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SUPPORTING OLDER DRIVERS THROUGH EMERGING IN-VEHICLE TECHNOLOGIES: PERFORMANCE-RELATED ASPECTS AND USER ACCEPTANCE

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OVERVIEW

This monograph represents an extended compilation of the articles listed below. Monograph chapters including text passages from these articles are assigned in the last column.

	Article	Monograph chapters including article text
I	Hartwich, F., Beggiato, M., Petzoldt, T., & Krems, J. F. (2017). *Supporting Older Drivers to Keep the Overview - Effects of Providing Prior Information about Intersections.* Manuscript submitted for publication.	1, 2.2.1, 2.2.3, 2.3.3, 2.3.3.1, 2.3.3.2, 5.1 - 5.4, 8.3
II	Hartwich, F., Witzlack, C., & Krems, J. F. (2014). *Age-specific contact analogue head-up displays: Will they be accepted by older drivers?* Paper presented at the European and Interdisciplinary Conference on Ageing and Safe Mobility, Bergisch Gladbach, Germany. Retrieved from http://www.bast.de/DE/Verkehrssicherheit/Publikationen/Veranstaltungen/U-Ageing-2014/Downloads-Papers/Hartwich.pdf?__blob=publicationFile&v=2	2.3.3.1, 2.3.5.2, 2.3.5.3, 6.1 - 6.4
III	Hartwich, F., Beggiato, M., & Krems, J. F. (2017). *Driving Comfort, Enjoyment, and Acceptance of Automated Driving - Effects of Drivers' Age and Driving Style Familiarity.* Manuscript resubmitted for publication.	1, 2.2.2, 2.3.4, 2.3.4.1, 2.3.4.2, 2.3.4.3, 2.3.5, 2.3.5.4, 7.1 - 7.4, 8.2.1
IV	Hartwich, F., Witzlack, C., Beggiato, M., & Krems, J. F. (2017). *The First Impression Counts – A Combined Driving Simulator and Test Track Study on the Development of Trust and Acceptance of Highly Automated Driving.* Manuscript submitted for publication.	2.3.4, 2.3.4.1, 2.3.5, 2.3.5.1, 2.3.5.4, 7.1, 7.2.1, 7.2.4, 7.3.2, 7.4, 8.2.2

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LIST OF ABBREVIATIONS

ADAS ..... Advanced Driver Assistance System

ANOVA ..... Analysis of Variance

AR ..... Augmented Reality

ARD ..... Augmented Reality Display

ATAVT ..... Adaptive Tachistoscopic Traffic Perception Test

CRDI ..... Continuous Response Digital Interface

DVE-system ..... driver-vehicle-environment system

ECOM ..... Extended Control Model

e.g. ..... for example

H ..... hypothesis

HAD ..... highly automated driving

i.e. ..... that is

IVIS ..... In-Vehicle Information System

MANOVA ..... Multivariate Analysis of Variance

MD ..... manual driving

Q ..... question

SCM ..... Surrogate Complexity Method

UFOV ..... Useful Field of View

UTAUT ..... Unified Theory of Acceptance and Use of Technology

ZVT ..... Zahlenverbindungstest [Trail Making Test]

SUMMARY

In the course of the current demographic change, the proportion of the population aged 65 and older is projected to steadily increase in many countries of the world (UN DESA Population Division, 2015). The ageing society is reflected in an increasing number of older road users (Koppel & Berecki-Gisolf, 2015), especially considering the growing need for older adults to maintain individual mobility (Eby & Molnar, 2012). This development raises new issues of transportation research, since age-related changes in mobility patterns as well as sensory, cognitive, and motor functions reduce older adults' traffic safety (Polders, Vlahogianni, Leopold, & Durso, 2015). Accordingly, new strategies to aid older drivers and their mobility needs are required, which could potentially be provided by emerging in-vehicle technologies (Karthaus & Falkenstein, 2016).

The overall aim of present dissertation project was to evaluate whether in-vehicle technologies that appear promising to support older drivers can actually contribute to their individual mobility, which requires an improvement in aspects related to driving performance as well as the acceptance of such systems in this age group. Therefore, contact-analogue head-up displays (also labelled as Augmented Reality Displays, ARDs) and highly automated driving were selected as two exemplary technologies, representing completely different levels of driving automation and accordingly different approaches to support drivers. The ARD-technology represents a technical implementation approach for IVIS and therefore an example for Automation Level 0 (no automation; SAE International, 2014) by helping the driver to execute the driving task manually through useful information. In contrast, the HAD-technology aims at supporting the driver by taking over the driving task, which corresponds to Automation Level 4 (high automation; SAE International, 2014). Despite these different approaches, both technologies were previously assumed to have a strong potential to support especially older drivers (Meyer & Deix, 2014; Polders et al., 2015; Rusch et al., 2013; Schall et al., 2013).

Three empirical studies were conducted to examine performance- and acceptance-related aspects of both technologies. All studies were carried out with a group of older drivers (maximum age range: 65-85 years) and a younger comparison group (maximum age range: 25-45 years) representing the 'average' (i.e. young, but experienced) driver in order to identify age-specific results.

Focusing on performance-related aspects of the ARD-technology, Study I represents a reaction time experiment conducted in a driving simulator. One age-specific beneficial function of such an ARD is to

provide prior information about approaching complex traffic situations, which addresses older drivers' tendency to process multiple information successively (serially) rather than simultaneously (parallel) (Davidse, Hagenzieker, van Wolffelaar, & Brouwer, 2009; Küting & Krüger, 2002). Therefore, the aim of this study was to examine the effects of an ARD providing prior information about approaching intersections on drivers' speed and accuracy of perceiving these intersections, which is considered a necessary precondition for a safe driving performance (Crundall & Underwood, 2011). Based on concerns about the counterproductive effects of presenting information via an ARD, especially in cases of inaccurate information, system failures were included in this examination. The ARD-information aided drivers from both age groups in identifying more relevant aspects of the intersections without increasing response time, indicating the potential of the system to support both older and younger drivers in complex traffic situations. Experiencing system failures (i.e. inaccurate information) did offset this positive effect for the study's duration, particularly for older drivers. This might be because it was difficult to ignore inaccurate prior information due to their presentation via an ARD.

Study II represents a driving simulator study on acceptance-related aspects of an ARD providing prior information about approaching intersections. This study focused on the effects of system experience on drivers' acceptance as well as on the identification of age-specific acceptance barriers that could prevent older drivers from using the technology. In summary, older and younger drivers' evaluation of the ARD was positive, with a tendency to more positive evaluations with than without system experience in the driving simulator. Compared to the younger group, older drivers reported a more positive attitude towards using the ARD, even though they evaluated their self-efficacy in handling the system and environmental conditions facilitating its usage as less strong.

Both performance- and acceptance-related aspects of HAD were addressed in Study III, a two-stage driving simulator study. The focus of the performance perspective shifted in parallel with the shift of the human role from driver to passenger due to the increasing driving automation. Accordingly, the examination of HAD was focused on the human evaluation of the automated system's driving performance. In this context, affective components of human-automation interaction, such as comfort and enjoyment, are considered important for the acceptance and thus usage of automated vehicles (Tischler & Renner, 2007). It is assumed that the implemented driving style has an impact on such affective components in the context of HAD (Bellem, Schönenberg, Krems, & Schrauf, 2016). One theoretical approach to increase the comfort of HAD recommends the implementation of familiar, natural driving styles to mimic human control (Elbanhawi, Simic, & Jazar, 2015). Therefore, the effects of driving automation and the familiarity of the HAD-style on driving comfort and enjoyment were examined. Automation increased both age groups' comfort, but decreased younger drivers'

enjoyment. For all dependent variables, driving style familiarity significantly interacted with drivers' age the same way: while younger drivers preferred a familiar HAD-style, older drivers preferred an unfamiliar driving style in a highly automated context. Accordingly, the familiarity approach can be supported at least for younger drivers, but not for older drivers, whose manual driving styles are characterised by strategies to compensate for age-related impairments of sensory, cognitive, or motor functions. HAD-style preferences of this age group seem to be more influenced by the desire to regain a driving style free from these compensation strategies than by a need for familiar driving manoeuvres.

In parallel with the evaluation of the ARD, acceptance-related issues in the context of HAD included the effects of system experience on drivers' acceptance and potential age-specific acceptance barriers. Considering a system-specific design issue, it was additionally examined whether drivers' acceptance of HAD is modifiable by the familiarity of the implemented driving style. In this driving simulator study, members of both age groups showed slightly positive a priori acceptance ratings, which significantly increased after the initial experience and remained stable afterwards. Similar to drivers' acceptance of the ARD, older drivers reported a more positive attitude towards using HAD despite their lower self-assessed self-efficacy and environmental conditions facilitating HAD-usage compared to younger drivers. Regarding HAD-style, acceptance was subject to the same interaction between drivers' age and driving style familiarity as driving comfort and enjoyment.

These findings demonstrate that effective approaches to support the independent mobility of older adults are provided by emerging in-vehicle technologies on different levels of driving automation. The majority of the performance-related improvements did apply to both older and younger drivers, confirming that automotive technologies suggested for older drivers have the potential to support drivers of other age groups as well. Regarding drivers' acceptance, findings suggest that both systems would be accepted by different age groups, which correspondents to the results from the performance perspective. The comparable acceptance patterns identified for two systems at different stages of driving automation, such as ARDs and HAD, indicate underlying general aspects of older adults' acceptance of in-vehicle technologies. This includes their strong need to preserve their individual mobility as well as their lower self-efficacy in handling relevant technologies and insufficient access to a support infrastructure. These insights can enrich both theories of older drivers' acceptance of in-vehicle technologies and measures to ensure the successful development and introduction of systems aiding them in maintaining a safe individual mobility.

Considering the importance of driving for older adults' physiological and psychological well-being (e.g. Adler & Rottunda, 2006; Lutin, Kornhauser, & Lerner-Lam, 2013), these results emphasise the potential of emerging in-vehicle technologies to improve both older drivers' traffic safety and quality of life.

ZUSAMMENFASSUNG

Im Zuge des aktuellen demografischen Wandels wird für zahlreiche Länder der Welt eine stetige Zunahme des Bevölkerungsanteils von Personen im Alter von 65 Jahren und älter prognostiziert (UN DESA Population Division, 2015). Die daraus resultierende alternde Gesellschaft spiegelt sich auch in der steigenden Anzahl älterer Verkehrsteilnehmer wieder (Koppel & Berecki-Gisolf, 2015). Dieser Effekt wird durch das ebenfalls ansteigende Bedürfnis älterer Personen, ihre Individualmobilität auch bis ins hohe Alter hinein aufrecht zu erhalten, noch verstärkt (Eby & Molnar, 2012). Berücksichtigt man die Auswirkungen altersbedingter Veränderungen von Mobilitätsmustern und fahrrelevanten Fähigkeiten auf die Sicherheit älterer Verkehrsteilnehmer (Polders et al., 2015), stellt diese demographische Entwicklung neue Herausforderungen an die Verkehrsforschung. So bedarf es neuartiger Strategien zur Unterstützung älterer Fahrzeugführer und ihrer Mobilitätsbedürfnisse. Aufgrund aktueller technologischer Entwicklungen eröffnen vor allem durch neuartige Fahrzeugtechnologien zur Fahrerunterstützung innovative Möglichkeiten, diesem Bedarf gerecht zu werden (Karthaus & Falkenstein, 2016). An diesem Punkt setzt die vorliegende Dissertation an.

Ziel des Dissertationsprojektes war es zu evaluieren, inwieweit aktuell in Entwicklung befindliche Fahrzeugtechnologien, die aus theoretischer Sicht als geeignete Mittel zur Unterstützung älterer Fahrer erscheinen, tatsächlich zu deren Individualmobilität beitragen können. Um das Potential derartiger Technologien abzuschätzen, wurde einerseits untersucht, inwieweit sie zur Verbesserung von Variablen, die in Beziehung zur Fahrleistung stehen, beitragen können. Anderseits wurde ihre Akzeptanz bei potentiellen zukünftigen Nutzern evaluiert. Für diese Untersuchungen wurden zwei exemplarische Technologien als Repräsentanten grundlegend unterschiedlicher Stufen der Fahrzeugautomatisierung ausgewählt: ein kontaktanaloge Head-up Display (auch Augmented Reality Display, ARD) und hochautomatisiertes Fahren. ARDs stellen einen technologischen Ansatz zur Implementierung von Fahrerinformationssystemen und dementsprechend ein Beispiel für Automatisierungsstufe 0 (no automation; SAE International, 2014) dar, indem sie den Fahrer durch die Bereitstellung verkehrsrelevanter Informationen bei der manuellen Ausführung der Fahraufgabe unterstützen. Im Gegensatz dazu zielt die Technologie des hochautomatisierten Fahrens auf eine Unterstützung des Fahrers durch die vollständige Übernahme der Fahraufgabe ab, was Automatisierungsstufe 4 (high automation; SAE International, 2014) entspricht. Trotz dieser grundlegend unterschiedlichen Ansätze wird beiden Technologien ein hohes Potential zur

Unterstützung insbesondere älterer Fahrer zugesprochen (Meyer & Deix, 2014; Polders et al., 2015; Rusch et al., 2013; Schall et al., 2013).

Die Untersuchung Performanz- und Akzeptanz-bezogener Aspekte beider Technologien erfolgte im Rahmen von drei empirische Studien. Um altersspezifische Befunde identifizieren zu können, wurden allen Studien mit Vertretern der Zielgruppe von älteren Fahrern (65-85 Jahre alt) sowie einer jüngeren Vergleichsgruppe ‚durchschnittlicher' (d.h. junger, erfahrener) Fahrer (25-45 Jahre alt) durchgeführt.

Bei Studie I handelte es sich um eine im Fahrsimulator durchgeführte Reaktionszeitstudie, in deren Rahmen Leistungs-bezogene Aspekte von ARDs untersucht wurden. Unter den vielfältigen Möglichkeiten zur Anwendung dieser Technologie wird vor allem die Präsentation von Vorinformationen über bevorstehende komplexe Fahrsituationen während der Fahrt als gewinnbringend für ältere Fahrer eingestuft. Diese Strategie adressiert die Tendenz älterer Fahrer zu einer eher seriellen als parallelen Verarbeitung gleichzeitig verfügbarer Informationen während der Fahrt (Davidse et al., 2009; Küting & Krüger, 2002). Vor diesem Hintergrund lag der Fokus von Studie I auf den Effekten einer kontaktanalogen Präsentation von Vorinformationen über bevorstehende Kreuzungen auf die Geschwindigkeit und Genauigkeit der Wahrnehmung dieser Kreuzungen durch den Fahrer, was eine Grundvoraussetzung für eine sichere Fahrleistung darstellt (Crundall & Underwood, 2011). Basierend auf bestehenden Befürchtungen über kontraproduktive Effekte einer kontaktanalogen Informationsdarstellung während der Fahrt, insbesondere im Falle inkorrekter Informationen, wurden zudem die Auswirkungen von Systemfehlern untersucht. Mit Hilfe der kontaktanalogen Vorinformationen gelang es sowohl älteren als auch jüngeren Fahrern, ohne erhöhten Zeitbedarf einen höheren Anteil relevanter Aspekte in Kreuzungssituationen wahrzunehmen. Allerdings wurde die positive Systemwirkung durch das Erleben von Systemfehlern (in diesem Fall inkorrekten Vorinformationen) zumindest für die Dauer der Untersuchung aufgehoben. Dieser Effekt war besonders ausgeprägt für ältere Fahrer und könnte auf die Schwierigkeit, inkorrekte Informationen auf Grund ihrer Darstellung im ARD zu ignorieren, zurückzuführen sein.

Studie II stellte eine Fahrsimulatorstudie zu Akzeptanz-bezogenen Aspekten eines ARDs, welches dem Fahrer Vorinformationen über bevorstehende Kreuzungen zur Verfügung stellt, dar. Inhalt dieser Studie waren zum einen die Effekte von Systemerfahrung auf die Nutzerakzeptanz des Systems, zum anderen altersspezifische Akzeptanzbarrieren, welche ältere Fahrer potentiell von der Nutzung der Technologie abhalten könnten. Insgesamt bewerteten sowohl ältere als auch jüngere Fahrer das ARD positiv. Dabei fielen Bewertungen auf Basis von Systemerfahrung im Fahrsimulator tendenziell besser aus als Bewertungen ohne vorherige Systemerfahrung. Obwohl ältere Fahrer im Vergleich zu jüngeren Fahrern ihre Selbstwirksamkeit im Umgang mit dem ARD sowie Umgebungsfaktoren, welche dessen

Nutzung unterstützen könnten, als geringer ausgeprägt wahrnahmen, war die positive Einstellung gegenüber der Nutzung des Systems bei ihnen im Durchschnitt stärker ausgeprägt.

