (Petiot et al., 2013).

Comparing the distribution of instances where the autopilot was disengaged over the different themes, as a function of the participants' driving style indicated no obvious distinctions between different driving styles in terms of reasons to disengage the autopilot.

The current chapter proposes several design opportunities to counteract the driver's inclination to disengage the automated driving system when there is no objective necessity to do so.

8
Conclusion and Discussion

Summary

The number of Driver Support Systems (ADS) in vehicles is rapidly growing, allowing drivers to delegate more and more of the driving tasks to the vehicle. Automated driving allows drivers to delegate control to the vehicle, so that the role of the driver gradually changes from an actuator to an operator, and ultimately to a passenger, along with a change in the driving experience (Eckoldt et al., 2012). As ADS are developed with a strong focus on safety, by reducing the number of accidents caused through human error, the behavior of highly automated vehicles is expected to be cautious and defensive, which may not always be in line with the driver's own and preferred driving behavior. The change in experience and the deviation of the behavior performed by an ADS from the driver's typical and preferred behavior may have a negative effect on people's willingness to use such systems. The question arises how to influence the change in experience that comes along with the introduction of automated driving without adjusting the behavior of ADS. This question is relevant as long as the driver maintains the ability to regain the control over the vehicle, even if the system does not require to take control back by the driver.

The first part of this thesis evolved around driving styles and the possibility to use a driving style questionnaire as a means to categorize drivers. Taking into consideration that drivers differ in their driving style and their attitude towards driving, what might strengthen one type of driver's willingness to use ADS might frustrate another type of driver, or may even stimulate greater involvement in risky behavior (Kaptein et al., 2012; Taubman-Ben-Ari & Yehiel, 2012). In order to learn more about the acceptance of ADS, it is necessary to understand how the acceptance of ADS is influenced by people's driving style. A relatively easy way to determine drivers' driving style is by means of a questionnaire, giving information about someone's self-reported driving style. A review of several driving style questionnaires that have been proposed in the literature revealed the Multidimensional Driving Style Inventory (MDSI) as the most suitable questionnaire to be used in future studies. To be able to use the MDSI, the stability of the different factors of the MDSI (Taubman-Ben-Ari et al., 2004) was validated. A factor analysis of data from 364 participants who completed the MDSI revealed five of the eight factors that resulted from the original factor analysis: Angry driving, Anxious driving, Dissociative driving, Distress-reduction driving, and Careful driving style. The scores indicated that all factors together determine what type of driver someone is.

However, the use of self-reported measures has been questioned due to the possibility of reporting biases (af Wåhlberg, 2009; af Wåhlberg & Dorn, 2015). This raised the question of

whether a questionnaire is a proper mean to identify a person's driving style, or whether driving style can be better measured from driving behavior. Therefore, the predictive value of the MDSI for driving behavior was investigated in a driving simulator, in terms of speeding, braking, steering, lateral positioning and maintaining distance to a preceding vehicle. Eighty-eight participants filled in the MDSI and drove in a simulator for thirty minutes. Different driving behaviors, including complying with the maximum speed, lateral position and the distance to preceding vehicles, were recorded. The objective data retrieved from the simulator were compared with scores resulting from the questionnaire data. It was concluded that the results from a driving style questionnaire may be used to get an indication of people's typical driving behavior. The correlations between the self-reported driving style obtained from the questionnaire and the driving behavior in the driving simulator are modest and limited to some driving styles but in line with previous research. This indicates that the MDSI may be used as a diagnostic tool for identifying the typical driving behavior of individual people within a driving simulator. The results also indicate that the driving styles Careful and Risky can be considered as opposites. However, the results from both this and the previous study do not reveal conclusive results that the use of the MDSI is a good way to create driver profiles according to driving style because it was concluded that the scores on all factors of the MDSI combined determine what type of driver someone is.

The second part of this thesis looked into the possibility to make use of personas as a tool to categorize drivers. Taking a closer look at Risky and Careful driving style, these can be represented on three bi-polar dimensions: the behavior, knowing the consequences of the behavior and the motivation of the behavior, resulting in eight different spaces within a framework characterizing eight different types of drivers (See Figure 5 in Chapter 4). A survey was conducted with 202 respondents who indicated for each persona how much they recognized themselves in that persona. The results reveal that all personas were selected by at least some of the respondents and that the majority of the participants scored a 7 or higher on a ten point scale as the highest score for the best matching persona. This implies that all eight of the personas are needed in order to cover the majority of the drivers and that there is no need to extend the number of personas. With respect to the validation of the framework, it was found that the more characteristics personas have in common the higher the correlation, indicating that the framework is a valid basis for generating driver personas and that it may be used as a diagnostic tool to identify differences between drivers in future studies and to be able to assign drivers to different driver profiles.

In the third part of this thesis, ambient light and sound were explored as means to alter the experience within a vehicle. The capacity of ambient light to alter the perception of speed and therefore influence the driving experience was investigated. The aim was to determine how different drivers experience the concept of an ambient light moving along the A-pillar inside the vehicle. The experience was operationalized in terms of attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. We were interested to see if this study supported the notion that a driver's attitude towards ambient light is highly individual and supports the idea of making use of personalized persuasion. In different conditions, the light moved at different speeds. The outcomes of the study showed that overall the ambient light that was used had a positive effect on the driving experience but that the attitude towards the ambient light was highly individual. The majority indicated a preference for the ambient light while some saw it more as a distraction or even inducing more stress. These results support the idea to make use of more personalized persuasion and provide an indication that the use of ambient light as a mean for persuasion may positively affect the willingness of drivers to use ADS.

Another way to compensate for the degradation in the driving experience, which is likely to result from more automated driving, may be by offering proper soundscapes. A study was conducted in a driving simulator, in which the influence of two different soundscapes on the driving experience was investigated, one giving a more exciting experience, the other supporting a more relaxing experience. Forty-four participants representing two different driving styles, assertive/risky or calm/careful, drove in a simulated automated vehicle, where they could put the autopilot function on or off. When the autopilot was enabled, one of the two soundscapes designed for this study was played. The results did not provide a conclusive answer that soundscapes personalized according to participants' driving style influenced the willingness to use the autopilot.

Finally, as no conclusive answers were found that more personalized soundscapes influenced the willingness to use the autopilot, alternative reasons why drivers may disengage the autopilot not related to the soundscape were investigated. This was done using data from the simulator study in which participants had the ability to drive autonomously but also to disengage the system, investigating the influence of two different soundscapes on the driving experience. The analysis of the qualitative data revealed six reoccurring themes covering the reasons why participants disabled the autopilot without there being a need to intervene: The speed maintained by the autopilot, The behavior of the autopilot in relation to overtaking other vehicles, Onset of boredom, Onset of sleepiness, Lack of trust in the autopilot and Enjoyment of manual driving. Several design opportunities related to the six reoccurring themes were proposed to counteract the driver's inclination to disengage the automated driving system when there is no objective necessity to do so.

Contributions

On an abstract level, this thesis contributes to a better understanding of drivers' needs in relation to automated driving, proposing guidelines to counteract the negative aspects of automated driving without changing the behavior of ADS.

To What Extent Can Driving Style Be Used to Categorize Drivers on the Base of Personalized Persuasion?

Through the validation of the MDSI it can be concluded that someone's driving style is personal and is built among five different factors: Angry driving, Anxious driving, Dissociative driving, Distress-reduction driving, and Careful driving. The results indicate that characterizing drivers in terms of a single dominant driving style is too simple. The scores on all the factors together determine what type of driver someone is. Therefore, characterizing drivers in terms of a single dominant driving style is not the most suitable solution to categorize drivers. The results of the validation of the MDSI did, however, reveal that driving styles Careful and Risky can be considered as opposites as they were categorized within one factor, Careful driving. Meaning that drivers can be categorized as either more careful or more risky.

Another approach was to make use of personas as a tool to categorize drivers, as the findings from both the study described in Chapter 2 and the study described in Chapter 3 do not reveal conclusive results that the use of the MDSI is the most appropriate way to create drivers profiles according to driving style. As mentioned before, Risky and Careful driving style could be analyzed from three perspectives, resulting in a framework with eight different spaces characterizing eight different types of drivers (See Figure 5 in Chapter 4) and thus eight different personas. Through validation of the personas it was concluded that the framework is a valid basis for generating driver personas. In our opinion, the framework and the corresponding personas are a better tool to assign drivers to different driver profiles compared to the MDSI used in the studies described in the first two chapters.

How to Increase the Acceptance of Intelligent Systems Through the Use of Personalized Persuasion?

As mentioned before, what might support one type of driver to use intelligent systems might not support another type of driver, or may even encourage greater involvement in risky behavior (Kaptein et al., 2012; Taubman-Ben-Ari & Yehiel, 2012). In this thesis, the use of personalized persuasion is proposed to compensate for the differences between drivers. The framework and personas proposed in this thesis provide information about the differences between drivers and several design opportunities can be derived from this. The four main categories of personalized persuasion are persuasion through information, persuasion through experience, persuasion through correction and persuasion through support. These four types of persuasion will either be related to more risky or more careful driving behavior corresponding to the eight different spaces in the framework.

For drivers who, according to the framework, are categorized as careful drivers, aware of the consequences of their driving behavior and extrinsically motivated, persuasion through information may increase the acceptance of intelligent systems. For drivers who, according to the framework, are categorized as careful drivers, aware of the consequences to their driving behavior and intrinsically motivated, persuasion through experience may support a comfortable experience that also provides ambient information about, for example, the driven speed. For drivers who, according to the framework, are categorized as careful drivers, unaware of the consequences of their driving behavior and extrinsically motivated, persuasion through correction may support this type of drivers to encourage them, for example, to speed up when they are driving 10 km/h under the speed limit. For drivers who, according to the framework, are categorized as careful drivers, unaware of the consequences of their driving behavior and intrinsically motivated, persuasion through support may increase the acceptance of ADAS by providing support for some of the driving tasks. For drivers who, according to the framework, are categorized as risky drivers, aware of the consequences of their driving behavior and extrinsically motivated persuasion through information may increase the acceptance as these drivers do not drive because of the sensation but because of the perceived benefits when moving faster through traffic. Lastly, for drivers who, according to the framework, are categorized as risky drivers, aware of the consequences of their driving behavior and intrinsically motivated, persuasion through experience may support the acceptance. For this type of driver, a system could be designed creating an experience that substitutes the experience of risky driving.

One of the design opportunities proposed in Chapter 4 was the use of ambient light to, on one hand, influence the perception of speed to influence the experience in the vehicle, and on the other hand, provide information about the actual driven speed. The results of the study performed around the use of ambient light indicated that ambient light can indeed have a positive influence on the driving experience. Next to this, the results also indicated that the attitude towards the ambient light was highly individual, supporting the notion of the use of personal persuasion. On the other hand, from the study in which the influence of two different soundscapes on the driving experience was investigated, no conclusive answer could be provided that ambient sound would have a positive influence on the personal experience as well. Overall the studies described in Chapter 5 and 6 do show an interesting start of the use of personalized persuasion within the context of automotive, however more research is needed to be able to definitively answer the question if and how personalized persuasion may increase the acceptance of intelligent systems.

Finally, the studies described in Chapter 6 and 7 made use of an autopilot system that can be categorized within level 2 of the SAE taxonomy. A critical note should be placed according to the use of automated vehicles within level 2 of the SAE taxonomy. The question still remains if level 2 of the SAE automation taxonomy is an appropriate level to implement in commercial vehicles when taking a look at results and discussion of Chapter 7. Are the benefits of a system that still requires full attention outweighing the disadvantages of the need to continuously monitor the system? The monotonous task of monitoring the system can result in inattention leading to dangerous situations when the driver is not fully aware of the system's status and the situation around the vehicle. This brings us to the question when talking about persuasive strategies for influencing the willingness to use intelligent systems, whether the focus should be on systems in the higher levels of the SAE taxonomy and not on level 2 of the SAE taxonomy.

Discussion

To be able to explore people's driving behavior as well as to investigate the effect of different persuasive strategies on the use of automated driving systems, a driving simulator was used. The use of a driving simulator has several advantages over the use of an instrumented vehicle on public roads (Helman & Reed, 2014). Firstly, a driving simulator provides more control and consistency among different participants and allows eliciting particular behaviors in situations that may be difficult to realize, unsafe or impractical in the real world (Reimer et al., 2006). Secondly, driving in a driving simulator enables risky behavior or situations without real threats for the drivers themselves, giving participants the opportunity to practice tendencies that are difficult to practice on real roads, because of the constraints on real-life behavior. Lastly, next to a controlled environment that makes it easier to reproduce particular situations it is also easier to extract data for analyses about the driver, the vehicle, and the environment. For those reasons, multiple studies were conducted in a driving simulator, and this may have affected the results. The simulators used in the different studies are fixed based simulators that provide no proprioceptive feedback about acceleration, deceleration, and lateral movement. Having no proprioceptive feedback of acceleration, deceleration and lateral movement makes the driving experience less realistic. Another limitation of the use of a driving simulator is simulator sickness that is related to participant's physical well-being. During the study described in Chapter 3, 17% of the participants were not able to complete the simulation part of the study due to simulator sickness, the other studies did not have any dropouts. This might also be due to the scenario used in these studies as the study described in Chapter 3 made use of urban areas while the other studies made use of rural areas or highway with less to no sharp corners, which seems to have a large effect on simulator sickness. As there are several disadvantages of using a driving simulator we cannot simply extrapolate towards the influence of the different concepts on the user experience on the road. Taking in consideration that participants did mention that when driving for five minutes or longer in the driving simulator, they started to behave more as they do when driving in their own vehicle on the road. This indicated that the findings revealed in the driving simulator may provide an indication of how the user experience will be affected in a vehicle on the road.