Leistungs- und Akzeptanz-bezogene Aspekte des hochautomatisierten Fahrens wurden in Studie III, einer zweistufigen Fahrsimulatorstudie, untersucht. Parallel zur Veränderung der Rolle des Menschen vom Fahrzeugführer zum Passagier im Zuge der zunehmenden Fahrzeugautomatisierung veränderte sich dabei auch der Fokus der Leistungsperspektive. Dem entsprechend stand die Bewertung der Fahrleistung des automatisierten Systems durch den mitfahrenden Menschen im Mittelpunkt dieser Untersuchung. Affektive Komponenten der Mensch-Automatisierungs-Interaktion wie Fahrkomfort und Fahrspaß werden in diesem Kontext als bedeutsam zur Gewährleistung der Nutzerakzeptanz und damit auch Nutzung automatisierter Fahrzeuge betrachtet (Tischler & Renner, 2007). Es wird angenommen, dass derartige affektive Komponenten im Kontext des hochautomatisierten Fahrens vor allem vom implementierten Fahrstil abhängen (Bellem et al., 2016). In einem theoretischen Ansatz zur Verbesserung des Fahrkomforts wird die Implementierung vertrauter (d.h. dem eigenen manuellen Fahrstil ähnlicher) Fahrstile empfohlen, um einen menschlichen Fahrzeugführer nachzuahmen und so Bedenken gegenüber einer automatisierten Fahrzeugführung abzubauen (Elbanhawi et al., 2015). Diesem Ansatz folgend wurden in Studie III die Effekte der Fahrzeugautomatisierung sowie der Ähnlichkeit des implementierten Fahrstils zum individuellen manuellen Fahrstil des jeweiligen Fahrers auf Fahrkomfort und Fahrspaß untersucht. Es konnte gezeigt werden, dass mit höherer Automatisierung der Fahrkomfort älterer und jüngerer Fahrer anstieg, der Fahrspaß jüngerer Fahrer sich jedoch verringerte. Alle abhängigen Variablen wurden von einer vergleichbaren Interaktion zwischen Fahreralter und Fahrstilähnlichkeit beeinflusst: Während jüngere Fahrer hochautomatisierte Fahrstile bevorzugten, die ihren jeweiligen manuellen Fahrstilen ähnelten, präferierten ältere Fahrer im hochautomatisierten Kontext eher unähnliche Fahrstile. Dem entsprechend kann der Vertrautheitsansatz basierend auf den Ergebnissen von Studie III zumindest für jüngere Fahrer unterstützt werden, nicht aber für die Zielgruppe älterer Fahrer, deren manuelle Fahrstile durch Kompensationsstrategien zum Ausgleich altersbedingter Einschränkungen ihrer sensorischen, kognitiven und motorischen Fähigkeiten geprägt sind. Fahrstilpräferenzen im hochautomatisierten Kontext scheinen in dieser Altersgruppe mehr von dem Wunsch, einen von diesen Kompensationsstrategien unbeeinträchtigten Fahrstil wiederzuerlangen, geprägt zu sein als von dem Bedürfnis nach vertraut gestalteten Fahrmanövern.

Analog zur Evaluation des ARDs beinhaltete die Untersuchung Akzeptanz-bezogener Aspekte des hochautomatisierten Fahrens die Effekte von Systemerfahrung auf die Nutzerakzeptanz sowie potentielle altersspezifische Akzeptanzbarrieren. Einen systemspezifischen Designaspekt aufgreifend

wurde zudem untersucht, ob die Nutzerakzeptanz des hochautomatisierten Fahrens ebenfalls durch den implementierten Fahrstil modifizierbar ist. Fahrer beider Altersgruppen berichteten tendenziell positive a priori Akzeptanzwerte, welche sich nach der Ersterfahrung mit dem System signifikant erhöhten und sich anschließend stabilisierten. Vergleichbar mit den Ergebnissen zum ARD war die positive Einstellung gegenüber der Nutzung eines hochautomatisierten Fahrzeuges bei älteren Fahrern im Durchschnitt stärker ausgeprägt als bei jüngeren, obwohl sie ihre Selbstwirksamkeit im Umgang mit dem System sowie unterstützende Umgebungsfaktoren als geringer ausgeprägt bewerteten. Bezüglich des hochautomatisierten Fahrstils unterlag die Systemakzeptanz derselben Interaktion zwischen Fahreralter und Fahrstilähnlichkeit wie Fahrkomfort und Fahrspaß.

Diese Ergebnisse demonstrieren, dass Fahrzeugtechnologien auf verschiedenen Automatisierungsstufen effektive Ansätze zur Unterstützung der Individualmobilität älterer Personen liefern können. Die Mehrzahl der identifizierten Leistungs-bezogenen Verbesserungen zeigte sich sowohl für ältere als auch jüngere Fahrer. Diese Befunde weißen auf das Potential von Systemen, welche den Bedürfnissen älterer Fahrer entsprechen, zur Unterstützung verschiedener Altersgruppen hin. Die Ergebnisse der Akzeptanzperspektive deuten an, dass die evaluierten Systeme von Fahrern verschiedener Altersgruppen akzeptiert werden würden, was die Ergebnisse der Leistungsebene widerspiegelt. Die Vergleichbarkeit der Muster verschiedener Akzeptanzprädiktoren, welche für zwei Systeme auf grundlegend unterschiedlichen Automatisierungsstufen identifiziert werden konnten, legt die Existenz zugrundeliegender genereller Aspekte der Fahrzeugtechnologie-Akzeptanz älterer Fahrer nahe. Diese beinhalten deren stark ausgeprägtes Bedürfnis zur Erhaltung ihrer Individualmobilität sowie deren geringere Selbstwirksamkeit im Umgang mit relevanten Technologien und den unzureichenden Zugang zu unterstützenden Infrastrukturen. Diese Erkenntnisse liefern Implikationen für theoretische Modelle der Akzeptanz von Fahrzeugtechnologien durch ältere Fahrer sowie für Maßnahmen zur Absicherung einer erfolgreichen Entwicklung und Markteinführung von Systemen, die darauf abzielen, ältere Menschen beim Erhalt ihrer Individualmobilität zu unterstützen.

Berücksichtigt man die Bedeutsamkeit des Fahrens eines eigenen Automobils für das physiologische und psychologische Wohlbefinden im Alter (Adler & Rottunda, 2006; Lutin et al., 2013; Whelan, Langford, Oxley, Koppel, & Charlton, 2006), unterstreichen diese Ergebnisse das Potential neu entstehender Fahrerunterstützungstechnologien für die Verbesserung der Verkehrssicherheit, aber auch Lebensqualität älterer Menschen.

1 INTRODUCTION

The ageing society represents one of the most considerable demographic transformations faced by the modern world. In the course of this demographic change, the proportion of the population aged 65 and older is projected to steadily increase in Germany (from 20 % to 33 % by 2050; Kubitzki & Janitzek, 2009), Europe (from 18 % to 24 % by 2030; Polders, Vlahogianni, Leopold, & Durso, 2015), and throughout the world (from 7 % to 14 % by 2040; Cauley, 2012). By 2050, the global population of older adults, identified as the age group with the fastest growing number of members, is expected to more than double its current size (UN DESA Population Division, 2015).

This development will increase the number of older road users (Koppel & Berecki-Gisolf, 2015; Kubitzki & Janitzek, 2009), especially considering the growing need for older adults to maintain individual mobility (Beckmann, Holz-Rau, Rindsfüser, & Scheiner, 2005; Eby & Molnar, 2012; European Conference of Ministers of Transport, 2002). The frequency of travelling has already been shown to rise among older adults (Sivak & Schoettle, 2012), with the private motor vehicle being the most preferred means of transport in this age group (Fiorentino, Fornells, Schubert, & Fernández-Medina, 2016). A related trend can be observed regarding the number of high-aged driver's license owners, which is expected to keep growing as well (Fiorentino et al., 2016; Koppel & Berecki-Gisolf, 2015). As a result, the ageing society is reflected in the population of vehicle drivers.

Given the well documented effects of age-related changes in sensory, cognitive, and motor functions on driving performance (e.g. Bayam, Liebowitz, & Agresti, 2005; Eby, Trombley, Molnar, & Shope, 1998; Polders et al., 2015), this situation requires new strategies to support older drivers and their mobility needs. Considering the importance of driving for socialising, independence, and the accessibility of health care services and shopping facilities (Adler & Rottunda, 2006; Lutin et al., 2013; Whelan et al., 2006), such strategies would positively affect both older drivers' safety and quality of life.

One opportunity to face this challenge is developing in-vehicle technologies to aid older drivers (Davidse et al., 2009; Karthaus & Falkenstein, 2016; Kocherscheid & Rudinger, 2005). Indeed, "there is a clear worldwide opportunity to positively impact global safety and mobility among older adults by designing a vehicle that recognises and helps to overcome some of the driving abilities that commonly decline in older adulthood" (Eby & Molnar, 2012, p. 14). As technological advances have enabled a fast progression of in-vehicle technologies, especially driving automation, innovative opportunities to

support driver groups with specific needs are arising. This issue is addressed in the present dissertation, which focuses on the opportunities given by emerging in-vehicle technologies to improve older adults' (i.e. persons aged 65 and older) safe and independent mobility. As human factors are already recognised as important for the design and introduction of new technologies, in general (Regan, Stevens, & Horberry, 2014), there is a great demand for research on human-centred questions regarding emerging technologies. For these reasons, two exemplary systems were examined out of a psychological perspective: contact-analogue head-up-displays (hereafter referred to as Augmented Reality Displays, ARD) and highly automated driving (HAD). Even though these technologies represent completely different stages of driving automation, both are assumed to have a strong potential to support especially older drivers (Meyer & Deix, 2014; Polders et al., 2015; Rusch et al., 2013; Schall et al., 2013), which was evaluated in the context of this dissertation.

Next to different aspects related to driving performance, user acceptance as a necessary precondition for the actual usage of technologies (Regan et al., 2014) was focal point of the evaluation of both systems. This issue is of specific interest in the context of older driver support, as older adults are supposedly less willing to use novel technologies than younger ones (Czaja & Lee, 2012) and place specific demands on the conceptualisation and design of such systems in order to ensure their acceptance (Jakobs, Lehnen, & Ziefle, 2008). Performance-related aspects and acceptance of ARD and HAD were examined in three studies, which form the empirical basis of this dissertation project.

Chapter 2.1 provides a theoretical framework, which serves as basis for the presentation of older drivers' specific demands (Chapter 2.2) as well as opportunities given by automotive technologies to meet these demands (Chapter 2.3). This is followed by an overview of general research questions (Chapter 3) and methodological considerations (Chapter 4) of this dissertation project. Specific research questions and methods as well as the results of the three empirical studies are described and discussed in the three subsequent chapters. The two studies presented in the Chapters 5 and 6 focus on an age-specific ARD. HAD was examined in a two-stage study, which is the topic of Chapter 7. The monograph concludes with a general discussion of the previously presented findings (Chapter 8), including limitations of the presented work as well as theoretical, practical, and methodological implications.

2 THEORETICAL BACKGROUND

2.1 The Driving Task

On a general level, traffic can be described as an interactive system consisting of three elements: road users, vehicles, and driving environment (Panou, Bekiaris, & Papakostopoulos, 2007). Accordingly, in the context of motorised individual traffic, driving represents an interaction of driver, vehicle, and environment (DVE-system). In this system, the driver's task includes operating the vehicle through the environment in order to reach the intended destination while taking into consideration characteristics of the vehicle (e.g. physical properties, technical equipment) and the environment (e.g. traffic density, visibility conditions, road surface) (Vollrath & Krems, 2011). Considering these requirements, driving represents "one of the most complex and safety critical everyday tasks in modern society" (Peters & Nilsson, 2007, p. 85).

Since human factors are reported to be the causing or at least contributing factors in a substantial majority of traffic accidents (Evans, 1996; Hankey et al., 1999, as cited in Medina, Lee, Wierwille, & Hanowski, 2004), the driver is considered the most critical element of the DVE-system (Panou et al., 2007). Therefore, a detailed description of the driver's task represents a necessary foundation to understand the reasons for traffic accidents and to derive measures that can aid the driver in performing the driving task (Küting & Krüger, 2002). For these reasons, the following chapters provide a descriptive model of the driving task (Chapter 2.1.1) as well as an overview of the driver abilities required to perform this task (Chapter 2.1.2).

2.1.1 The Extended Control Model (ECOM)

In the absence of one universal, generally accepted model of the driving task, the literature provides a variety of models, which are either focusing on different parts of the driving task or aiming at different applications (Carsten, 2007; Panou et al., 2007; Ranney, 1994). A suitable starting point for the derivation of support measures is provided by descriptive models, which focus on the description of relevant subtasks that have to be performed by the driver of a vehicle (Vollrath & Krems, 2011). Among such models, the Extended Control Model (ECOM) proposed by Hollnagel, Nåbo, and Lau (2003) represents a comparatively complex approach, which was developed in consideration of the

limitations of well-established predecessor, such as Michon's (1985) hierarchical model of the driving task. Within the framework of the ECOM, driving is understood as a hierarchical control task consisting of four simultaneous levels of control (see Figure 1), which differ by their frequency of occurrence, their typical duration, the demands to the driver's attention, and the type of control, which can be either compensatory (feedback) or anticipatory (feedforward). Compensatory control describes corrective actions, which take place whenever the actual state does not comply with the defined goals. In contrast, anticipatory control describes proactive actions, which are based on predictions of future states. In the current version of the model, the following four levels of control are proposed (Engström & Hollnagel, 2007; Hollnagel et al., 2003; Hollnagel & Woods, 2005):

- **Targeting:** On the top level, general goals of the driving task (e.g. the driving destination, general driving performance criteria) are defined. Control processes on this level occur comparably seldom (mostly prior to the trip) and require a duration of several minutes. As they are carried out anticipatory, their demands to the driver's attention are high. The results of these processes determine the goals that are pursued on the next lower monitoring level.

- **Monitoring:** The monitoring level includes periodical, barely demanding, compensatory check-ups of the current vehicle state (e.g. tank level) as well as continuous, highly demanding, anticipatory examinations of the vehicle's location in relation to the environment (e.g. the distance to the driving destination). This involves keeping track of traffic signs (e.g. indications of directions, warnings) and traffic signals.

- **Regulating:** In accordance with the plans defined on the monitoring level, activities on the next lower regulation level aim at the manipulation of the vehicle's position in relation to other traffic elements (e.g. overtaking other vehicles, steering to avoid an obstacle, braking in front of a red traffic light). Regulating activities are primary anticipatory and cover a duration between one second and one minute. Depending on the familiarity of the required actions and the complexity of the environment, they can be either barely or highly demanding and occur with a medium up to a very high frequency.

- **Tracking:** The lowest level describes continuously exercised, compensatory, automated and thus barely demanding activities with a maximum duration of one second, which aim at an accurate implementation of the actions selected on the regulation level (e.g. adjusting the lateral position of the vehicle while overtaking other vehicles, keeping a certain speed), especially in the case of unexpected disturbances (e.g. wind gusts, suddenly occurring pedestrians).

As an extension of preceding models of the driving task, the ECOM takes into account the dynamical aspects of driving and the interactions between the different levels of control (Engström & Hollnagel, 2007). On the one hand, the control processes on each level determine the goals and criteria of the lower levels (e.g. time pressure on the targeting level may lead to a higher target speed on the tracking level). On the other hand, disturbances on one level may temporarily suspend the goals of higher levels (e.g. stopping the vehicle despite time pressure to identify its actual position in an unknown driving environment).