Next, it should be kept in mind that questionnaires used in the studies may be sensitive to biases such as social desirability or overestimating one's own skills compared to the skills of other drivers (Delhomme, 1991; Freund et al., 2005). Also, people may behave differently in a driving simulator than in real traffic due to the laboratory type of setup.

As already discussed in Chapter 6, the use of personalized persuasion based on differences in driving styles may not be the most suitable solution. Instead, personal persuasion might be more effective if the choice is based on personality characteristics of the driver (for example, sensation seeking (Zuckerman & Neeb, 1980). It may also be that drivers' preferences for persuasion are related to other characteristics. Kaptein (Kaptein et al., 2012) showed that personalized persuasion may be more effective by creating tailored persuasive messages to influence people's behavior, by making use of the strategies defined by Cialdini (Cialdini, 2001). These strategies are based on human preferences for automatic, shortcut responses to messages. For example, some people are more inclined to act on a request under social pressure, others are more inclined when asked by an authority figure. Possibly, persuasion strategies related to these differences between people might be more effective. Another possibility is that the driving style that people prefer while driving manually is not in line with the needs and motivations when the driving is automated. Multiple studies looked into the adoption of the user's driving style by autonomous vehicles (Basu et al., 2017; Yusof et al., 2016) and found that drivers prefer a more defensive driving style compared to their own when being driven by an automated vehicle. The implication of this would be that drivers do not have to be compensated in different ways, depending on their driving style, when being driven in an autonomous vehicle.

The study described in Chapter 5 reveals that overall ambient light used as a persuasion strategy had a positive effect on the driving experience and that the attitude towards the ambient light was highly individual. This provides an interesting starting point to continue the research on personalized persuasion and the effects on the willingness to use intelligent systems in vehicles. Next, Chapter 6 described the use of soundscapes to influence the willingness to use intelligent systems in vehicles. The results of this study were inconclusive. As this was a first attempt to make use of soundscapes as a means to persuade drivers, more research is needed to definitively conclude that sound is not a proper means to use as a persuasive strategy.

As stated on multiple occasions throughout this thesis, drivers differ in their needs, interests, and characteristics, and therefore strategies that are tuned towards these differences are needed in order to increase overall acceptance of intelligent systems in vehicles. The studies described in this thesis are a first attempt to make use of personalized persuasion in vehicles. Although the results were inconclusive with respect to the use of personalized persuasion in automated vehicles, more research is needed to provide a definitive answer if the use of personalized persuasion in vehicles can benefit the acceptance of automated systems.

Future Research

The research presented in this thesis provides promising results related to personalized persuasion in the context of automotive to influence the willingness of drivers to make use of automated driving systems in vehicles. More research is needed to investigate the potential of personalized persuasion strategies in order to positively influence different types of drivers.

The framework proposed in Chapter 4 was validated through the personas derived from the framework. The correlations among the personas reveal that the more dimensions the personas have in common the higher the correlations between those personas are. Also, it was found that all personas are selected by at least some of the respondents and that the majority of the participants scored a 7 or higher as the highest score for the best matching persona. The three dimensions on which the framework is built upon are not conspicuously mentioned within the personas. The framework could be additionally evaluated through exploring how participants would distribute the eight personas among the eight different spaces of the framework, by asking participants to match the personas with the corresponding space in the framework. The results of this study should indicate if the translation of the different dimensions towards the personas is accurate.

Several design opportunities are derived from the framework of which two were further explored in the thesis, which mainly focused on the use of ambient light and sound. In Chapter 5 a start was made to see to what extent drivers differ in perception towards ambient light and Chapter 6 reports a study with the use of two soundscapes that were aimed at a specific group of drivers according to the framework. Yet further research is needed to examine the use of ambient light and/or sound in terms of personalized persuasion within the context of automotive. One direction may be to further explore the use of visual stimuli, as the study in Chapter 5 concluded that overall the use of ambient light had a positive effect on the driving experience. Future work in this direction may be an exploration of different patterns, for example, a pattern that is linked to different types of information as the study described in Chapter 5 was related to the driven speed. Other information that is recorded by the vehicle can also be of interest for patterns to relate to. Another direction of future research may concern the effects of sounds when enlarging the difference in soundscapes, taking the soundscape design for assertive/risky drivers to more extreme, for example, by creating more up-tempo and complex sounds compared to the soundscapes used in Chapter 6. Also investigating other types of sounds which may be more beneficial for influencing the experience within the vehicle may be interesting. For example, making using of sounds derived from nature, animal sounds or sounds generated by plants and water. Lastly, a future direction of research is to explore a multi-modal direction in which both auditory and visual or yet other modalities are combined, for example, haptics.

Ambient light and sound are only two of multiple examples of persuasion strategies that may be used to influence driver's experiences within an automated vehicle. In Chapter 4, different design opportunities related to the eight different spaces in the framework were mentioned. Other design opportunities mentioned connecting to persuasion through information, persuasion through support or persuasion through correction. For future work, these different design opportunities, as well as the persuasion experience used in Chapter 5 and 6, could be explored in more depth to learn the potential of these concepts in terms of influence on the willingness of drivers to make use of intelligent systems in vehicles. Next, it is also interesting to get an understanding of the effects of those concepts when there is no consonance with the needs and interests of the driver.

The personas derived from the framework proposed in Chapter 4 were used as a categorization tool in Chapter 6 and 7. Additional evaluation and design activities could be done by using the framework and personas. The personas may not only be used for categorizing drivers, the framework may also be used as an inspiration/guidance to design for the different groups of drivers deriving from the framework. Finally, none of the studies described in the thesis are performed in an instrumented vehicle and, as mentioned in the discussion part of this chapter, the results of the studies cannot simply be extrapolated towards the influence on the user experience on the road. Thus, for future work, it is interesting to examine the effects of both the driving behavior as well as persuasion concepts in an instrumented vehicle on the road in real traffic conditions.

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Appendices

Appendix A: Dutch Version of MDSI

Ik doe ontspannende activiteiten tijdens het rijden	Nooit	1	2	3	4	5	6	7	Altijd
Ik rij met opzet dicht op andere weggebruikers (bumperkleven)	Nooit	1	2	3	4	5	6	7	Altijd
Ik maak gebruik van de claxon of sein met groot licht naar mijn voorganger om mijn frustratie te uiten	Nooit	1	2	3	4	5	6	7	Altijd
Ik heb het gevoel dat ik alles onder controle heb tijdens het rijden	Helemaal niet	1	2	3	4	5	6	7	Heel erg
Ik rij door bij een stoplicht wanneer het net op rood is gesprongen	Nooit	1	2	3	4	5	6	7	Altijd
Ik geniet van de sensatie van het opzoeken van de grenzen tijdens het rijden	Helemaal niet	1	2	3	4	5	6	7	Heel erg
Op een lege snelweg rij ik normaal op of net onder het snelheidslimiet	Nooit	1	2	3	4	5	6	7	Altijd
Tijdens het rijden probeer ik mij te ontspannen	Nooit	1	2	3	4	5	6	7	Altijd
Wanneer de baan naast mij in een file begint te rijden probeer ik zo snel mogelijk bij die baan in te voegen	Nooit	1	2	3	4	5	6	7	Altijd
Ik raak gefrustreerd van autorijden	Helemaal niet	1	2	3	4	5	6	7	Heel erg
Ik zit soms te dagdromen tijdens het rijden om de tijd te doden	Nooit	1	2	3	4	5	6	7	Altijd
Ik vloek naar anderen	Nooit	1	2	3	4	5	6	7	Altijd
Wanneer het stoplicht op groen springt en de auto voor mij trekt niet meteen op, wacht ik geduldig tot deze wegrijdt	Nooit	1	2	3	4	5	6	7	Altijd
Ik rij voorzichtig	Nooit	1	2	3	4	5	6	7	Altijd
Wanneer ik in gedachten verzonken ben of afgeleid, zie ik niet dat er iemand bij een zebrapad staat	Nooit	1	2	3	4	5	6	7	Altijd
In een file denk ik aan manieren om sneller door het verkeer heen te komen	Nooit	1	2	3	4	5	6	7	Altijd
Wanneer het stoplicht op groen springt en de auto voor mij trekt niet meteen op, probeer ik die bestuurder aan te sporen om te gaan rijden	Nooit	1	2	3	4	5	6	7	Altijd

Op een kruispunt waar ik voorrang moet verlenen, wacht ik tot het andere verkeer is gepasseerd	Nooit	1	2	3	4	5	6	7	Altijd
Wanneer iemand net voor mij wil invoegen, rij ik op een assertieve manier om dit te voorkomen	Nooit	1	2	3	4	5	6	7	Altijd
Ik doe mijn haar / make-up tijdens het rijden	Nooit	1	2	3	4	5	6	7	Altijd
Ik ben afgeleid of druk met iets anders bezig zodat ik niet door heb dat de auto voor mij heeft afgeremd, waardoor ik hard moet remmen om ongelukken te voorkomen	Nooit	1	2	3	4	5	6	7	Altijd
Ik hou van risico's nemen tijdens het rijden	Helemaal niet	1	2	3	4	5	6	7	Heel erg
Mijn gedrag is gebaseerd op het motto "beter veilig dan sorry"	Helemaal niet	1	2	3	4	5	6	7	Heel erg
Ik houd van de sensatie van het flirten met de dood of een crash	Helemaal niet	1	2	3	4	5	6	7	Heel erg
Ik maak mij zorgen als ik in slecht weer rijdt	Helemaal niet	1	2	3	4	5	6	7	Heel erg
Ik mediteer tijdens het rijden	Nooit	1	2	3	4	5	6	7	Altijd
Ik vergeet dat het groot licht aanstaat tot-dat een andere weggebruiker seint met zijn lichten	Nooit	1	2	3	4	5	6	7	Altijd
Wanneer iemand iets doet op de weg dat mij irriteert, sein ik met mijn lichten	Nooit	1	2	3	4	5	6	7	Altijd
Ik krijg een kick als ik mij niet aan de regels houd	Helemaal niet	1	2	3	4	5	6	7	Heel erg
Ik schat tegemoet komend verkeer verkeerd in bij het passeren	Nooit	1	2	3	4	5	6	7	Altijd
Ik voel me nerveus tijdens het rijden	Helemaal niet	1	2	3	4	5	6	7	Heel erg
Ik word ongeduldig tijdens de spits	Helemaal niet	1	2	3	4	5	6	7	Heel erg
Ik voel me angstig tijdens het rijden	Helemaal niet	1	2	3	4	5	6	7	Heel erg
Ik wil de ruitenwissers aanzetten, in plaats daarvan zet ik de lichten aan	Nooit	1	2	3	4	5	6	7	Altijd
Ik probeer bij een stoplicht weg te rijden in de derde versnelling (of bij een automaat in de neutrale mode)	Nooit	1	2	3	4	5	6	7	Altijd
Ik plan mijn routes slecht, waardoor ik in verkeersituaties terecht kom die ik had kunnen voorkomen	Nooit	1	2	3	4	5	6	7	Altijd

Ik maak gebruik van spier-ontspannende technieken tijdens het rijden	Nooit	1	2	3	4	5	6	7	Altijd
Ik plan lange reizen vooraf	Nooit	1	2	3	4	5	6	7	Altijd
Ik raak bijna iets door het verkeerd inschatten van de ruimte bij inparkeren	Nooit	1	2	3	4	5	6	7	Altijd
Ik voel me op mijn gemak tijdens het rijden	Helemaal niet	1	2	3	4	5	6	7	Heel erg

Appendix B: Dutch Personas

Finn / Lotte

Finn brengt veel tijd door in zijn auto wanneer hij aan het werk is. Autorijden is dan wel niet zijn werk, het neemt wel veel tijd in beslag. Door het aantal uren dat Finn doorbrengt op de weg voelt hij zich vrij zeker over zijn rijgedrag en voor hem is het bijna een sport om zo min mogelijk brandstof te verbruiken tijdens het rijden. Daardoor is de gereden snelheid vaak lager dan de maximum snelheid. Hij vindt technologieën die hem bij deze manier van rijden ondersteunen erg handig, en wanneer hij aan een nieuwe auto toe is, is hij altijd geïnteresseerd in innovaties op het gebied van intelligente systemen die het zuinig rijden ondersteunen.