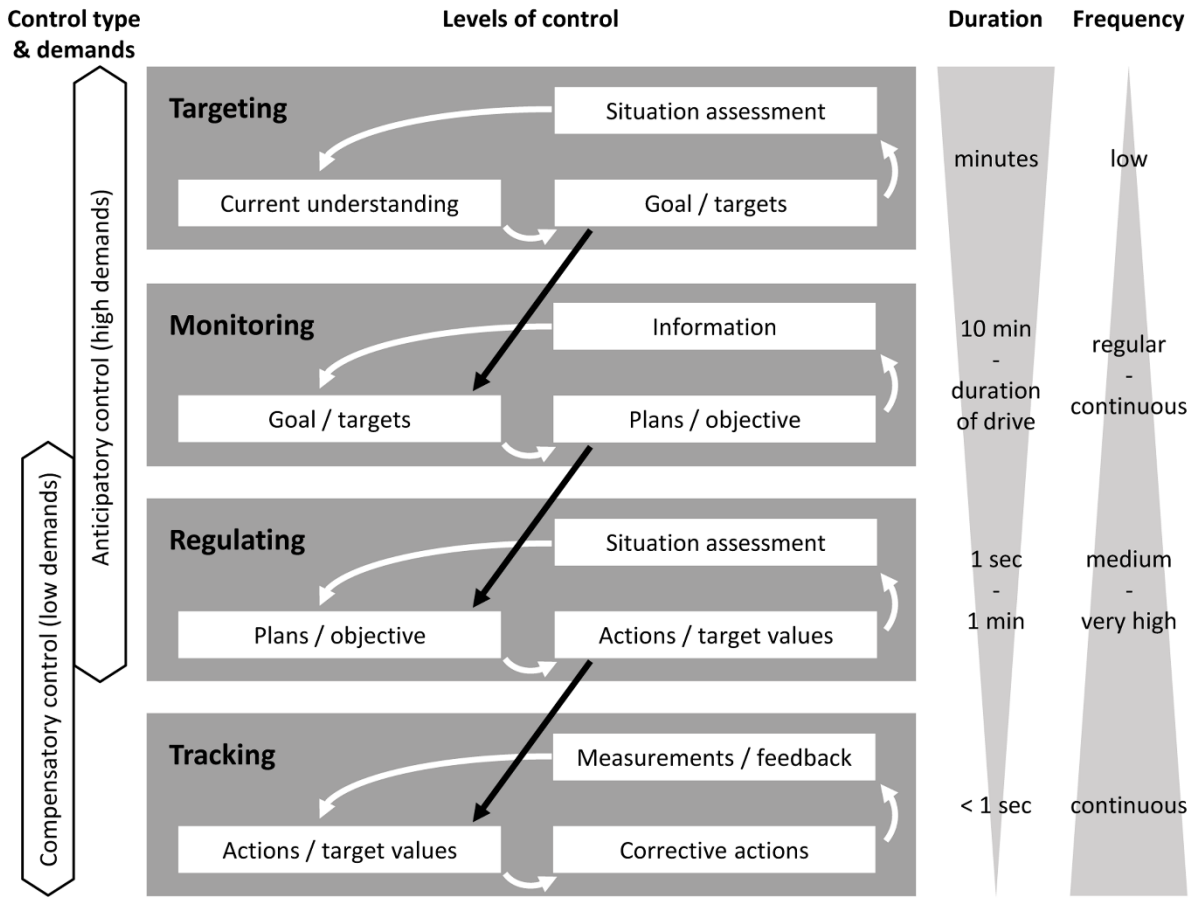

Figure 1. The Extended Control Model (adapted from Hollnagel & Woods, 2005, p. 153).

2.1.2 Demands on the Driver

Activities on each level of the driving task require a complex interaction of numerous sensory, cognitive, and motor abilities (e.g. Burgard, 2005; Peters & Nilsson, 2007; Polders et al., 2015). This chapter provides a short overview of those abilities considered most important for a fast and accurate acquisition of driving-relevant information, an effective information processing, and an appropriate responding.

Sensory abilities provide necessary information about the vehicle (e.g. location, technical status) and the environment (e.g. other road users, traffic signs and signals, road markings, potential hazards) (Eby et al., 1998). In the driving context, vision is considered the most important sense, as driving-related information input is mainly visual (Hills, 1980; Owsley & McGwin, 2010; Sivak, 1996). The most relevant visual abilities include visual acuity (especially dynamic acuity), sensitivity to glare, and contrast sensitivity (Anstey, Wood, Lord, & Walker, 2005; Eby et al., 1998; Hakamies-Blomqvist, Siren, & Davidse, 2004). Additional driving-relevant functions are accommodation ability, which is required to perceive information at different distances (Burgard, 2005), and visual search, which enables the fast detection of relevant information (Karthaus & Falkenstein, 2016). Associations with driving safety have also been reported for the extend of the Useful Field of View (UFOV) (De Raedt & Ponjaert-Kristoffersen, 2000; Owsley & McGwin, 1999, 2010). As an interlink between visual and cognitive (specifically attentive) abilities, the UFOV indicates the visual field area over which information can be acquired within one eye fixation (Ball, Beard, Roenker, Miller, & Griggs, 1988).

Cognitive abilities are necessary to select and interpret relevant information about the vehicle and the environment and to decide on an adequate response (Eby et al., 1998; Vollrath & Krems, 2011). Associations with a safe performance of the driving task have been reported for information progressing speed and attentional abilities as well as executive functions and short term memory capacity (Anstey et al., 2005).

Due to the dynamic nature of traffic, the speed at which (especially visual) information is processed is of particular importance, as adequate reaction times are crucial for safe driving (Davidse et al., 2009). The variety of available information and potential reactions requires several attentional abilities (Eby et al., 1998): sustained attention (vigilance) to maintain attention to relevant information for a sustained period of time, selective attention to ignore irrelevant information (e.g. advertising poster) while focusing attention on relevant information (e.g. dashboard information, nearby other road users), and divided attention to focus on several relevant sources of information or tasks

simultaneously (e.g. searching for traffic signs while monitoring other road users, switching the indicator while shifting gears) (Parasuraman, 2000; Parasuraman & Nestor, 1991).

Executive functions describe superordinate cognitive processes, which control and integrate other cognitive activities, such as dealing with novelty, making decisions, planning responses, or monitoring performance (Bryan & Luszcz, 2000). These functions are premised on an adequately functioning short-term memory, which, however, is limited in its information capacity and duration (Baddeley, 1984, 1986). Both aspects are considered highly relevant to driving (Anstey et al., 2005; Eby et al., 1998).

Motor abilities are required to improve the driver's information acquisition and to operate the vehicle. Regarding information acquisition, flexibility of the head and the neck are important (Burgard, 2005) to enable control glances into the side mirrors and over the shoulders, which are necessary to observe blind spots and detect other road users when merging or changing lanes (Davidse et al., 2009; Eby et al., 1998). Operating the vehicle in order to carry out the previously selected actions requires strength and flexibility of the driver's upper (e.g. for steering, shifting gears, switching the indicator) and lower (for using the pedals) extremities (Burgard, 2005; Eby et al., 1998; Peters & Nilsson, 2007). Of particular importance is the speed at which these actions are performed, as slow motor responses contribute to the driver's reaction time and therefore increase the risk of collisions (Anstey et al., 2005; Eby et al., 1998).

2.2 Characteristics of Older Drivers

Considering the importance of sensory, cognitive, and motor abilities for safe driving, age represents a relevant characteristic of the driver-element within the DVE-system (see Chapter 2.1), as it can have substantial effects on these functions. It has to be mentioned that age-related functional declines underlie a considerable intra- and interindividual variability regarding their onset, development, and severity (Karthaus & Falkenstein, 2016; Koppel & Charlton, 2013). Consequently, the population of older adults represents a very heterogeneous group in terms of their performance capacity (Burgard, 2005; Eby & Molnar, 2012; Kaiser & Oswald, 2000). However, despite these individual differences, even healthy older adults are likely to experience at least some level of declines in those abilities associated with safe driving (Anstey et al., 2005; Koppel & Charlton, 2013; Polders et al., 2015).

In consideration of the average ageing process, the group of older adults is usually defined by the age of 65 and older (Kubitzki & Janitzek, 2009). The definition of *older drivers* in the context of the present

dissertation is guided by this convention. For members of this age group, the specific need for driver support arises from the mismatch between the effects of driving-relevant functional declines (see Chapter 2.2.1) and compensatory self-regulation strategies (see Chapter 2.2.2) on their accident involvement (see Chapter 2.2.3) on the one hand and the importance of mobility for a healthy and satisfying ageing process (see Chapter 2.2.4) on the other hand.

2.2.1 Age-Related Functional Limitations

In some cases, the demands of the driving task can exceed the capabilities of older drivers due to declines of sensory, cognitive, and motor functions, which are likely to be experienced by the majority of adults at least to a certain degree due to natural ageing. The resulting difficulties particularly relate to the monitoring, regulating, and tracking level of the driving task (see Chapter 2.1.1). Functional declines regarding cognitive abilities (primarily information processing speed and attention capacities) and visual functions have been identified as especially germane in the driving context (Anstey, Horswill, Wood, & Hatherly, 2012).

Regarding **cognitive abilities**, a consistent finding is the general decrease of older adults' information processing speed (Salthouse, 1996, 2004, 2009). This development has extensive consequences for the control processes on all levels of the driving task, as older drivers require more time to detect and process sensory information, integrate relevant information, and make decisions about adequate reactions (Eby & Molnar, 2012; Koppel & Charlton, 2013; Owsley, 2013). While this general slowing might be less of a concern on the targeting level, where the majority of decisions is made before driving, it becomes safety-critical on lower levels of the driving task, as the available time window for actions decreases level by level (see Figure 1). Considering that most activities on the tracking level are executed automated and might even benefit from older drivers' long-time driving experience, activities on the regulating level might be most critically affected by age-related declines regarding information processing speed, as they require anticipatory control in a comparatively short time window.

Further, attention capacities have been shown to decline with age (Ponds, Brouwer, & van Wolffelaar, 1988; Verhaeghen, Steitz, Sliwinski, & Cerella, 2003). Regarding selective attention, older drivers experience increased difficulties differentiating between relevant and irrelevant stimuli (Hakamies-Blomqvist et al., 2004) and therefore focusing their attention on driving-relevant information while inhibiting irrelevant information (Hahn, Wild-Wall, & Falkenstein, 2011). Additional difficulties occur regarding the division of attentional resources, which is required for the parallel processing of multiple information and operating of vehicle controls (Hakamies-Blomqvist, Mynttinen, Backman, &

Mikkonen, 1999; Korteling, 1994). This results in a tendency for older drivers to employ a successive (serial) rather than simultaneous (parallel) information processing and vehicle operating strategy (Stamatiadis, Taylor, & McKelvey, 1991), especially in complex situations (Merat, Anttila, & Luoma, 2005) and under time pressure (Bélanger, Gagnon, & Yamin, 2010). These declines contribute to older drivers' increased reaction times, as they prolong the search for and the processing of relevant information (Wikman & Summala, 2005). They also result in increased rates of errors, such as overlooking relevant information due to an inappropriate attentional focus (Davidse et al., 2009). As an adequate information detection and processing while driving is required especially on the monitoring, regulating, and tracking level of the driving task, all of these levels can be affected by the declines of attentional capacities. A missing or delayed detection of relevant information on any of these levels (e.g. a yield sign on the monitoring level, cross traffic at an intersection on the regulating level, a slippery road surface on the tracking level) can result in the selection of an unsafe action (e.g. turning instead of stopping at an intersection) and therefore contribute to older drivers' accident risk (Hakamies-Blomqvist, 1993).

In addition, natural ageing is associated with several **sensory** impairments, of which those regarding visual functions are of capital importance in the driving context. Structural changes of the eyes can lead to a reduced visual acuity and contrast sensitivity as well as an increased glare sensitivity (Eby et al., 1998; Haegerstrom-Portnoy, Schneck, & Brabyn, 1999). These declines can further limit information processing on each level of the driving task (Davidse et al., 2009) due to difficulties recognising traffic signs, traffic lights, and other road users (Clarke, Ward, Bartle, & Truman, 2010; Eby & Molnar, 2012). However, reported associations between these changes and older drivers' accident risk are outnumbered by findings on the relevance of other visual functions, such as the reduction of the visual fields (Anstey et al., 2005). This regards the UFOV (Ball et al., 1998) as well as peripheral vision (Cerella, 1985), complicating the detection of relevant information in older drivers' direct view as well as in the periphery.

Declines in **motor abilities**, such as flexibility, muscle strength, and coordination, can contribute to the age-related difficulties mainly caused by cognitive and visual impairments (Koppel & Charlton, 2013). On the monitoring and the regulation level, these motor changes affect the execution of the driving task by complicating the detection of relevant information (e.g. vehicles in the blind spot). On the regulation and tracking level, motor declines further contribute to prolonged reaction times based on a slower initiation and execution of movements which are required to use vehicle controls, such as pedals and steering wheel (Karthaus & Falkenstein, 2016).

2.2.2 Compensatory Strategies

In part, older drivers are able to compensate for their impairments by changing their driving behaviour (Koppel & Charlton, 2013; Molnar & Eby, 2008). Many of their compensation strategies pertain to the targeting level of the driving task (see Chapter 2.1.1) and represent decisions that are made before driving. These strategies aim at minimising their exposure to circumstances which they perceive as dangerous. On this level, older drivers have been shown to avoid demanding traffic situations (e.g. high-speed roads, rush hour traffic) and driving conditions (e.g. darkness, rain, unfamiliar areas) (Blanchard & Myers, 2010; Eby & Molnar, 2012; Lutin et al., 2013). Further, they tend to reduce the amount of kilometres driving annually as well as the number and length of their trips (Benekohal, Michaels, Shim, & Resende, 1994).

Additionally, older drivers compensate for their functional limitation during driving through a situational adaption of their driving style, which primarily pertains to the regulation level of the driving task. This includes driving slower (Burgard, 2005), adopting longer headways (Strayer & Drews, 2004), or choosing larger gaps to cross at intersections (Middleton, Westwood, Robson, & Kok, 2005) than younger drivers, which contributes to an increase of the time available for the control processes on the regulation level itself as well as the next lower tracking level.

These compensation strategies represent an important resource of older drivers, as they aid them in reducing driving-related mistakes based on the avoidance of difficult circumstances. However, they can also have counteractive consequences and even negatively affect older drivers' traffic safety by contributing to their accident involvement, which is explained in Chapter 2.2.3. Further, these avoidance tendencies limit the individual mobility of this age group, with consequences exceeding the topic of mobility and affecting other areas of life, which is specified in Chapter 2.2.4.

2.2.3 Accident Involvement and Consequences

The specific accident risk of older drivers results from a combination of exposure patterns, functional declines, and an increased physical vulnerability. The exposure patterns of this age group are closely linked to the compensation strategies described in Chapter 2.2.2. Within this framework, older drivers tend to limit their driving activities to essential trips such as going to the grocery store (Langford & Koppel, 2006; Vollrath, 2007) and avoid demanding driving environments, such as highways (Benekohal et al., 1994; Blanchard & Myers, 2010). In addition, older adults who are retired will not need to drive to and from their workplace. These factors contribute to a relative reduction of older

drivers' own traffic safety in two respects: First, the remaining trips, which are mainly supply trips within a reduced radius from home, are more likely to take place in urban than in rural traffic systems (Benekohal et al., 1994), at least for persons living in urban areas (Hanson & Hildebrand, 2011), which applies to the majority of older adults (e.g. 70 % in Europe, 78 % in Northern America; UN DESA Population Division, 2015). Compared to members of younger age groups, this exposes older drivers to an increased proportion of complex traffic situations, such as urban intersections (Vollrath, 2007). Second, older adults' driving reduction results in a lower annual mileage (Benekohal et al., 1994), which has constantly been reported to be associated with a higher accident risk per distance driven (Hakamies-Blomqvist, 1998; Hakamies-Blomqvist, Raitanen, & O'Neill, 2002; Langford, Methorst, & Hakamies-Blomqvist, 2006). This association is usually attributed to a higher likelihood of trips in urban environments and a reduced fitness to drive identified for low mileage drivers compared to high mileage drivers (Janke, 1991; Langford et al., 2013; Langford & Koppel, 2005). Therefore, some age-specific compensation strategies can be counterproductive by increasing older drivers' accident risk (Hakamies-Blomqvist, 1993; Langford et al., 2006).

However, next to the long-time driving experience associated with age, these compensation strategies are also considered one reason for the imbalance between older drivers' functional test performance and driving performance. Thus, on road, seniors consistently perform more successful than expected based on their performance in laboratory tasks testing their sensory, cognitive, or motor functions (Karthaus & Falkenstein, 2016; Koppel & Charlton, 2013). As a result, the functional limitations associated with ageing primarily become safety-relevant in complex and unexpected driving situations, where older drivers can not solely rely on trained and thus automated actions or their compensation strategies (Karthaus & Falkenstein, 2016).

As a consequence of this interaction between functional declines and compensation strategies, drivers aged 65 and older are not more likely to make driving-related mistakes than younger drivers, in general. Instead, they tend to demonstrate different patterns of mistakes from those of other age groups (Eby & Molnar, 2012; Kaiser & Oswald, 2000; Koppel & Charlton, 2013; Polders et al., 2015). Thus, they are even underrepresented in specific kinds of accidents, such as those attributable to alcohol consumption, speeding, risky driving behaviour, or loss of vehicle control (Hakamies-Blomqvist, 1994; Hakamies-Blomqvist et al., 2004).

In contrast, older drivers have been shown to be particularly at risk in complex traffic situations such as intersections, which require perception of multiple stimuli, interaction with other road users, and parallel execution of various actions under time pressure (Bélanger et al., 2010; Kaiser & Oswald, 2000; Kubitzki & Janitzek, 2009; Langford & Koppel, 2006). As a result of their functional declines and

changed mobility patterns, they accordingly appear to be over-involved in multi-vehicle accidents at intersections, as the demands of these situations can exceed the capabilities of older drivers (Cooper, 1990; Langford & Koppel, 2006; Merat et al., 2005). Mistakes regarding who has the right-of-way have been identified as main reason for these accidents (Clarke et al., 2010; Kaiser & Oswald, 2000; Kubitzki & Janitzek, 2009). These mistakes are either based on a missing recognition of the intersection itself, the applied right-of-way regulation, or potential hazards such as other vehicles, or a misjudgement regarding other road users' behaviour and speed (Hakamies-Blomqvist, 1993; Laberge, Creaser, Rakauskas, & Ward, 2006). In a literature review, Karthaus and Falkenstein (2016) conclude that older drivers' risk of making mistakes in these situations may be even higher than indicated by accident rates, as these statistics do not include near-accidents which occur even more frequently.

The most direct relation between physical changes associated with ageing and traffic safety concerns the outcomes of accidents. As a result of their enhanced frailty, older drivers are more likely to be seriously injured or to die in an accident than members of other age groups (Koppel, Bohensky, Langford, & Taranto, 2011; Langford & Koppel, 2006; Li, Braver, & Chen, 2003). Considering the age-specific interaction between functional declines and compensation strategies as well as the increased severity of accident outcomes (European Conference of Ministers of Transport, 2002; Langford & Koppel, 2006; A. Morris, Welsh, & Hassan, 2003), there is a demand for approaches reducing older drivers' mistakes at intersections, especially regarding the right-of-way regulation.

2.2.4 The Relevance of Driving for Older Adults

In consideration of the presented age-related functional declines, exposure patterns, and increase of vulnerability, the cessation of driving may appear to be a reasonable approach to ensure older adults' traffic safety. However, as stated by a considerable amount of literature, "mobility is an essential attribute to the quality of life in older people" (Karthaus & Falkenstein, 2016, p. 1). Being mobile represents a necessary prerequisite for an independent way of living (Kubitzki & Janitzek, 2009). It enables older adults to meet relatives and friends, pursue activities outside of their homes, and access health care services and shopping facilities (Anstey et al., 2005; Kubitzki & Janitzek, 2009; Whelan et al., 2006). Beyond these relations between mobility, social participation, and self-care, driving represents "a symbol of freedom, independence and self-reliance, and having some control of their life" (Whelan et al., 2006, p. 1).

Some of these functions could also be fulfilled by other means of transport, such as public transport. However, public transportation services are limited in their flexibility and range, especially in suburban

and rural regions (Forrest, Bunker, Songer, Coben, & Cauley, 1997; Lutin et al., 2013). Even seniors living in urban regions prefer driving their private vehicle based on the higher flexibility and comfort compared to other means of transport (Gelau, Metker, Schröder, & Tränkle, 1994). Further, private vehicles provide more perceived security, based on older adults' social fears (Kaiser, 1999; Mollenkopf, 1999) and fears of being assaulted when using public transportation services (Adler & Rottunda, 2006; Straight, 2003). For these reasons, driving a vehicle represent the most important mode to stay mobile for this age group (Kaiser & Oswald, 2000; Karthaus & Falkenstein, 2016).

As a consequence, driving cessation and even limitation as compensation for driving-related difficulties have been shown to impair older adults' happiness, quality of live, and physical and psychological well-being (Kubitzki & Janitzek, 2009; Mollenkopf, 2002; Whelan et al., 2006). In this age group, giving up driving is experienced as limitation of life and "an overwhelming loss of independence" (Adler & Rottunda, 2006, p. 231). Driving cessation is associated with reduced mobility (Adler & Rottunda, 2006), reduced outdoor activities (Marottoli et al., 2000), and increased social isolation (Chihuri et al., 2016; Liddle, Mckenna, & Broome, 2004; Ragland, Satariano, & MacLeod, 2004). Older adults giving up driving reported feelings of decreased self-worth and self-esteem and even loss of identity (Eisenhandler, 1990). For these reasons, the restriction of driving can lead to a decreased health status (Edwards, Perkins, Ross, & Reynolds, 2009; Forrest et al., 1997), an impaired cognitive status (Bassuk, Glass, & Berkman, 1999), or increased symptoms of depression (Chihuri et al., 2016; Marottoli et al., 1997; Ragland, Satariano, & MacLeod, 2005) for members of this age group.

Taking into account the importance of driving for a healthy and satisfying ageing process, driver support providing an adequate trade-off between traffic safety and prolonged mobility should be preferred to driving cessation (Karthaus & Falkenstein, 2016). Therefore, strategies which address older adults' driving-related difficulties would not only positively affect their traffic safety, but also their quality of life.

2.3 Supporting Older Drivers through In-Vehicle Technologies

Strategies to improve traffic safety can address the driver (e.g. training, information campaigns), the environment (e.g. intersection design, signage), or the vehicle element (e.g. vehicle design, assistance systems) of the DVE-system (see Chapter 2.1). In consideration of the specifics of older drivers, various researchers have suggested the supportive potential of emerging automotive technologies (e.g. Davidse et al., 2009; Karthaus & Falkenstein, 2016; Koppel & Charlton, 2013) such as In-Vehicle

Information Systems (IVIS) and Advanced Driver Assistance Systems (ADAS). Primarily, these suggestions focus on the possibilities to compensate for older drivers' age-related functional declines given by such systems. Beyond safety, IVIS and ADAS are also expected to increase the driving comfort, driving enjoyment, and mobility of this age group (Caird, 2004; Eby & Molnar, 2012; Gish, Vrkljan, Grenier, & Van Miltenburg, 2016). However, researchers also point out that new systems may even increase the complexity and demands of the driving task, resulting in counterproductive effects, especially on driving safety (Peters & Nilsson, 2007). In this context, the importance of an age-appropriate system design considering the specific limitations and needs of older drivers is emphasised (Jahn & Krems, 2013; Young, Koppel, & Charlton, 2016).

In this dissertation, the age-specific support potential of two in-vehicle technologies was evaluated: Augmented Reality Displays (ARDs) and highly automated driving (HAD). Both systems are classified within the framework of a general taxonomy of in-vehicle technologies in Chapter 2.3.1 and compared to each other in Chapter 2.3.2. The Chapters 2.3.3 and 2.3.4 focus on each of the evaluated systems and relevant aspects related to driving performance. Representing a necessary precondition for the usage of technologies (Regan et al., 2014), user acceptance is addressed in Chapter 2.3.5, which provides an overview of previous findings on the general and system-specific technology acceptance among older drivers.

2.3.1 Taxonomy of In-Vehicle Technologies

The variety of in-vehicle technologies supporting the driver can be classified by their level of automation, which defines the degree to which they take over the execution of the driving task (Eby & Molnar, 2012). Several taxonomies have been developed to define distinct degrees of driving automation. The three most established ones have been published by the German Federal Highway Research Institute (Bundesanstalt für Straßenwesen, BASt; Gasser et al., 2012), the American National Highway Traffic Safety Administration (NHTSA, 2013), and the International Society of Automotive Engineers (SAE International, 2014). Out of these three taxonomies, the classification approach by SAE International represents the most recent and comprehensive one, which is outlined in Figure 2.

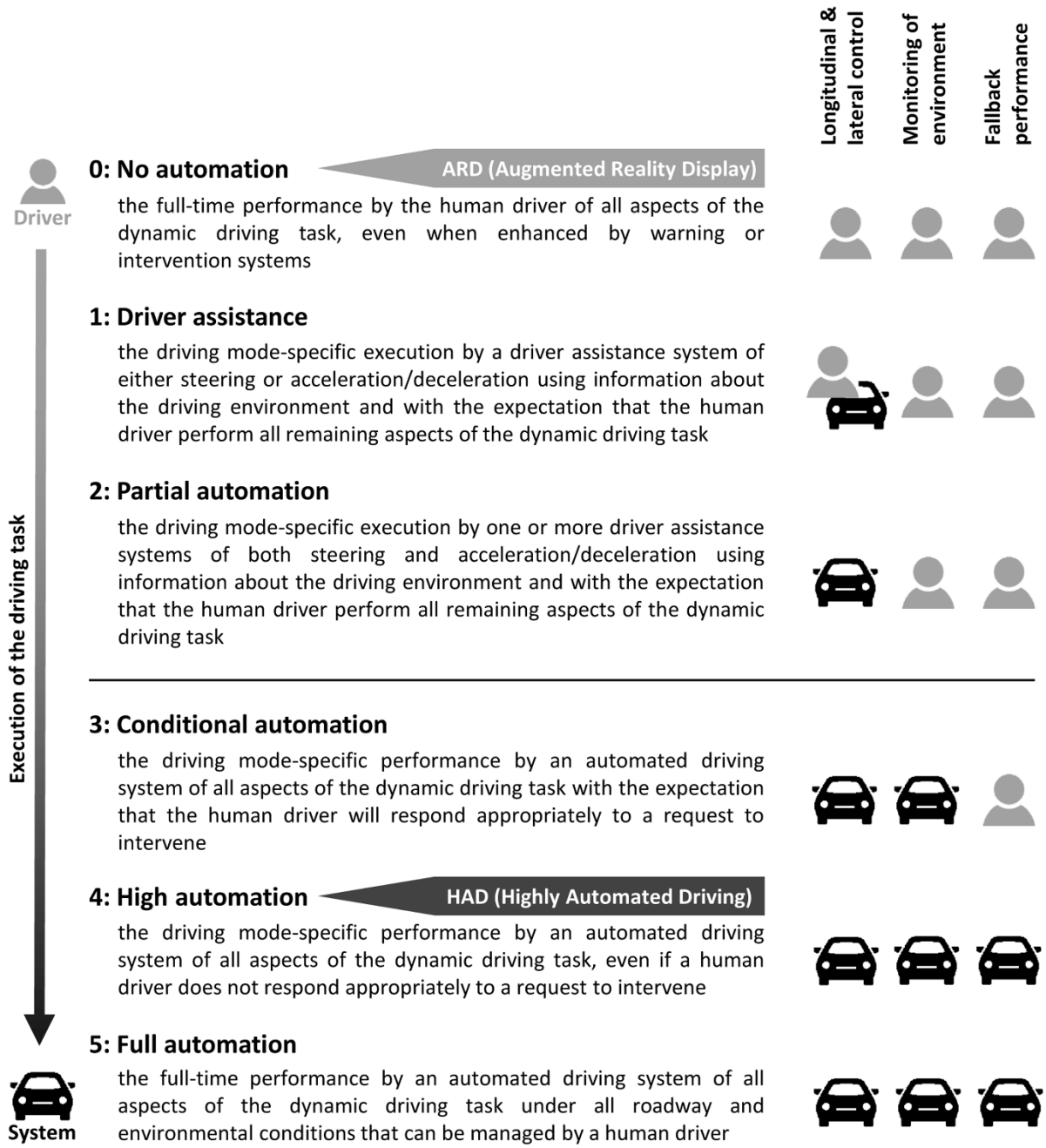

Figure 2. Levels of driving automation (adapted from SAE International, 2014, p. 2), including selected in-vehicle technologies for older drivers.

The six levels of driving automation established by SAE International (2014) differ by the execution of the longitudinal and lateral vehicle control, the monitoring of the driving environment, and the fallback performance, which can be either controlled by the human driver or the automated system. Accordingly, the taxonomy spans from *no automation* (Level 0), where these three elements of the driving task are executed by the driver, to *full automation* (Level 5), where all elements are controlled

by the system. The distinction between *partial automation* (Level 2) and *conditional automation* (Level 3) is considered the most meaningful one. From Level 3, the entire driving task, including longitudinal and lateral control as well as monitoring the driving environment, is performed by the system with the exception of the fallback performance, which requires the driver to resume the driving task any time the demands of the driving environment exceed the boundaries of the automated system. This changes at the two highest levels, on which the system is capable of executing all three elements of the driving task in some (Level 4: *high automation*) or all driving scenarios (Level 5: *full automation*).

2.3.2 Selected In-Vehicle Technologies Suitable for Older Drivers

In-vehicle technologies recommended for the support of older drivers range from IVIS providing additional information (Automation Level 0) to fully automated driving overtaking the entire driving task (Automation Level 5) (for an overview, see e.g. Davidse, 2006; Hakamies-Blomqvist et al., 2004; Koppel & Charlton, 2013; Kubitzki & Janitzek, 2009; Polders et al., 2015). In the present dissertation, these recommendations were evaluated for two exemplary technologies: Augmented Reality Displays (ARDs) and highly automated driving (HAD). Both systems are expected to be especially beneficial for older drivers by addressing crucial driving-related difficulties of this age group, which is explained in detail in the subsequent Chapters 2.3.3.1 (ARD) and 2.3.4.1 (HAD). Further, they both are focus points of current technology-centred research and development activities. Despite these similarities, they represent opposite ends of the driving automation taxonomy (see Figure 2) and therefore completely different approaches of driver support:

The **ARD-technology** represents a technical implementation approach for an IVIS and accordingly an example for Automation Level 0, aiding the driver in the manual execution of the driving task by providing useful information. Thereby, it supports the driver's perception, processing, and understanding of driving situations. However, all of these aspects as well as deciding on adequate actions and subsequently executing these actions remain parts of the driver's task, which still requires the sensory, cognitive, and motor abilities described in Chapter 2.1.2. In terms of the ECOM (Hollnagel & Woods, 2005) (see Chapter 2.1.1), ARDs can contribute to the driver's situations assessment on each level of the driving task (depending on their specific functions). When driving with an ARD, the driver's task is to compare this situation assessment with the targets or plans formulated on higher levels of the driving task and accordingly select and execute appropriate actions (e.g. driving manoeuvres) in order to ensure a safe driving performance. Therefore, the full-time driving performance is delivered by the human driver, but can be enhanced by an ARD.

In contrast, the **HAD-technology** aims at supporting the driver by taking over the driving task, which corresponds to Automation Level 4 or even Level 5. Accordingly, the system takes over the detection and processing of the driving situation as well as the selection and execution of adequate actions. With reference to the ECOM, this includes all control processes on the monitoring, regulating, and tracking level of the driving task. The human driver's task is reduced to control processes on the targeting level, which are mostly carried out prior to driving (e.g. selecting the destination of a trip). While fully automated driving (Level 5) enables the automated execution of the driving task under all roadway and environmental conditions, a human execution of the driving task might be required under certain conditions in the context of highly automated driving (Level 4), resulting in a higher relevance of human-centred research issues on this level of driving automation. However, the specific research questions addressed in this dissertation are applicable to both Level 4 and Level 5.

Therefore, the two selected systems represent examples for either side of the key distinction of driving automation allocated between Automation Level 2 and Level 3. Accordingly, these systems also differ by the expected time horizon regarding their market introduction in the automotive sector. While the ARD-technology, also labelled as "HUD 2.0" (Boeriu, 2011), represents a direct advancement of nowadays available head-up displays (HUDs) and therefore a rather current technological development, the marketable realisation of HAD is mapped in a rather distant future despite the fast progressing technological development in this context. Details on both systems in the context of older driver support are presented in the subsequent Chapters 2.3.3 (ARD) and 2.3.4 (HAD).

2.3.3 Augmented Reality Display (ARD)

Augmented Reality (AR) is defined as "a real-time direct or indirect view of a physical real-world environment that has been enhanced/*augmented* by adding virtual computer-generated information to it" with the aim to enhance the user's perception of his environment (Carmigniani & Furht, 2011, p. 3). In the driving context, ARDs project information through the windshield and merge it with the driver's perspective of the environment, creating the visual impression that the virtual information is part of the environment (Poitschke et al., 2008). This kind of display enables a variety of applications to aid drivers in the execution of the driving task. Previously evaluated ARD-functions include navigation (Kim & Dey, 2009; Medenica, Kun, Paek, & Palinko, 2011; Poitschke et al., 2008), braking assistance (Tönnis, Lange, & Klinker, 2007), hazard warning (Rusch et al., 2013; Schall et al., 2013), or collision warning (Charissis, Papanastasiou, Mackenzie, & Arafat, 2011).