Jan / Kelly

Jan ervaart zijn manier van rijden als ontspannen, comfortabel en veilig voor zichzelf en zijn passagiers. Hij houdt zich altijd aan de verkeersregels, omdat hij ervan overtuigd is dat er een reden is waarom deze regels bestaan. Hij heeft heel wat rijervaring doordat hij dagelijks naar zijn werk rijdt, en vindt he ook niet erg te rijden wanneer hij op vakantie gaat. Hij vindt het niet erg om op onbekende plekken te rijden en is zelfverzekerd over zijn rijgedrag. Hij vindt niet echt dat hij intelligente systemen in zijn voertuig nodig heeft, omdat hij gelooft dat hij vanwege zijn rijervaring de volledige controle over zijn voertuig heeft. Hij weet hoe hij om moet gaan met moeilijke situaties.

Sam / Sabine

Sam heeft zijn rijbewijs al enige tijd en weet hoe hij moet rijden. Maar rijden op zichzelf is niet iets wat hij echt leuk vindt. Sam is een zeer sociaal persoon en hij kan soms niet stoppen met praten. Wanneer andere mensen bij hem in de auto zitten, vindt hij het leuk om de hele weg te kletsen, en wanneer hij alleen is, zingt of neuriet hij vaak mee met de radio, volledig gefocust op de muziek. Hierdoor is Sam vaak niet met zijn gedachten bij het rijden, waardoor hij langzamer gaat rijden en voor langere periodes achter een vrachtwagen blijft hangen of 60 km/h rijdt waar 80 km/h is toegestaan. Omdat autorijden niet echt zijn ding is, staat hij open voor systemen die een aantal van de taken van het rijden kunnen overnemen.

Matt / Sandra

Matt heeft niet altijd het volste vertrouwen in zichzelf tijdens het rijden, mede door enkele negatieve ervaringen tijdens het rijden. Vooral in wat drukker verkeer en meer complexe situaties is hij meer angstig. Matt is onzeker tijdens het rijden, hij probeert drukke verkeersmomenten en meer complexe situaties wanneer mogelijk te mijden. Om voorbereid te zijn, kent hij alle systemen in de auto die hem kunnen ondersteunen bij het rijden en in situaties die hij kan tegenkomen tijdens het rijden. Bij het kopen van een nieuwe auto is hij altijd geïnteresseerd in de systemen in een voertuig die hem kunnen ondersteunen tijdens het rijden.

John / Sarah

John maakt zich geen zorgen over de kosten en het brandstofverbruik van zijn voertuig, zolang hij maar op tijd op zijn bestemming is. Voor zijn werk moet hij veel buiten de deur zijn, en dat resulteert in heel wat uren op de weg. John is een zelfverzekerde bestuurder, die vaak toch wel gehaast is. Hij heeft al een aantal bekeuringen voor te hard rijden en hij is altijd op zoek hoe hij sneller door het verkeer kan, en soms frustreert of irriteert hij daarbij andere weggebruikers. Hij probeert de verkeersregels naar zijn hand te zetten. Hij is van mening dat intelligente systemen in zijn voertuig hem alleen zullen tegen houden in zijn rijgedrag.

Mark / Lexi

Mark houdt van de sensatie van het rijden en het gevoel dat snelheid kan creëren. Hij geeft de voorkeur aan een voertuig met een zeer krachtige motor, misschien wel de beste die hij kan kiezen als hij een auto koopt. Hij houdt van autorijden en maakt op zondag graag een ritje met zijn auto. Hij vindt het leuk om soms naar Duitsland te gaan om de grenzen van zijn auto te testen of naar Luxemburg om door de heuvels te rijden en de krachten die de scherpe bochten creëren te ervaren. Ondersteunende systemen in een auto houden de auto en hem meer in toom en maken de ervaring minder spannend, waardoor hij deze systemen minder of niet gebruikt.

Tom / Kate

Tom ziet rijden meer als een must dan een lust en zijn familie bekritiseert vaak zijn rijgedrag. Ze zeggen dat hij meer aandacht moeten besteden aan het rijden en aan de situatie rondom zijn auto, zodat hij minder onstuimig rijdt. Tom vindt het rijden nogal saai en ziet het zelfs als een verspilling van zijn tijd. Als hij alleen is in zijn auto, dan is hij vaak bezig met andere zaken dan autorijden. Bijvoorbeeld, het voeren van een telefoon gesprek of het reageren op berichten op zijn telefoon, wat niet echt bevorderlijk is voor zijn rijgedrag.

Seth / Melissa

Seth is een misschien wat overmoedige bestuurder, die zijn rijbewijs sinds iets meer dan een paar jaar heeft. Hij is ervan overtuigd dat hij volledige controle heeft over zijn auto en dat hij in staat is te rijden met hogere snelheden, alles kan overzien en in staat is om op tijd te stoppen. Echter, volgens anderen leidt deze overmoedigheid soms tot een verkeerde inschatting van zijn vaardigheden en bepaalde situaties, resulterend in riskant gedrag en situaties. Zijn risicovol gedrag wordt versterkt doordat Seth geen probleem ziet in het gebruik van zijn mobiele telefoon tijdens het rijden. Hij geniet van het rijden en maakt niet echt gebruik van systemen die het rijden ondersteunen of een deel van de rij taken overneemt.

Appendix C: Questionnaire Applied in Chapter 5

Think about a particular moment that you were driving on a two lane urban road with a maximum speed of 80 km/h outside rush hour. We would like to indicate to what extend the next couple of statement are applicable to you regarding that your last driving trip mentioned before.

	Not at all						Very Much
I purposely tailgate other drivers	○	○	○	○	○	○	○
I feel I have control over driving	○	○	○	○	○	○	○
I enjoy the sensation of driving on the limit	○	○	○	○	○	○	○
On a clear road, I usually drive at or below the limit	○	○	○	○	○	○	○
I drive cautiously	○	○	○	○	○	○	○
I sometimes feel frighten while driving	○	○	○	○	○	○	○
I like to take risks while driving	○	○	○	○	○	○	○
I am calm while driving	○	○	○	○	○	○	○
I prefer to drive above the limit	○	○	○	○	○	○	○
I base my behavior on the motto “Better safe than sorry”	○	○	○	○	○	○	○
I feel comfortable while driving	○	○	○	○	○	○	○
I enjoy the excitement of speeding	○	○	○	○	○	○	○
On a clear road, I usually drive faster than then the limit	○	○	○	○	○	○	○

For the assessment of the driving trip in combination the light system, please fill out the following questionnaire. The questionnaire consists of pairs of contrasting attributes that may be applicable. The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression.