2.3.3.1 Support Potential for Older Drivers

ARDs have a strong potential to support older drivers by compensating for several of the presented age-related functional declines (see Chapter 2.2.1), especially regarding information processing speed, attention capacities, and visual abilities (Färber, 2000; Rusch et al., 2013; Schall et al., 2013). Presenting significant traffic information by superimposing the driver's field of view instead of providing an extra display could contribute not only to reduce the amount of glances away from the road ahead, as it is already achieved by conventional HUDs, but also to facilitate switching attention between driving environment and displayed information. Additionally, this display structure allows for a very intuitive information design and therefore places comparatively less cognitive demands on drivers (e.g. by minimising working memory demands) (Kim & Dey, 2009). Especially the reduction of cognitive demands is strongly recommended for an age-appropriate design of IVIS (Jahn & Krems, 2013).

Since ARDs represent a technological approach to display information during driving, their benefit is directly related to the content presented through this approach. Therefore, an age-specific ARD should be oriented towards the needs and limitation of its target group in terms of the presented information as well. One potential function of an age-specific ARD considered beneficial for older drivers is the early presentation of information about approaching intersections before arrival (prior information) (Davidse, 2006; Davidse et al., 2009; Küting & Krüger, 2002; Rompe, 2012). Corresponding to their tendency to a serial information processing and responding, this would allow them to serially process some of the relevant intersection information before entering this complex environment. This should improve their visual processing of intersections (e.g. reduction of missed traffic signs or road users) by reducing the amount of new information needed while driving through the intersection itself and therefore diminishing the situation's complexity. The benefit of this approach has already been demonstrated in other contexts, such as the facilitation of identifying critical information in complex auditory environments through auditory prior information (Getzmann, Lewald, & Falkenstein, 2014).

However, researches evaluating the effects of ADAS and IVIS have raised the issue that "no technical system will be 100% failure-free" (Mahr & Müller, 2011, p. 120) and therefore perfectly reliable (Naujoks, Kiesel, & Neukum, 2016), motivating studies on the immediate and lasting behavioural effects of occasional system failures. In the case of the IVIS evaluated in this study, the most apparent system failure would be the presentation of inaccurate information about approaching intersections. On an immediate level, this failure could increase intersection complexity due to the mismatch between ARD-information and environment and therefore complicate drivers' visual processing of intersections. This effect might be more pronounced for older drivers given their functional declines (Falkenstein & Poschadel, 2008), which could cause a greater distraction by inaccurate information

presented via an ARD. In previous studies on in-vehicle warning systems, occasionally false information lastingly reduced drivers' compliance and therefore system effectiveness (Cotté, Meyer, & Coughlin, 2001; Naujoks et al., 2016). Accordingly, occasional inaccurate information might also lastingly reduce the benefits of the ARD evaluated in this study.

2.3.3.2 Speed and Accuracy of Perceiving Traffic Situations

Prior information about complex traffic situations presented via an ARD are expected to enhance drivers' ability of perceiving these traffic situations based on a more effective attention allocation. The ability to perceive traffic situations accurately and quickly enough is considered a necessary precondition for a safe driving performance (Crundall & Underwood, 2011). Particularly relevant for driving is visual processing speed, "the amount of time needed to make a correct judgement about a visual stimulus" (Owsley, 2013, p. 52). Limitations in this field lead to difficulties detecting traffic information and responding appropriately under the time pressure applied by the dynamic of road traffic (Eby & Molnar, 2012; Owsley, 2013). Based on the established conclusion that accidents occur because drivers "fail to look at the right thing in the right time" (Lee, 2008, p. 525), an ARD supporting drivers' visual processing of traffic situations is expected to improve driving performance as well.

The connection between speed and accuracy of perceiving traffic situations and driving performance can also be explained within the framework of the ECOM (see Chapter 2.1.1). In terms of this model, the presented ARD-concept supports the execution of the driving task on the monitoring level by providing information about approaching driving situations and traffic regulations earlier and guiding the driver's attention to relevant parts of the driving environment. Since this generates more time available for the control processes on this level, it should result in a more appropriate output in terms of the goals selected for the next lower regulation level. Based on the interactive nature of the ECOM, supporting activities on the monitoring level will positively affect the performance on the regulation level of the driving task in terms of selecting safer driving manoeuvres (e.g. braking instead of crossing the intersection based on a reduction of missed road users at the intersection). However, these theoretical considerations still have to be verified empirically.

2.3.4 Highly Automated Driving (HAD)

Technological advances have enabled a fast progression of driving automation in recent years, which is expected to fundamentally change road traffic in the near future. While ADAS already have the capability of taking over either lateral or longitudinal vehicle control in defined cases (Level 1 of driving

automation; SAE International, 2014), future automated vehicles are supposed to take over full vehicle control without a need for constant monitoring or intervening by the driver (Level 4 and 5 of driving automation; SAE International, 2014) (see Figure 2). In these higher levels of automation, the human role changes from active driver to passenger (Elbanhawi et al., 2015).

Provided a successful system introduction, HAD promises numerous benefits for future mobility. It is assumed that it has the potential to be safer, more environmentally friendly, and more efficient than manual driving (MD) (Level 0 of driving automation; SAE International, 2014). Specifically, it is expected to reduce the number of crashes by compensating for human errors as well as to decrease traffic congestions, fuel consumption, and emissions by time- and resource-efficient driving (Anderson et al., 2016; Lutin et al., 2013; Meyer & Deix, 2014). Simultaneously, it is anticipated that HAD allows the driver to relax (Becker, Aranda Colas, Nordbruch, & Fausten, 2014; Stanton & Marsden, 1996) and engage in non-driving activities (de Winter, Happee, Martens, & Stanton, 2014; Merat, Jamson, Lai, & Carsten, 2014) due to transferring the driving task to the automated system. Thereby, the technology represents an opportunity to resolve many of the transportation challenges faced by an ageing society, which is further explained in Chapter 2.3.4.1.

To ensure that the expected potential of HAD can be fully reached, human-machine interaction is considered a key issue (Banks & Stanton, 2016; Gasser et al., 2012). Especially the inherent transfer of the driving task from the human driver to an automated system raises new human-centred questions that need to be addressed in order to ensure drivers' acceptance of this technology. One core issue in this context is to identify automated driving styles that can provide a positive (i.e. comfortable and enjoyable) experience of HAD, which is considered a necessary preconditions for its acceptance and thus usage (Bellem et al., 2016). Aspects of driving comfort and enjoyment in HAD are described in Chapter 2.3.4.2. Chapter 2.3.4.3 focuses on the relevance of the automated driving style in this context.

2.3.4.1 Support Potential for Older Drivers

In addition to the general benefits expected from HAD, the technology has a strong potential to support especially older drivers. In terms of the ECOM (see Chapter 2.1.1), HAD takes over the activities on the monitoring, regulating, and tracking level of the driving task and thereby removes the majority of driver-related aspects of the DVE-system, among them the effects of age on driving-relevant abilities (see Chapter 2.2.1). As a result, older drivers' strategies to compensate for their difficulties on these three levels become unnecessary. Since these strategies also include decisions on the targeting level of the driving task, HAD indirectly affects targeting activities as well. This means that HAD could reduce

the need for older adults to employ self-limiting compensation strategies, such as avoiding demanding driving conditions (e.g. darkness, rain, long distances, unfamiliar areas) and traffic situations (e.g. high-speed roads, complex intersections, rush hour traffic).

To summarise, HAD could enhance both older drivers' safety and mobility (Meyer & Deix, 2014; Polders et al., 2015; Reimer, 2014) to the level of those drivers without age-related declines (Lutin et al., 2013). Considering the importance of individual mobility towards being independent and connected to society through old age (see Chapter 2.2.4), the technology could contribute to a healthy ageing process both physically and psychologically, for instance by facilitating older persons' independent access to social activities, shopping facilities, or medical services.

2.3.4.2 Driving Comfort and Driving Enjoyment

Having a positive experience while driving has already been identified as a main factor in the decision to purchase vehicles (Tischler & Renner, 2007) or ADAS (Engeln & Vratil, 2008). Therefore, affective components of human-automation-interaction are assumed to have an impact on the acceptance and thus usage of automated vehicles as well (Elbanhawi et al., 2015). Due to the comparable technical sophistication across automobile brands, vehicles are increasingly distinguished by the comfort they provide (Hartung, Mergl, & Bubb, 2005). Comfort is also the strongest predictor of purchase intentions regarding ADAS, even if they are mere safety systems (Arndt, 2011). Next to safety and efficiency, the potential to increase driving comfort is considered one of the main motivations for forwarding driving automation (European Road Transport Research Advisory Council, 2017). Technical aspects of comfort have been investigated in a long research tradition, mainly focusing on products like hand tools (e. g. Kuijt-Evers, Groenesteijn, De Looze, & Vink, 2004) or seats (e. g. Hertzberg, 1958; Kremser, Guenzkofer, Sedlmeier, Sabbah, & Bengler, 2012) and operationalising comfort by physical and physiological parameters. Noise, vibration, and harshness have been identified as main variables affecting physiological driving comfort (Qatu, 2012). However, most of these studies did not include the psychological facets of driving comfort that are considered necessary to explain inter-individual comfort differences beyond physiological parameters (Constantin, Nagi, & Mazilescu, 2014; Engelbrecht, 2013; Engeln & Vratil, 2008).

A global definition including psychological aspects describes comfort as "a pleasant state of physiological, psychological and physical harmony between a human being and the environment" (Slater, 1985, p. 4). More specific definitions are inconsistent with each other, but share a few key assumptions: comfort (1) is a subjective construct and thus can differ between individuals, (2) is affected by physical, physiological, and psychological factors, and (3) results from the interaction

between the individual and the environment (De Looze, Kuijt-Evers, & Van Dieën, 2003). According to the Joy and Convenience in Activities Model (Engeln, Engelbrecht, & Kieninger, 2008), which has been applied to automotive technology by Engelbrecht (2013), comfort is a pleasant experience that results from relaxation when low action intensity is required, for example when drivers are assisted by ADAS. It is unclear if this is applicable to HAD, which requires very low driving-related action intensity on the one hand, but is associated with a loss of control on the other hand. Based on these definitions, psychological driving comfort is understood as a subjective, pleasant state of relaxation given by confidence and an apparently safe vehicle operation (Constantin et al., 2014), "which is achieved by the removal or absence of uneasiness and distress" (Bellem et al., 2016, p. 45), in this dissertation.

In HAD, the associated loss of control produces new comfort-relevant issues addressing both physiological (motion sickness, the effects of road disturbances) and psychological (naturalness of driving manoeuvres, apparent safety) facets of driving comfort (Elbanhawi et al., 2015). While the traditional research on driving comfort might be transferable to the novel physiological aspects of comfort in HAD, there is a lack of research applicable to the psychological facets of driving comfort, which are of growing importance in the context of automated driving (Elbanhawi et al., 2015). Therefore, the focus of this dissertation is on the novel psychological aspects of comfort in HAD named by Elbanhawi, Simic, and Jazar (2015).

Next to comfort, the enjoyment of driving is another crucial affective component of the interaction between driver and automotive technology (Engelbrecht, 2013). It is described as the "pleasurability of the driving task" (E. A. Morris & Guerra, 2015, p. 26), emphasising the positive value of executing driving-related activities beyond the mere arrival to the driving destination. Enjoyment is mainly caused by active, dynamic driving, but also by comfortable sliding, which describes an unhurried, comfy, and less dynamic way of driving (Tischler & Renner, 2007). In the Joy and Convenience in Activities Model (Engeln et al., 2008), enjoyment is also outlined as a pleasant experience that results from activation. Considering these definitions, the effects of the paradigm shift from driver to passenger on the enjoyment of driving are uncertain. Taking over the interaction between driver, vehicle, and environment, HAD would at least allow comfortable sliding. In a survey with 4886 respondents, MD was expected on average to be more enjoyable than highly and fully automated driving (Kyriakidis, Happee, & de Winter, 2015). However, findings like this one were mainly obtained without actual system experience. While they can provide a first impression of drivers' concepts of emerging technologies, such as HAD, user' evaluations of systems that they have not experienced yet are uncertain and unstable (Hoeffler, 2003). This has been identified as a major shortage of research on affective components of driving, especially in the context of older driver support (Gish et al., 2016).

2.3.4.3 Automated Driving Style

One aspect considered important for a positive experience of automated driving is the implemented driving style (Bellem et al., 2016), which summarises "observable patterns of parameter sets related to the manoeuvre and trajectory planning level" (Griesche, Käthner, & Krähling, 2014, p. 102). Elbanhawi, Simic, and Jazar (2015) name two aspects of HAD-styles relevant for psychological driving comfort: naturalness (familiarity of driving manoeuvres to the driver) and apparent safety (ideal manoeuvre execution to make the driver feel safe). Summala's (2007) Safety Margin Model also emphasises the relationship between driving comfort and apparent safety, stating that during MD, comfort results from operating within so-called safety margins. These margins represent learned, strongly habituated, and individually different thresholds regarding driving parameters such as deceleration intensity or time-to-collision with other road users and obstacles. Uncomfortable feelings are indicators for approaching or exceeding those safety margins.

In the context of HAD, there are different approaches to increase driving comfort, such as minimising the physical forces on the driver. Psychological facets of comfort in HAD are addressed by the approach to implement familiar, natural driving styles to mimic human control in non-critical everyday driving situations: "executing familiar manoeuvres would undoubtedly contribute to the passenger comfort improvement, as they would eradicate the sense of having a robotic operator" (Elbanhawi et al., 2015, p. 12). According to this approach, psychological driving discomfort resulting from the loss of control associated with HAD could be reduced by meeting drivers' expectations and experiences regarding the execution of driving manoeuvres. Such an individualised, expectation-conformal, and therefore predictable HAD-style might increase the apparent safety of driving manoeuvres and drivers' trust in automated driving functions (Butakov & Ioannou, 2015). Taking into account the Safety Margin Model (Summala, 2007), a familiar HAD-style (i.e. a driving style similar to a driver's individual MD-style) would be composed of driving manoeuvres executed within each drivers' individual safety margins and therefore avoid feelings of discomfort. In the context of HAD, positive similarity effects are already known for the interaction between human passengers and virtual agents explaining the functionality of an automated vehicle: Perceived similarity between such an agent and a passenger is positively correlated with the degree the passenger likes and trusts the agent (Verberne, Ham, & Midden, 2015). Transferring the familiarity-approach to the driving style of an automated vehicle, an individual, familiar HAD-style based on each driver's MD-style could increase the psychological comfort in HAD, since MD-behaviour differs between individuals (Bauer, 2012; Miyajima et al., 2007) and is based on inter-individually differing comfort zones regarding the execution of driving manoeuvres (Summala,

2007), which might result in individually differing expectations regarding the HAD-style (Butakov & Ioannou, 2015).

2.3.5 System Acceptance

Unless driver support systems "are accepted by drivers, they will not deliver the benefits intended by those who designed them (…), drivers will not buy them (…), disable them out of frustration or use them in a manner unintended by designers" (Regan et al., 2014, p. 5). For these reasons, the acceptance of emerging technologies among potential users needs to be examined as a basis for a successful system design and introduction (Nordhoff, van Arem, & Happee, 2016). Accordingly, acceptance represents an essential aspect of the technological support of older drivers. Before presenting previous findings on the general and system-specific technology acceptance of this age-group (see Chapters 2.3.5.2 – 2.3.5.4), an overview of the conceptualisation of *acceptance* within this dissertation project is provided in Chapter 2.3.5.1.

2.3.5.1 Definition

Over the years, a variety of attempts to define and assess users' acceptance of systems have been developed, while a prevailing approach is still lacking (Adell, 2007). Established definitions range from attitudes towards the system to observable usage behaviour (for an overview, see Adell, 2010; Adell, Várhelyi, & Nilsson, 2014). This multitude of approaches reflects the complexity of the acceptance concept, emphasizing the relevance of several determinants, which do not solely relate to the system itself, but also to its users and the context of its usage (Regan et al., 2014). Hence, the selection of a suitable conceptualisation depends on its particular application including the intended user group as well as the context in which it is implemented.

Within the framework of this dissertation, acceptance is primarily defined as direct attitudes towards a system, referring to the concept of Van der Laan, Heino, and de Waard (1997). In this context, *attitudes* are described as drivers' predispositions or tendencies to respond to a system positively or negatively, assuming that drivers would more probable use positively evaluated systems than negatively evaluated ones. According to Van der Laan et al. (1997), attitudes are formed based on two dimension: the satisfaction experienced when using a system and its perceived usefulness. This approach represents one of the most well-established definitions of acceptance and was developed in conjunction with a standardised procedure to assess drivers attitudes towards automotive systems, representing a major step in the historical development of acceptance definitions (Adell, 2007). Based

on its explicit development for an automotive context, this definition is highly applicable to an overall evaluation of drivers' acceptance of emerging in-vehicle technologies. In addition, it is sensitive to certain of the specific requirements of older system users, since the perceived usefulness of a system has previously been identified as a major precondition for system acceptance in this age group (Jakobs et al., 2008).

For the assessment of selected research questions addressed within this dissertation, this concept was extended in order to gain a more comprehensive understanding of potential acceptance barriers regarding emerging in-vehicle technologies. Such an extended model is provided by the Unified Theory of Acceptance and Use of Technology (UTAUT), which was developed by Venkatesh, Morris, Davis, and Davis (2003) based on a review and empirical comparison of previous acceptance models. According to the theory and the associated measurement procedure, which are detailed in Figure 3, the usage behaviour regarding a system is affected by eight predictors: *facilitating conditions* and *behavioural intention to use the system* as well as the latter's three direct determinants (*performance expectancy*, *effort expectancy*, *social influence*) and three indirect determinants (*attitude towards using the technology*, *self-efficacy*, *anxiety*). The theory, which has meanwhile been further developed (UTAUT2; Venkatesh, Thong, & Xu, 2012), originally addressed information systems in a working context, but has been successfully applied to other contexts, such as automotive technologies (Adell, 2010).

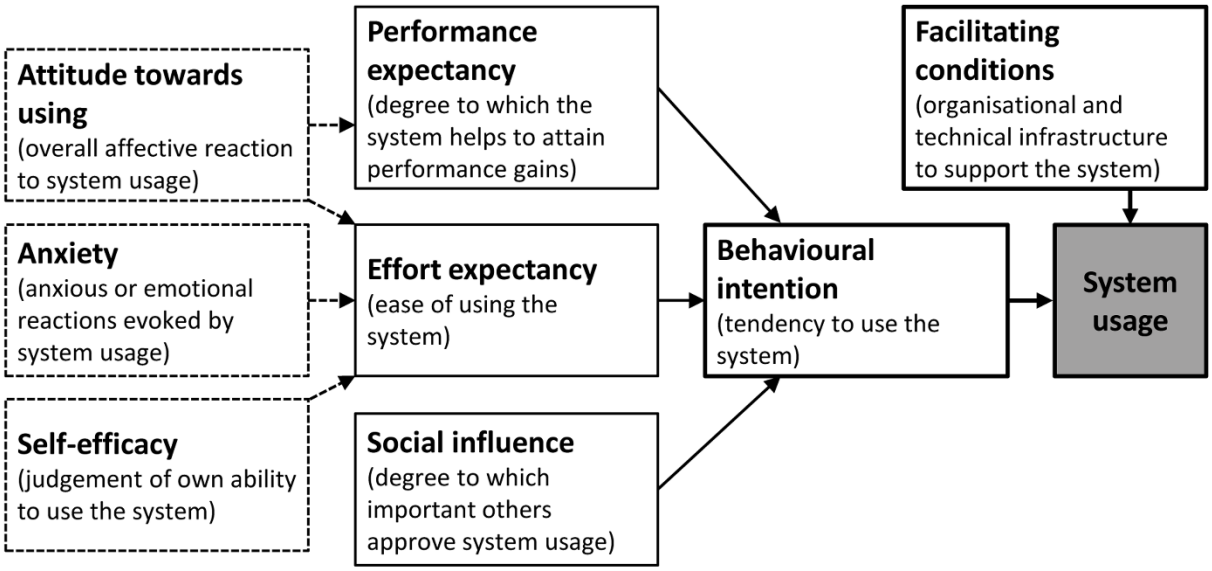

Figure 3. Direct and indirect determinants of system usage according to the Unified Theory of Acceptance and Use of Technology (Venkatesh et al., 2003).

Next to the varying approaches to define the concept of acceptance, an additional distinction has to be made between the terms of *acceptance* and *acceptability*. In contrast to acceptance, *acceptability* describes a person's judgement about a technology without prior interaction with it (Payre, Cestac, & Delhomme, 2014). Thereby, acceptability represents a first indicator of the future usage of emerging technologies, since it enables an early system evaluation by potential users, even if the current stage of the technological system development does not yet allow for an actual system experience. This prospective judgement is an important feedback within a user-centred system design process. However, this kind of evaluation is found to be abstract (Skippon & Garwood, 2011), uncertain and unstable (Hoeffler, 2003), and thus of limited validity when predicting future system usage (Fraedrich & Lenz, 2015). Therefore, including any form of system experience (e.g. prototypes or simulations) would enhance the validity of potential future users' judgements about emerging technologies.

2.3.5.2 General Technology Acceptance of Older Adults

As promising as innovative in-vehicle technologies like ARDs or HAD might be, older drivers can only benefit from them if they are open-minded to use them. But there is empirical evidence of age-specific acceptance barriers concerning emerging technological systems. In general, older adults demonstrate a lower willingness to use new technologies compared to younger persons (Czaja & Lee, 2012; Lerner, Singer, & Huey, 2008). Even despite the usage of technologies tends to globally increase among seniors, it is still considerably less pronounced in this than in any other age group (Koppel & Charlton, 2013). One reason might be that the current older generation's understanding of technology is strongly influenced by the mechanical and haptic character of the machines they grew up with. Thus, they have more reservations to use electronic systems with no or only restricted possibilities to influence their functionality (Jakobs et al., 2008). This assumption does not imply that older drivers refuse to use any kind of innovative in-vehicle technology, as the stereotypical view on seniors may suggest. However, it places higher demands on the conceptualisation and design of such systems in order to develop technologies that will be accepted and thus used by members of this age group. Previous research on this topic points out that older adults' evaluation of technical devices strongly depends on their perceived benefit and usefulness (Jakobs et al., 2008; Melenhorst, Rogers, & Caylor, 2001).

2.3.5.3 Acceptance of ARDs

Even though ARDs are recommended to support older drivers, indications of their acceptance in this age group are very rare. Regarding in-vehicle technologies in general, Musselwhite and Haddad (2007) stated that older drivers are willing to accept such system, given they feel aided by them in the

execution of the driving task. Among other systems, the participants of this study evaluated a dashboard sign display as useful for distinguishing between important and unimportant road signs. Presenting this information in an ARD instead of the dashboard might further increase the reported acceptance ratings (Musselwhite & Haddad, 2007). Among the few studies examining ARDs in consideration of older drivers, some provide at least side notes on the participants' opinions on the evaluated systems. Charissis et al. (2011) reported older drivers' positive attitudes towards an ARD providing collision avoidance information. However, these attitudes were solely expressed in unsystematic verbal feedback given by the participants. In a comparison of different display modes for a navigation systems, older drivers preferred an ARD instead of a conventional head-down display (Kim & Dey, 2009). Considering these first findings as well as the expected suitability of ARDs for the needs of older drivers from a theoretical point of view, it seems plausible to expect a positive overall attitude towards this technology. However, there is still a demand for systematic evaluations of older drivers' acceptance regarding ARDs in order to identify potential acceptance barriers and ensure a successful system development.

2.3.5.4 Acceptance of HAD

Examining the acceptance of highly automated vehicles among potential users is considered "very important, as it is a prerequisite for implementation success and determines whether they will be actually used" (Nordhoff et al., 2016, p. 4). However, given that HAD cannot be experienced currently by the majority of drivers, there is an absence of systematic findings on their willingness to allocate the vehicle control to an automated system. Few indications are given by surveys on a priori acceptability of HAD. Even though such studies reveal a general openness to HAD (Fraedrich & Lenz, 2015), they also indicate concerns regarding the technology. In an online survey, the majority of 1000 respondents claimed they could barely or never imagine delegating vehicle control, especially steering control, to an automated system (Wolf, 2015). A cross-national public opinion survey about self-driving vehicles showed participants holding mostly positive attitudes towards the technology; however, they also expressed safety- and driving performance-related concerns (Schoettle & Sivak, 2014).

Even less data exists for the specific user group of older drivers; indications of their acceptance of HAD can only be derived from findings on general technology usage. As stated in Chapter 2.3.5.2, these results demonstrate that older adults are generally less likely to use technology than younger adults (Czaja et al., 2006). However, older adults are willing to use varied systems provided they help them maintain their independence (Barrett, 2014), which is highly applicable to HAD. The more participants aged 55 and older perceived different Advanced Driver Assistance Systems (ADAS) as a restriction of

their self-determination and driving enjoyment in a survey, the more they evaluated them in a negative way (Jakobs et al., 2008), which could also apply to HAD.

To summarise, the few findings on the acceptance of highly automated vehicles among drivers across various ages are mostly based on studies of their general technology usage or surveys on HAD-acceptability. Therefore, system experience needs to be included in further research on HAD-acceptance. Existing studies including system experience have examined ADAS that take over either lateral or longitudinal vehicle control in defined use cases (Level 1 of driving automation; SAE International, 2014), which represent a less advanced stage of automation compared to HAD (see Figure 2). In an on-road study by Beggiato, Pereira, Petzoldt, and Krems (2015), drivers' a priori acceptance of an Adaptive Cruise Control (ACC) was at the midpoint of the scale, but then grew steeply after the first system experience. Subsequent experiences led to a slight increase of acceptance, which stabilised at a relatively high level after the fifth ACC drive. A significant increase of drivers' acceptance after the initial system experience was also reported for other ADAS, such as parking assistance (Trösterer, Wurhofer, Rödel, & Tscheligi, 2014) or Stop & Go assistance for traffic congestions (Brookhuis, van Driel, Hof, van Arem, & Hoedemaeker, 2009). An examination of the transferability of these findings on higher stages of driving automation is still pending.

3 OVERALL RESEARCH QUESTIONS

Based on the implications for the maintenance of older adults' mobility given by previous research, the aim of this dissertation was to evaluate the potential of emerging in-vehicle technologies as support measures for older drivers.

Therefore, Augmented Reality Displays (ARDs) and highly automated driving (HAD) were selected as two exemplary technologies, representing opposite ends of the taxonomy of driving automation (see Chapter 2.3.1) and accordingly completely different approaches to support drivers (for details, see Chapter 2.3.2). ARDs as an IVIS-technology aim at presenting useful information in order to facilitate the execution of the driving task, which is completely allocated to the human driver himself. In contrast, HAD provides support by taking over the demanding driving task. Despite these different approaches, both technologies have been identified as potentially suitable for the support of older drivers based on theoretical considerations as well as recommendations formulated within previous research (see Chapters 2.3.3.1 and 2.3.4.1). This potential was evaluated out of two perspectives, resulting in two overall research questions, which were examined for each technology:

(1) Does the system contribute to achieve an improvement in aspects related to driving performance? (performance perspective)

(2) Is the system expected to be accepted as support measure among older drivers? (acceptance perspective)

To answer these two general questions for both technologies, four thematic areas were specified, which are described in detail in the subsequent paragraphs.

The focus of the **performance perspective (1)** was on aspects related to a safe driving performance, i.e. the execution of the driving task in a manner that prevents the driver from harming himself or other road users (e.g. avoiding collisions). Regarding this perspective, the diversity of the support approaches behind the two systems is reflected in the examined research topics, which represent system-specific, performance-related issues addressing the identified knowledge gaps in current research:

The evaluation of the ARD providing prior information about approaching intersections was focused on its effects on drivers' ability to perceive these situations, which represents a fundamental

precondition for a safe driving performance (for details, see Chapter 2.3.3.2). Based on this empirically validated connection between the perception of a traffic situation and a safe driving performance, it was assumed that improvements in drivers' ability to perceive intersection due to the ARD would subsequently allow for a safer driving performance in these situations. Considering the concerns about the counterproductive effects of such an ARD especially in cases of providing inaccurate information (see Chapter 2.3.3.1), system failures were included in this examination.

In the evaluation of HAD, the focus of the performance perspective shifted in parallel with the shift of the human role due to the increasing driving automation. Since the driving task is executed by the system and the driver becomes a passive passenger on this automation level (see Chapter 2.3.1), a human driving performance that could be improved by the system is missing. Accordingly, the examination of HAD did not focus on human performance, but on the human perception and evaluation of the automated system's driving performance. Based on previous research on the affective components of driving (see Chapter 2.3.4.2), it was assumed that highly automated vehicles have to provide a comfortable and enjoyable driving experience, which is connected to the apparent safety of the automated driving performance (see Chapter 2.3.4.3), in order to be accepted and used by drivers. In this context, the theoretical approach to improve the human perception of the automated driving performance by means of the automated driving style (see Chapter 2.3.4.3) was evaluated. Therefore, effects of driving automation and the familiarity of the automated driving style on the driving comfort and enjoyment experienced by the drivers were examined.

The **acceptance perspective (2)** was integrated based on the fact that even the most helpful technological system is not able to contribute to an improvement of older adults' mobility, if drivers were not willing to use it (see Chapter 2.3.5). For this reason, the evaluation of both systems focused on the effects of system experience on drivers' acceptance as well as on the identification of age-specific acceptance barriers that could prevent older drivers from using the technology. In addition, the effects of system-specific design issues on drivers' acceptance were examined. In the case of the ARD, it was investigated whether older drivers preferred one of two possible display durations. Regarding HAD, it was examined whether drivers' acceptance is modifiable by the familiarity of the implemented driving style. Figure 4 provides an overview of this four thematic areas and the associated research topics, which were addressed in the three studies forming the empirical basis of this dissertation project.

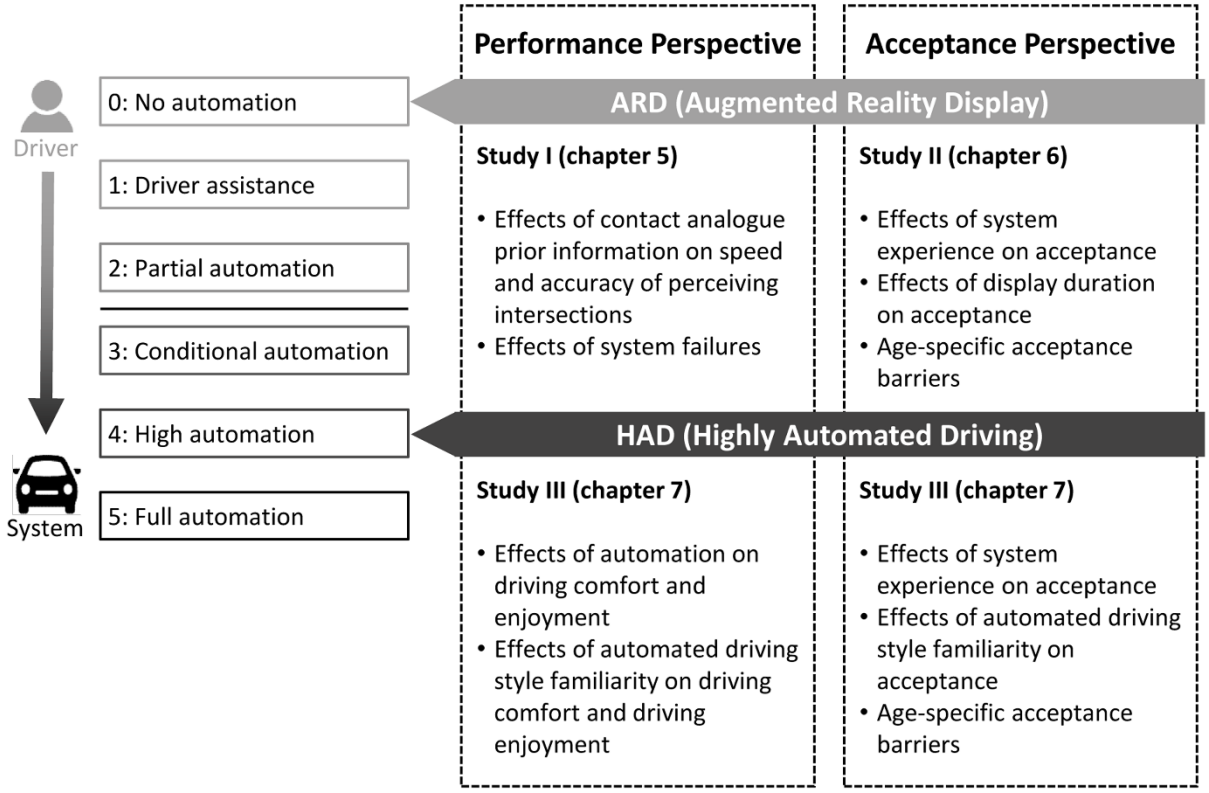

Figure 4. Overview of research topics addressed in the dissertation project.