	1	2	3	4	5	6	7	
annoying	○	○	○	○	○	○	○	enjoyable
not understandable	○	○	○	○	○	○	○	understandable
creative	○	○	○	○	○	○	○	dull
easy to learn	○	○	○	○	○	○	○	difficult to learn
valuable	○	○	○	○	○	○	○	inferior
boring	○	○	○	○	○	○	○	exciting
not interesting	○	○	○	○	○	○	○	interesting
unpredictable	○	○	○	○	○	○	○	predictable
fast	○	○	○	○	○	○	○	slow
inventive	○	○	○	○	○	○	○	conventional
obstructive	○	○	○	○	○	○	○	supportive
good	○	○	○	○	○	○	○	bad
complicated	○	○	○	○	○	○	○	easy
unlikable	○	○	○	○	○	○	○	pleasing
usual	○	○	○	○	○	○	○	leading edge
unpleasant	○	○	○	○	○	○	○	pleasant
secure	○	○	○	○	○	○	○	not secure
motivating	○	○	○	○	○	○	○	demotivating
meets expectations	○	○	○	○	○	○	○	does not meet expectations
inefficient	○	○	○	○	○	○	○	efficient
clear	○	○	○	○	○	○	○	confusing
impractical	○	○	○	○	○	○	○	practical
organized	○	○	○	○	○	○	○	cluttered

attractive	○	○	○	○	○	○	○	unattractive
friendly	○	○	○	○	○	○	○	unfriendly
conservative	○	○	○	○	○	○	○	innovative

Overall, how did the light system support your awareness of the driver speed?

In what terms was the use of the light system useful while driving?

What do you think of the use of the light system in combination with Cruise Control?

To what extend did you had the feeling that the light system influenced your speed perception?

Appendix D: Audio Files

The audio files used in the study described in Chapter 6 can be downloaded through the following link:

https://www.doi.org/10.4121/uuid:ef51f0ec-6730-4107-a814-b2d0ae66d3bb

Appendix E: Questionnaire Applied in Chapter 6 and 7 (Dutch)

Om de het geluid in relatie met de autopilot functie te beoordelen willen wij u vragen om de onderstaande vragenlijst in te vullen. De vragenlijst bestaat uit paren van contrasterende uitdrukkingen. De cirkels tussen de woorden vertegenwoordigen gradaties tussen de tegenstellingen. De mate waarmee u eens bent met één van de twee uitdrukkingen kunt aangeven door de juiste cirkel af te vinken.

	1	2	3	4	5	6	7	
onplezierig	○	○	○	○	○	○	○	plezierig
onbegrijpelijk	○	○	○	○	○	○	○	begrijpelijk
creatief	○	○	○	○	○	○	○	saai
makkelijk te leren	○	○	○	○	○	○	○	moeilijk te leren
waardevol	○	○	○	○	○	○	○	inferieur
vervelend	○	○	○	○	○	○	○	spannend
niet interessant	○	○	○	○	○	○	○	interessant
onvoorspelbaar	○	○	○	○	○	○	○	voorspelbaar
snel	○	○	○	○	○	○	○	langzaam
orgineel	○	○	○	○	○	○	○	conventioneel
belemmerend	○	○	○	○	○	○	○	ondersteuned
goed	○	○	○	○	○	○	○	slecht
complex	○	○	○	○	○	○	○	eenvoudig
afstotend	○	○	○	○	○	○	○	aantrekkelijk
gebruikelijk	○	○	○	○	○	○	○	nieuw
onaangenaam	○	○	○	○	○	○	○	aangenaam
vertrouwd	○	○	○	○	○	○	○	niet vertrouwd
motiverend	○	○	○	○	○	○	○	demotiverend

volgens verwachting	○	○	○	○	○	○	○	Niet volgens verwachting
inefficiënt	○	○	○	○	○	○	○	efficiënt
overzichtelijk	○	○	○	○	○	○	○	verwarrend
onpraktisch	○	○	○	○	○	○	○	praktisch
ordelijk	○	○	○	○	○	○	○	rommelig
aantrekkelijk	○	○	○	○	○	○	○	onaantrekkelijk
aardig	○	○	○	○	○	○	○	onaardig
conservatied	○	○	○	○	○	○	○	innovatief

Stel je voor dat de autopilotfunctie in combinatie met het geluid op de markt was en je kon het systeem in je eigen auto krijgen

	Heel erg oneens						Heel erg mee eens
Ik zou het system in de komende 6 maanden gebruiken	○	○	○	○	○	○	○
Met behulp van het system kan ik sneller reageren op situaties	○	○	○	○	○	○	○
Ik zou het system nuttig vinden tijdens het rijden	○	○	○	○	○	○	○
Het gebruik van het system verbeterd mijn rijpresen-taties	○	○	○	○	○	○	○
I zou voorspellen dat ik het system in de komende 6 maanden zou gebruiken	○	○	○	○	○	○	○
Mensen die mijn gedrag beïnvloeden zouden denken dat ik het systeem zou moeten gebruiken	○	○	○	○	○	○	○
Als ik het system gebruik, verminder ik de risico dat ik betrokken ben bij een ongeval	○	○	○	○	○	○	○
Het zou makkelijk voor mijn zijn om vaardig te worden in het gebruik van het systeem	○	○	○	○	○	○	○
De autoriteiten zouden nuttig zijn voor het gebruik van het system	○	○	○	○	○	○	○

Ik zou het system makkelijk in gebruik vinden	○	○	○	○	○	○	○
I zou van plan zijn het system in de komende 6 maanden te gebruiken	○	○	○	○	○	○	○
Mijn interactie met het system zou duidelijk en begrijpelijk zijn	○	○	○	○	○	○	○
Het systeem leren te gebruiken is voor mij makkelijk	○	○	○	○	○	○	○
Mensen die belangrijk voor mijn zijn zouden denken dat ik het systeem zou moeten gebruiken	○	○	○	○	○	○	○
In het algemeen zou de autoriteiten het gebruik van het systeem ondersteunen	○	○	○	○	○	○	○

Zou u kort de redenen kunnen beschrijven waarom u autopilot uitschakelde (als u dat heft gedaan)?

Wat vind u van het geluid dat is gekoppeld aan de autopilot functie?

Wat denk u van de autopilot functie in auto’s?

Appendix F: Questionnaire Applied in Chapter 6 and 7 (English)

For the assessment sound in relation with the autopilot function, please fill out the following questionnaire. The questionnaire consists of pairs of contrasting attributes that may be applicable. The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression.