4 OVERALL METHODOLOGICAL CONSIDERATIONS

Three empirical studies were conducted to examine the research questions associated with the four thematic areas described in Chapter 3 (see Figure 4). Performance aspects of the ARD-technology were examined in Study I, a reaction time experiment, which was presented in a driving simulator in order to increase external validity (see Chapter 5). Study II represents a driving simulator study on the acceptance of ARDs (see Chapter 6). All research questions regarding HAD were addressed in Study III, a two-stage driving simulator study (see Chapter 7).

All studies were conducted with a group of older drivers as well as a younger comparison group in order to identify age-specific results. The group of older drivers was consistently defined by a maximum age range of 65-85 years. The lower limit of 65 years was based on the definition of older drivers established in the literature (Kubitzki & Janitzek, 2009). The upper limit of 85 years was chosen to restrict the increasing heterogeneity of driving-relevant abilities associated with increasing age (Burgard, 2005; Eby & Molnar, 2012; Kaiser & Oswald, 2000) in order to standardise the definition of older drivers throughout the dissertation project. The younger comparison group was defined by a maximum age range of 25-45 years in all studies, which aimed at comparing older drivers to the 'average' (i.e. young, but experienced) driver. The lower limit of 25 years was set to clearly differentiate this group from novice drivers, who represent another specific sub group of drivers characterised by their limited driving experience (Fofanova & Vollrath, 2011). The upper limit of 45 years was chosen to exclude functional overlaps between the two age groups. Hereafter, this comparison group is referred to as *younger drivers*.

While the system-specific research topics related to driving performance did not allow for a direct comparison between ARDs and HAD based on their diverse nature, the comparability of acceptance-related issues was facilitated by applying identical instruments to assess drivers' acceptance of both technologies. These instruments were chosen corresponding to the definition of acceptance used in this dissertation (see Chapter 2.3.5.1). Accordingly, general attitudes towards the evaluated systems were assessed using the Van der Laan acceptance scale (Van der Laan et al., 1997). Determinants of drivers' acceptance beyond attitudes were assessed using the questionnaire based on the Unified Theory of Acceptance and Use of Technology (UTAUT; Venkatesh et al., 2003). Details on both instruments are presented in the Chapters 6.2.4 and 7.2.4.

5 STUDY I:

AUGMENTED REALITY DISPLAY – PERFORMANCE ASPECTS

The potential of Augmented Reality Displays (ARDs) to improve performance-related aspects of older drivers' mobility was evaluated in a reaction time experiment, which was conducted in a driving simulator. By compensating for age-related declines in driving-relevant visual and cognitive functions, such as information processing speed, attention capacities, and visual abilities (see Chapter 2.2.1), projecting useful traffic information through the windshield and merging it with the driver's perspective of the environment via an ARD is considered a useful approach to aid older drivers in the manual execution of the driving task (see Chapter 2.3.3.1).

Since the potential of such an In-Vehicle Information System (IVIS) is directly related to the presented content, the function of the ARD evaluated in Study I was defined in consideration of older drivers' specific needs for support. Therefore, focal point of this study was an ARD providing early information about approaching intersections before arrival (prior information). Such prior information is recommended as a strategy to support older drivers by addressing their tendency to process multiple information successively (serially) rather than simultaneously (parallel). Accordingly, the presentation of prior information about approaching complex traffic situation is expected to enhance their ability of perceiving these situations based on a more effective attention allocation (see Chapter 2.3.3.1). Since the ability to perceive traffic situations accurately and quickly is a necessary precondition for a safe driving performance (see Chapter 2.3.3.2), improvements in this ability were interpreted as an indicator for the potential of the evaluated ARD to enhance the safety of older adults' driving performance.

However, presenting additional information in the driver's direct field of view also raises concerns about counterproductive effects of ARDs for older drivers, especially in cases of inaccurate information, which might increase the complexity of traffic situations due to the mismatch between ARD-information and environment (see Chapter 2.3.3.1). Therefore, system failures were also included in this study.

5.1 Aims and Research Hypotheses

The aim of Study I was to investigate the effects of an ARD providing accurate or inaccurate prior information about approaching intersections (ARD-information) on younger and older drivers' visual processing performance at these intersections. Visual processing was operationalised as accuracy and speed of perceiving a particular traffic situation.

In detail, we examined three hypotheses (H), which are explained below:

(H1) Effect of age:
Older drivers will have poorer visual processing performance at intersections than younger drivers.

(H2) Effect of ARD-information:
Drivers will have an improved visual processing performance at intersections with than without ARD-information. This will be especially pronounced for older drivers.

(H3) Effect of ARD-failure:
Drivers will have poorer visual processing performance at intersections when given inaccurate than given accurate prior information.

H1 was tested to evaluate whether the SCM could replicate well-documented findings, such as the age differences regarding information processing. H2 was expected based on previous recommendations and initial positive findings on the effects of presenting prior information to older drivers in complex traffic situations. As intersections are comparably demanding for drivers of all age groups (Kubitzki & Janitzek, 2009), we expected this effect for younger drivers as well, albeit to a lesser extent. H3 was based on the assumption that inaccurate prior information presented via an ARD would increase rather than decrease the complexity of intersections. Visual processing performance was further examined after receiving accurate ARD information post receiving inaccurate information to additionally explore the lasting effects of system failures.

5.2 Method

5.2.1 Study Design

We employed a 2 x 4 mixed design with drivers' age and ARD-information as independent variables. Drivers' age was the between-subjects factor, divided into younger and older drivers. The ARD-information was varied within subjects by presenting four different types of information about approaching intersections: no information, accurate information, inaccurate information, and accurate information after experiencing inaccurate information.

5.2.2 Participants

The total sample of 52 participants consisted of 26 younger (25-45 years of age) and 26 older drivers (65-83 years of age). The younger drivers (9 female, 17 male) had a mean age of 32.6 years (*SD* = 6.2) and held their driver's license for a mean of 13.4 years (*SD* = 6.3). The older drivers (7 female, 19 male) had a mean age of 70.4 years (*SD* = 4.6) and held their driver's license for a mean of 49.2 years (*SD* = 9.5).

All participants needed to currently hold a valid driver's license and to drive an annual minimum of 1,000 kilometres. Although none of the participants reported ARD-experience prior to the study, one older participant possessed a conventional HUD providing navigation information. Participation required a signed informed consent and was monetarily compensated.

5.2.3 The Surrogate Complexity Method (SCM)

5.2.3.1 Basic Principle

We developed the SCM for a standardised and economic assessment of drivers' accuracy and speed of perceiving traffic situations. The SCM-principle is oriented towards the Adaptive Tachistoscopic Traffic Perception Test (ATAVT; Schuhfried GmbH, 2010) from the Vienna Test System, which assesses the ability to obtain an overview in complex visual situations. In the ATAVT, participants observe images of traffic situations presented briefly on a computer screen and subsequently answer a multiple choice question about which elements were present in the image.

The SCM-concept aimed at examining whether drivers focused on the relevant areas of traffic situations to obtain safety-relevant information. Further, this method needed to allow for a standardised manipulation of situation complexity. For these reasons, we adopted the visual presentation of driving situations from the ATAVT, with the exception of altering the response mode. Therefore, we added a series of numbers to the traffic-relevant areas of the presented driving situations (see Figure 5). The participants' task was to vocalise all numbers in random order as quickly as possible. The participants ended their response by saying "stop" immediately after naming all numbers they could identify.

Figure 5. Example for a presented driving situation including surrogates (numbers) added to relevant areas. White circles have been included in this figure to make the surrogates more salient to the reader of this dissertation, but were not presented to the participants in the experiment.

Based on this response mode, the added numbers served as surrogates for relevant situation elements, which drivers need to detect and process for a safe reaction (e.g. other road users, traffic signs, intersecting lanes in which crossing traffic could potentially occur). Naming one of these numbers indicated that participants perceived the corresponding part of the traffic situation. The task's basic assumption is that drivers who are able to focus their attention more reliably and quickly to the relevant elements of a traffic situation have a higher likelihood and speed of identifying all surrogates in the SCM-task, which are located in relevant sections of the presented driving situation images. Therefore, a greater ability to perceive traffic situations is assumed to correspond to a better SCM-performance. In the presented study, surrogates could be arbitrary numbers between zero and nine.

5.2.3.2 Dependent Variables

Two dependent variables define a participant's SCM-performance: (1) response accuracy (the proportion of trials in which the participant named all surrogates correctly) and (2) response time (the temporal difference between displaying the image of the traffic situation and the participant's "stop"-

response). A stronger SCM-performance corresponds to (1) a higher response accuracy and (2) a shorter response time. However, provided the constancy of the other variable, either a sole increase in accuracy or a sole decrease in response time represent a SCM-performance improvement as well.

5.2.4 Implementation of the SCM for the ARD-Evaluation

5.2.4.1 Trial Structure

To apply the SCM to the ARD-evaluation, all driving situations represented urban intersections, which were visualised from the perspective of a driver who is about to cross the intersection. Before presenting such an intersection image including the surrogates (the SCM-image) in the driving simulator (see Chapter 5.2.5), the ARD-information regarding the structure and right-of-way regulation of this intersection was depicted in a previous image revealing the identical intersection from a distance of 75 metres away (the ARD-picture).

As illustrated in Figure 6, a complete experimental trial consisted of three steps:

1. The ARD-image was presented in combination with an announcement tone, which aimed at informing the participants of the beginning of a new trial. The ARD-image lasted for three seconds and included the ARD which presented information about the approaching intersection.

2. A three-second duration black screen followed to represent the necessary time to drive 75 metres to the intersection given the speed limit of 50 km/h (in an urban area in Germany).

3. Participants observed the SCM-image including the surrogates until saying “stop”.

The prior information presented in an ARD-image was expected to guide drivers’ attention to the relevant sections of the corresponding SCM-images, which depended on the structure and right-of-way regulation of the presented intersection. For instance, when approaching a T-junction with a lane proceeding straight ahead as well as a left turn lane regulated by a yield sign, relevant traffic elements would be located in front and on the left of the driver rather than on the right. Receiving prior ARD-information would guide drivers’ attention to these areas and enhance the likelihood and speed of detecting the surrogates located there, resulting in a better SCM-performance.

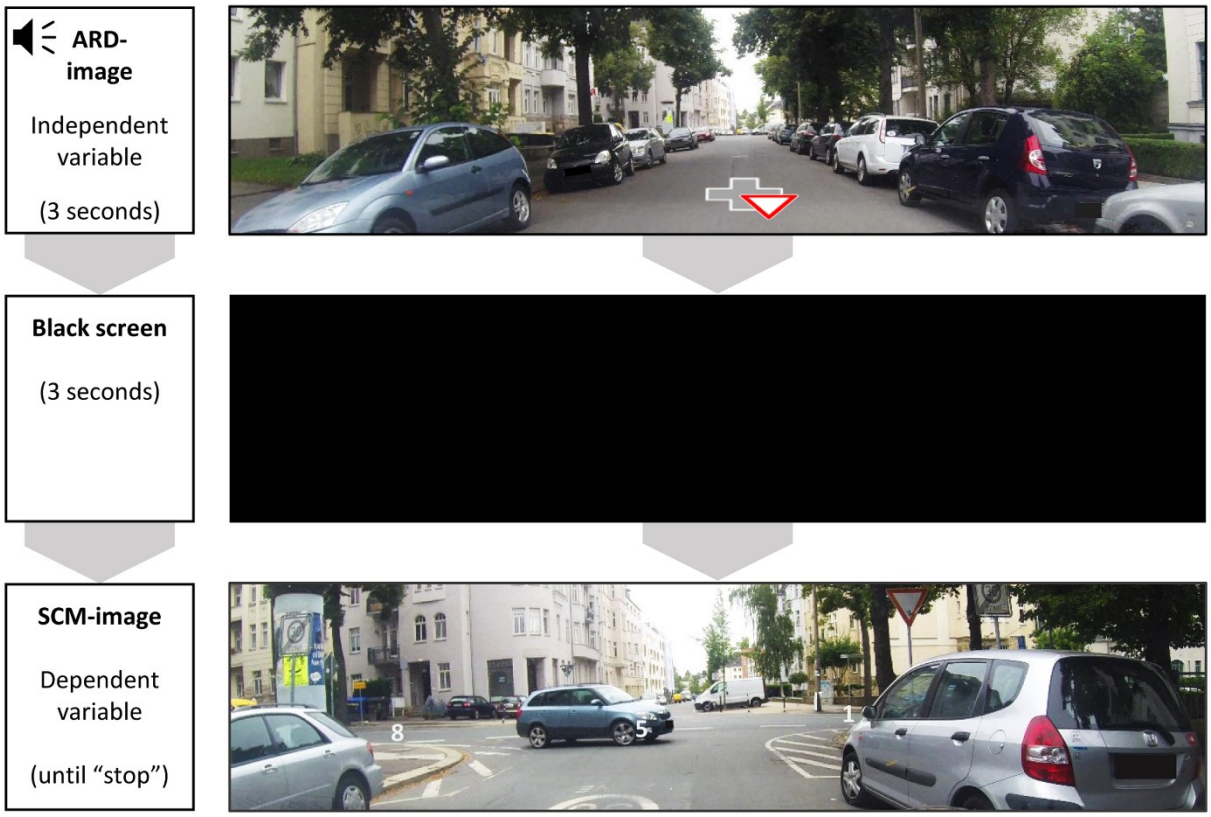

Figure 6. Experimental trial sequence for applying the Surrogate Complexity Method (SCM) to the evaluation of an Augmented Reality Display (ARD).

5.2.4.2 Variation of ARD-Information

The ARD-information varied by a sequence of distinct SCM-sections, which differed by the information type provided in the ARD-image (see Table 1). In the baseline-condition, the ARD-image provided an outlook on the approaching intersection without additional ARD-information. This condition comprised two sections to control for training or fatigue effects. One section was presented at the beginning (Section 1: baseline I) and the other was presented at the end (Section 5: baseline II) of the experiment. After presenting an accurate ARD in Section 2 (correctness), the ARD worked inaccurately in Section 3 (failure) by providing alternating accurate and inaccurate information about the approaching intersection. This was followed by a second section without ARD-failures (Section 4: recovery).

Each section consisted of six experimental trials with an identical distribution of three possible right-of-way regulation types (traffic light, right of way, yield) to ensure comparability of intersection-images between the different sections. The number of surrogates added to one image varied from one to five numbers and was balanced between the five sections. The six trials of Section 3 were presented in a

fixed order to provide participants with an identical experience of unpredictable system failures. The trials were presented in a randomised order in the remaining sections to control for order effects.

Table 1

Variation of the ARD-Information in Five Experimental Sections with Six Trials Each

Section	ARD-information	Order of trials within section
1. Baseline I	6 trails without information	Randomised
2. Correctness	6 trials with accurate information	Randomised
3. Failure	3 trials with accurate information (a), 3 trials with inaccurate information (i)	Fixed: i, i, a, i, a, a
4. Recovery	6 trials with accurate information	Randomised
5. Baseline II	6 trials without information	Randomised

Note. ARD = Augmented Reality Display.

5.2.4.3 Visual Material

All intersection images in colour presented were taken from the driver's position while driving through an urban environment. The images were captured with a GoPro Hero 3+ and processed with a resolution of 4200 x 1077 pixels. From the driver's perspective, the right-of-way of the intersections was regulated by one of three possible elements: a traffic light, a right-of-way sign, or a yield sign. We used the Microsoft PowerPoint 2007 software to add surrogates to SCM-images and ARD-symbols to ARD-images. To ensure that surrogate detection in the SCM-images was not influenced by their visual features, the numbers were clearly visible given the participant glanced in their direction, but were not salient enough to capture participants' attention alone (see Figure 6). The ARD contained information about structure and right-of-way regulation of the approaching intersection, which were combined in one colour symbol (see Figure 7). A schematic plan view of the intersection illustrated the structure. The matching traffic sign positioned on the road's right side, used by the driver to approach the intersection, represented the right-of-way regulation. In the ARD-images, the symbols were positioned on the street in front of the driver's vehicle, as it could be projected by an ARD (see Figure 6).