	1	2	3	4	5	6	7	
annoying	○	○	○	○	○	○	○	Enjoyable
not understandable	○	○	○	○	○	○	○	understandable
creative	○	○	○	○	○	○	○	Dull
easy to learn	○	○	○	○	○	○	○	difficult to learn
valuable	○	○	○	○	○	○	○	Inferior
boring	○	○	○	○	○	○	○	Exciting
not interesting	○	○	○	○	○	○	○	Interesting
unpredictable	○	○	○	○	○	○	○	predictable
fast	○	○	○	○	○	○	○	Slow
inventive	○	○	○	○	○	○	○	conventional
obstructive	○	○	○	○	○	○	○	Supportive
good	○	○	○	○	○	○	○	Bad
complicated	○	○	○	○	○	○	○	Easy
unlikable	○	○	○	○	○	○	○	Pleasing
usual	○	○	○	○	○	○	○	leading edge
unpleasant	○	○	○	○	○	○	○	Pleasant
secure	○	○	○	○	○	○	○	not secure
motivating	○	○	○	○	○	○	○	demotivating

meets expectations	○	○	○	○	○	○	○	does not meet expectations
inefficient	○	○	○	○	○	○	○	Efficient
clear	○	○	○	○	○	○	○	Confusing
impractical	○	○	○	○	○	○	○	Practical
organized	○	○	○	○	○	○	○	Cluttered
attractive	○	○	○	○	○	○	○	unattractive
friendly	○	○	○	○	○	○	○	Unfriendly
conservative	○	○	○	○	○	○	○	Innovative

Imagine that the autopilot function in combination with the sound was on the market and you could get the system in your own car

	Strongly Disagree						Strongly Agree
I would intend to use the system in the next 6 months	○	○	○	○	○	○	○
Using the system enables me to react to the situations more quickly	○	○	○	○	○	○	○
I would find the systems useful in my driving	○	○	○	○	○	○	○
Using the system increases my driving performance	○	○	○	○	○	○	○
I would predict I would use the system in the next 6 months	○	○	○	○	○	○	○
People who influence my behavior would think that I should use the system	○	○	○	○	○	○	○
If I use the system, I will decrease my risk of being involved in an accident	○	○	○	○	○	○	○
It would be easy for me to become skillful at the using the system	○	○	○	○	○	○	○
The authority would be helpful in the use of the system	○	○	○	○	○	○	○
I would find the system easy to use	○	○	○	○	○	○	○
I would plan to use the system in the next 6 months	○	○	○	○	○	○	○
Using the system enables me to react to the situations more quickly	○	○	○	○	○	○	○

My interaction with the system would be clear and understandable	○	○	○	○	○	○	○
Learning to operate the system is easy for me	○	○	○	○	○	○	○
Using the system enables me to react to the situations more quickly	○	○	○	○	○	○	○
People who are important to me would think I should use the system	○	○	○	○	○	○	○
In general, the authority would support the use of the system	○	○	○	○	○	○	○

Can you shortly describe the reasons why you disabled the autopilot function (if you did)?

What do you think of the soundscape connected to the autopilot function?

What do you think of the autopilot function in vehicles?

List of Publications

Related to This Thesis

Hooft van Huysduynen, H., Terken, J. M. B., & Eggen, J. H. (2018). Why Disable the Autopilot AutomotiveUI '17 Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, 23-25 September 2018, Toronto, Canada (pp. 293-301). New York: Association for Computing Machinery, Inc.

Hooft van Huysduynen, H., Terken, J. M. B., & Eggen, J. H. A Satisfying Experience for Autonomous Driving Through Personalized Soundscapes (Submitted)

Hooft van Huysduynen, H., Terken, J.M.B. & Eggen, J.H. (2018). The relation between self-reported driving style and driving behaviour. A simulator study. Transportation Research. Part F: Traffic Psychology and Behaviour, 56C, 245-255.

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Other

Karjanto, J., Yusof, N., Terken, J.M.B., Hassan, M.Z.B., Delbressine, F.L.M., Hooft van Huysduynen, H. & Rauterberg, G.W.M. (2017). The identification of Malaysian driving styles using the multidimensional driving style inventory. MATEC Web of Conferences, 90:01004

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Mubin, O., Bartneck, C., Feijs, L.M.G., Hooft van Huysduynen, H., Hu, J. & Muelver, J. (2012). Improving speech recognition with the robot interaction language. Disruptive Science and Technology, 1(2), (pp. 79-88).

Curriculum Vitae

Hanneke Hooft van Huysduynen was born on 12 September 1988 in Eindhoven, The Netherlands. Af-ter obtaining her diploma in 2007 at the Christiaan Huysgens College in Eindhoven, she studied Indus-trial Design at the Eindhoven University of Technology (TU/e), the Netherlands. In 2014 she graduated with a project called ‘Do You Want to Play?’, of which the thesis was nominated for the ‘Gerrit van der Veer prijs’. After graduation, Hanneke worked for three months as a research assistant at the Department of Industrial Design at the TU/e, facilitating creative design sessions to support innova-tion among multiple stakeholders as well as transcribing and analyzing the results of these sessions in order to improve the supportive tool for these sessions. After this, she started working on her PhD research on Personalized Persuasion to Increase Compliance with Automated Driving at the Department of Industrial Design at the TU/e, of which the results are presented in this thesis.

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The work of a PhD is often seen and experienced as an individual effort, however this thesis would not have been here without the help and support of others. I would like to thank you all for all the support and help, that each of you provided in your own way.

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Summary

Personalized Persuasion to Increase Acceptance of Automated Driving

Technology forecasters are predicting that in the future, vehicles as we know them nowadays, will disappear. Intelligent systems, also known as Automated Driving Systems (ADS), will allow drivers to delegate driving activities such as steering, accelerating, and decelerating to the vehicle, and ultimately all driving controls will be executed by the vehicle (Nirschl, 2007). The delegation of control to the vehicle creates automated vehicles in which the role of the driver gradually changes from an actuator to an operator, and ultimately to a passenger, along with a change in the driving experience (Eckoldt, Knobel, Hassenzahl, & Schumann, 2012). As ADS are developed with a strong focus on safety, the behavior of highly automated vehicles is expected to be cautious and defensive which may not always be in line with the driver's own and preferred driving behavior. Next to a change in experience, the deviation of the behavior performed by an ADS from the driver's typical and preferred behavior may have a negative effect on people's willingness to use such systems.

From observations of everyday traffic it is clear that not all drivers behave in the same way. Research on differences among drivers has confirmed the existence of individual differences between drivers. The choice of driving speed, distance to a preceding vehicle, overtaking other vehicles and the tendency to commit traffic violations (Elander, West, & French, 1993) constitute behavioral tendencies of drivers. These habits are usually referred to by the term 'driving style' (Ishibashi, Okuwa, Doi, & Akamatsu, 2007). Accordingly, drivers are typically characterized as, for instance, careful, risky, or anxious drivers (Taubman-Ben-Ari, Mikulincer, & Gillath, 2004).

To the extent that behavior of ADS deviates from driver's typical driving style, the willingness to use ADS may be jeopardized. In order to learn more about the compliance with ADS, it is needed to understand how the compliance with ADS is influenced by people's driving style. Such insight enables the exploration of means to influence people's willingness to comply with such systems that are tuned to the needs and interest of specific driver groups. An easy way to determine drivers' driving style is by means of a questionnaire, giving information about someone's self-reported driving style. The stability of the different factors of the Multidimensional Driving Style Inventory (MDSI) (Taubman-Ben-Ari et al., 2004) was validated. A factor analysis of the data of 364 participants who completed the MDSI revealed five of the eight factors that resulted from the original factor analysis: Angry driving, Anxious driving, Dissociative driving, Distress-reduction driving, and Careful driving style. The scores indicated that all factors together determine what type of driver someone is.

However, the use of self-reported measures has been questioned due to the possibility of reporting biases (af Wåhlberg, 2009; af Wåhlberg & Dorn, 2015). This raised the question of whether a questionnaire is a proper mean to identify a person's driving style, or whether driving style can be better measured from driving behavior. Therefore, the predictive value of the MDSI for driving behavior was investigated in a driving simulator, in terms of speeding, braking, steering, lateral positioning and maintaining distance to a preceding vehicle. Eighty-eight participants filled in the MDSI and drove in a simulator for thirty minutes. Different driving behaviors, including complying with the maximum speed, lateral position and the distance to preceding vehicles, were recorded. The objective data retrieved from the simulator were compared with scores resulting from the questionnaire data. It was concluded that the results from a driving style questionnaire may be used to get an indication of people's typical driving behavior. The correlations between the self-reported driving style obtained from the questionnaire and the driving behavior in the driving simulator are modest and limited to some driving styles but in line with previous research. This indicates that the MDSI may be used as a diagnostic tool for identifying the typical driving behavior of individual people within a driving simulator. The results also indicate that the driving styles Careful and Risky can be considered as opposites. However, the results from both this and the previous study do not reveal conclusive results that the use of the MDSI is a good way to create driver profiles according to driving style because it was concluded that the scores on all factors of the MDSI combined to determine what type of driver someone is.

Taking a closer look at Risky and Careful driving style, these can be analyzed from three perspectives: the behavior, knowing the consequences of the behavior and the motivation of the behavior. From a behavioral perspective, the driving styles Risky and Careful can be considered as opposites. A noticeable difference between careful and risky drivers is the driving speed, as risky drivers often tend to drive at or faster than the maximum speed, while careful drivers more often drive below the maximum speed being more cautious and sustainable while driving. A second aspect relates to whether drivers are aware of the consequences of their driving behavior or not. Young et al. (Young et al., 2010) mentioned that a variety of reasons can determine why drivers speed; for some, speeding is unintentional, for others, speeding is an intentional act. This dimension can be placed perpendicular to the dimension of careful versus risky driving. As last, the behavior can occur through internal (personality) or external motivations (goals or distractions). This results in eight different spaces within the framework characterizing eight different types of drivers (See Figure 5 in Chapter 4).

Differences in preferred driving behavior between drivers may influence their willingness to make use of intelligent systems in vehicles. Personas are a common way to capture differences between people and can be used as a tool for identifying the typical driving behavior of individual people. The eight personas that were created according to the three bi-polar dimensional model capturing differences between drivers were validated. A survey was conducted with 202 respondents who indicated for each persona how much they recognized themselves in that persona. The results reveal that all personas were selected by at least some of the respondents and that the majority of the participants scored a 7 or higher on a ten point scale as the highest score for the best matching persona. This implies that all eight of the personas are needed in order to cover the majority of the drivers and that there is no need to extend the number of personas. With respect to the validation of the framework, it was found that the more characteristics personas have in common the higher the correlation, indicating that the framework is a valid basis for generating driver personas and that it may be used as a diagnostic tool to identify differences between drivers in future studies and to be able to assign drivers to different driver profiles.

There may be several reasons for drivers to decide to neglect the assistance provided by ADS. Thus, there is a need for ways to enhance people's willingness to adopt intelligent systems. One way is the use of persuasive technologies. However, since people differ in their needs and interests, strategies that are intended to persuade one type of driver to use intelligent systems may have no or even a negative influence on other types of drivers (Taubman-Ben-Ari & Yehiel, 2012). For example, a careful driver who receives an advice to slow down to create a gap for another vehicle will likely comply with this advice, while an angry driver who receives the same advice may just neglect this advice and speeds up to close the gap. Taking the differences in driving behavior and style into account may enhance the willingness to use intelligent systems while driving by creating tailored, more personalized persuasion.

In modern traffic, measures are implemented to regulate speeding, which may annoy drivers who pursue an exciting and riskier driving experience and make them exceed speed limits. Others prefer a more relaxing experience resulting in socially desired driving behavior. The capacity of ambient light was investigated to alter the perception of speed and therefore influence the driving experience. The aim was to determine how different drivers experience the concept of an ambient light moving along the A-pillar inside the vehicle. The experience was operationalized in terms of attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. We were interested to see if this study supported the notion that a driver's attitude towards ambient light is highly individual and supports the idea of making use of personalized persuasion. In different conditions, the light moved at different speeds. The outcomes of the study showed that overall the ambient light that was used had a positive effect on the driving experience but that the attitude towards the ambient light was highly individual. The majority indicated a preference for the ambient light while some saw it more as a distraction or even inducing more stress. These results support the idea to make use of more personalized persuasion and provide an indication that the use of ambient light as a mean for persuasion may positively affect the willingness of drivers to use ADS.

Another way to compensate for the degradation in the driving experience, which is likely to result from more automated driving, may be by offering proper soundscapes. A study was conducted in a driving simulator, in which the influence of two different soundscapes on the driving experience was investigated, one giving a more exciting experience, the other supporting a more relaxing experience. Forty-four participants representing two different driving styles, assertive/risky or calm/careful, drove in a simulated automated vehicle, where they could put the autopilot function on or off. When the autopilot was enabled, one of the two soundscapes designed for this study was played. The results did not provide a conclusive answer that soundscapes personalized according to participants' driving style influenced the willingness to use the autopilot.

Finally, as no conclusive answers were found that more personalized soundscapes influenced the willingness to use the autopilot, alternative reasons why drivers may disengage the autopilot not related to the soundscape were investigated. This was done using data from the simulator study in which participants had the ability to drive autonomously but also to disengage the system, investigating the influence of two different soundscapes on the driving experience. The analysis of the qualitative data revealed six reoccurring themes covering the reasons why participants disabled the autopilot without there being a need to intervene: The speed maintained by the autopilot, The behavior of the autopilot in relation to overtaking other vehicles, Onset of boredom, Onset of sleepiness, Lack of trust in the autopilot and Enjoyment of manual driving. Several design opportunities related to the six reoccurring themes were proposed to counteract the driver's inclination to disengage the automated driving system when there is no objective necessity to do so.

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