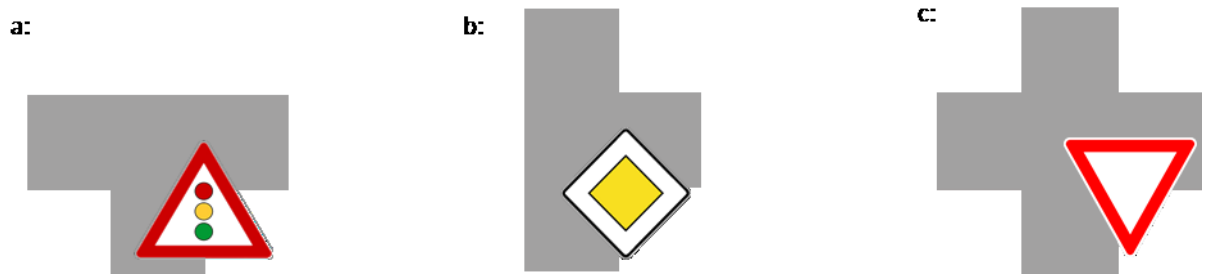

Figure 7. Examples of the Augmented Reality Display symbols presenting prior information on the structure and right-of-way regulation (a: traffic light; b: right of way; c: yield) of approaching intersections.

The experimental trials' composition and presentation to the participants during the experiment was created using Microsoft PowerPoint 2007.

5.2.5 Setting

To achieve a high degree of realism, the SCM was presented in a static driving simulator with a 180° horizontal field of view provided by three screens with a height of 2.5 metres. All images were projected by three LCD-projectors, each with a resolution of 1650 x 1050 pixels. The participants sat in the driver's seat and could view the realistically sized intersections from the driver's perspective. A full-HD digital camera positioned next to the vehicle mock-up recorded participants' responses.

5.2.6 Procedure

After signing an informed consent, participants completed a demographic questionnaire. They subsequently sat in the driving simulator and received SCM-instructions during a training section, consisting of six experimental trials. We solely presented an SCM-image to explain the task in the first trial, whereas the second trial included a complete SCM-sequence (see Figure 6) to familiarise participants with the procedure. In this second trial, the ARD-image was equivalent to the baseline-condition and did not incorporate additional ARD-information. Afterwards, an explanation of the ARD and sample images of possible ARD-information were provided. This was followed by four training trials representing complete SCM-sequences including accurate ARD-information in the ARD-picture.

After this training section, the five experimental SCM-sections (see Table 1) were executed without breaks between them. Next, participants performed a trail making test (Zahlenverbindungstest, ZVT;

Oswald & Roth, 1987), a standardised procedure assessing information processing speed, used to validate the SCM. Participants received their compensation at the end of the experiment, which lasted approximately 75 minutes.

5.3 Results

5.3.1 Data Preparation

Response time and accuracy were derived from the video recordings using the annotation software ELAN 4.3.1. An answer was rated as correct provided participants named all numbers added to the SCM-picture without omissions, independent of order. However, additions were also rated as incorrect to exclude strategic task solving such as naming all numbers from zero to nine in every trial. Response time was operationalised as the time differential between the first video frame displaying the SCM-picture and a participant's "stop"-response.

Based on the absence of significant differences between the two baseline-sections regarding response accuracy, $t(51) = -.49$, $p = .624$, and response time, $t(51) = -.99$, $p = .323$, participants' baseline condition performance was calculated by averaging baseline I and II values. Table 2 overviews the statistical hypotheses that were tested using mixed ANOVAs.

Table 2

Statistical Hypotheses regarding the Effects of Age and ARD-Information on Drivers' Response Accuracy and Time in the SCM-Task

Hypothesis (H)	Response accuracy	Response time
H1: Effect of age	$M_{65\text{-}83\ years} < M_{25\text{-}45years}$	$M_{65\text{-}83\ years} > M_{25\text{-}45years}$
H2: Effect of ARD-information	$M_{Correctness} > M_{Baseline}$	$M_{Correctness} < M_{Baseline}$
H3: Effect of ARD-failure	$M_{Failure} < M_{Correctness}$	$M_{Failure} > M_{Correctness}$

Note. ARD = Augmented Reality Display, SCM = Surrogate Complexity Method, M = mean.

5.3.2 Validity of the SCM

For an initial validation of the SCM, the participants' performance was correlated with their performance on the ZVT (Oswald & Roth, 1987). The speed measure of the ZVT significantly correlated with the response time of the SCM at each assessment. Correlation coefficients ranged from $r = .57$ to $r = .63$ ($p < .001$), indicating a high convergent validity.

5.3.3 Response Accuracy

Figure 8 depicts the proportion of correctly answered trials per age group and ARD-condition.

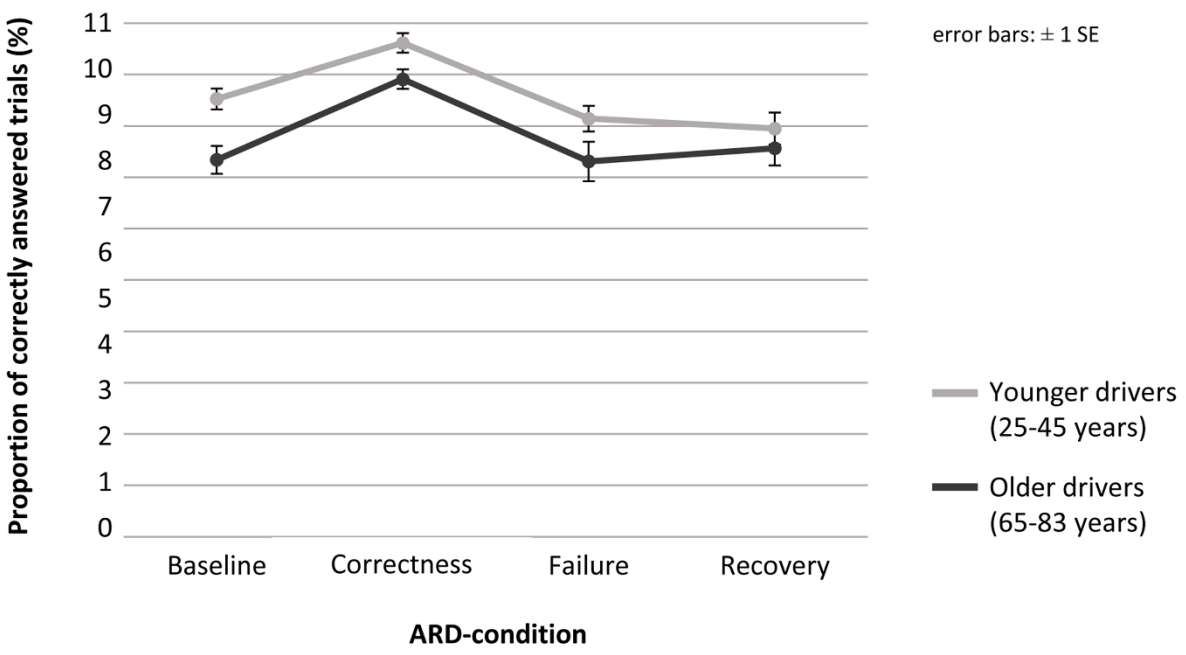

Figure 8. Effects of Augmented Reality Display condition (ARD-condition) on younger and older drivers' response accuracy in the Surrogate Complexity Method task.

There was a significant age effect, indicating that older drivers on average made more SCM-mistakes than younger drivers, $F(1, 50) = 8.67$, $p = .005$, $\eta_p^2 = .15$ (H1). Additionally, response accuracy was significantly affected by ARD-condition, $F(3, 150) = 19.00$, $p < .001$, $\eta_p^2 = .28$. According to Bonferroni-corrected pairwise comparisons, the proportion of correctly answered trials significantly increased in the correctness-section compared to the baseline-condition ($p < .001$) (H2). Neither the failure- ($p = .681$) nor recovery-section ($p = 1.000$) significantly differed from the baseline-condition. However,

the proportion of correctly answered trials was significantly smaller in both sections compared to the correctness-section ($p < .001$) (H3). Given the absence of a significant interaction between age group and ARD-condition, $F(3, 150) = .97$, $p = .411$, $\eta_p^2 = .02$, these effects can be assumed for both younger and older drivers.

5.3.4 Response Time

Correctly answered trials were only included in the analysis of response time to avoid confounding effects of incorrect responses (e.g. shorter response times due to missed surrogates). The mean time values for the two age groups and across the four ARD-conditions are displayed in Figure 9.

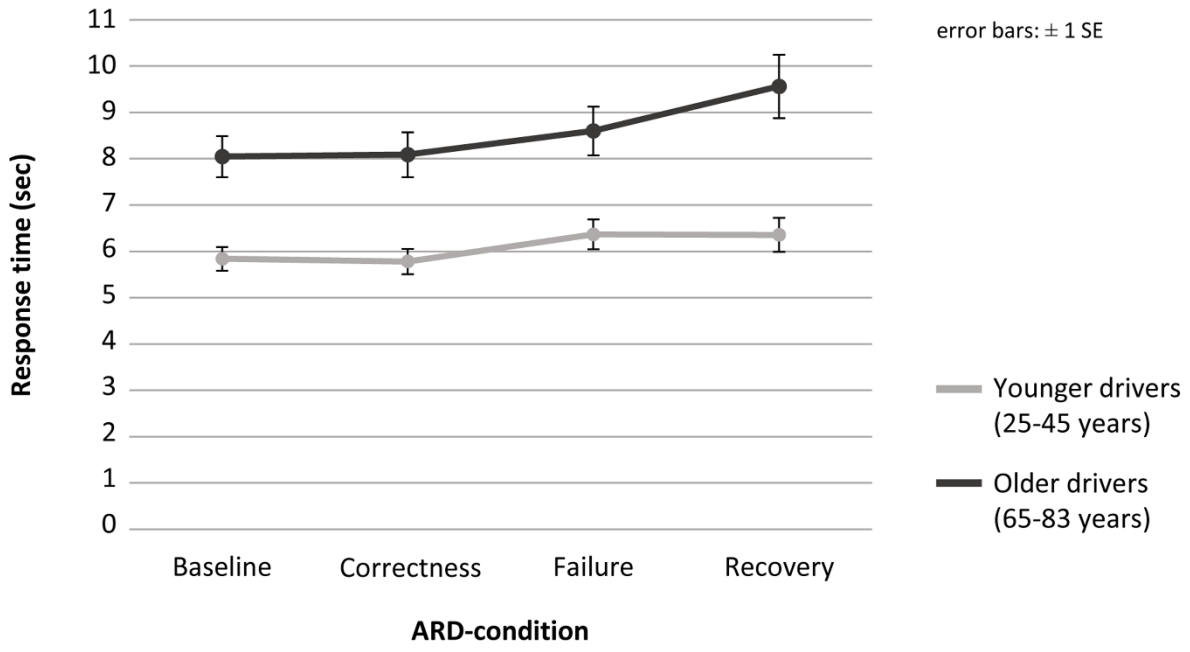

Figure 9. Effects of Augmented Reality Display condition (ARD-condition) on younger and older drivers' response time in the Surrogate Complexity Method task.

Older drivers required significantly more time than younger drivers to complete the SCM, $F(1, 50) = 15.05$, $p < .001$, $\eta_p^2 = .23$ (H1). There was a significant main effect of ARD-condition on response time as well, $F(1.89, 94.61) = 11.86$, $p < .001$, $\eta_p^2 = .19$ (Greenhouse-Geisser-corrected). According to Bonferroni-corrected pairwise comparisons, participants did not solve the SCM significantly faster in the correctness-section than in the baseline-condition ($p = 1.000$) (H2). However, experiencing ARD-failures increased response time in the failure-section itself ($p = .020$) as well as in

the subsequent recovery-section (p = .002) compared to the previous correctness-section (H3). In addition, there was a significant interaction between age group and ARD-condition, $F(1.89, 94.61) = 3.17$, $p = .049$, $\eta_p^2 = .06$ (Greenhouse-Geisser-corrected). Figure 9 clarifies that this applies to the failure- and recovery-section. Although response time stabilised after the failure-section for younger drivers, it further increased in the subsequent recovery-section for older drivers.

5.4 Discussion

We examined the effects of an ARD providing either accurate or inaccurate prior information about approaching intersections on younger and older drivers' visual processing performance at these intersections, which was assessed using the SCM. The results largely confirmed the hypotheses formulated in Chapter 5.1. Across all ARD-conditions, older drivers' response time and accuracy in the SCM was poorer than younger drivers' (H1). Even though providing accurate information via an ARD did not change drivers' response time, it increased the response accuracy in both age groups (H2). Thus, the ARD helped drivers identify more relevant elements at intersections without increasing the required time. Interestingly, this effect was comparable for younger and older drivers, confirming that systems supporting drivers in complex traffic situations could benefit a wide variety of age groups.

Experiencing the ARD providing inaccurate ARD-information led to poorer SCM-performances of younger and older drivers in the failure-section itself as well as in the subsequent recovery-section, in which the ARD worked accurately again. The proportion of correctly answered trials reverted to the baseline-level in both age groups and in both sections. In addition, response time significantly increased for both age groups during the failure-section and failed to decline in the recovery section. Younger drivers' response time remained stable in this section while older drivers' response time further increased. To summarise, the experience of system failures led to poorer SCM-performance in the failure- and recovery-sections compared to the correctness-section (H3) as well as to the baseline-condition. Therefore, the SCM-performance in the failure-section was probably not only negatively affected by the absence of accurate prior information, but also by the increase of intersection complexity due to the information mismatch. Drivers' mistrust of the ARD after experiencing its failure may explain the remaining poorer SCM-performance in the recovery-section. Older drivers seemingly tried to compensate for the inaccurate ARD by allowing themselves more time to finish their response. This resulted in a slight, although not significant, increase in response accuracy. Thus, previous experience of system failures more negatively affected older drivers' SCM-performance than those experiences did for younger drivers.

Given the importance of visual processing for a safe driving performance (Crundall & Underwood, 2011; Vollrath, 2007), these results indicate the potential presenting prior information has to aid both older and younger drivers in complex traffic situations. This corresponds with previous research indicating a lack of information as the main cause for accidents due to right-of-way violations not only among older drivers, but drivers of all age groups (Vollrath, 2007). The ARD-technology provided an appropriate display to present this information due to its possibilities regarding the positioning of information. However, comparative studies are required to identify the specific benefits of this display type to existing forms, such as conventional HUDs. Emphasis should thereby be placed on the system's reliability and its effects on drivers' trust given failures were more detrimental, at least short-term, for (especially older) drivers' perception performance than the absence of a system. This might be because it was difficult to ignore inaccurate prior ARD-information due to its position in the driver's relevant field of view. Thus, ARD-systems should allow the driver to deactivate them effortlessly when required while driving. Future research should address long-term effects of occasional system failures on drivers' usage behaviour.

From a methodological perspective, the SCM turned out to be an economical and useful approach for a standardised assessment of drivers' ability to perceive traffic situations. The results of the presented study corroborate previous findings on age differences in information processing speed (Salthouse, 1996, 2004, 2009) and on the benefits of presenting prior driving information for older adults (Caird, Chisholm, & Lockhart, 2008; Davidse et al., 2009). However, these results should be interpreted in consideration of a few methodological limitations.

Primarily, the validity of the SCM needs verification prior to its further usage. The consistently significant, high correlations between participants' performance on the SCM and the ZVT (Oswald & Roth, 1987), which assesses information processing speed, represent initial evidence for high convergent validity of the SCM. Further, we attempted to enhance its external validity by presenting traffic situations full sized in the driving simulator, allowing participants to perceive them from the driver's natural perspective. Nevertheless, future research is needed on other psychometric criteria of the SCM. In addition, limiting the number of surrogates to a maximum of five per SCM-image produced a ceiling effect for participants' response accuracy. Despite the significant differences between age groups and ARD-conditions, the mean proportion of correctly answered trials was higher than 70 % in each experimental condition. To be able to discover more subtle differences between experimental conditions, the complexity of traffic situations should be increased by a greater number of surrogates per SCM-image in subsequent applications of the method.

6 STUDY II: AUGMENTED REALITY DISPLAY – ACCEPTANCE ASPECTS

After identifying the potential of Augmented Reality Displays (ARDs) to improve older drivers' perception of traffic situations in Study I, the system was evaluated from the acceptance perspective in Study II. This perspective was integrated into the system evaluation based on the assumption that the beneficial effects revealed in Study I cannot be delivered unless potential future users are actually willing to use the ARD (see Chapter 2.3.5). Accordingly, the aim of Study II was to extend the rare previous indications of older drivers' overall acceptance of ARDs (see Chapter 2.3.5.3) and to identify details on potential age-specific acceptance barriers, which need to be considered in order to ensure an age-appropriate system development and introduction. Since being able to experience a novel technology increases the validity of future users' judgement about such a system (see Chapter 2.3.5.1), drivers' acceptance of ARDs was examined in a driving simulator study in order to give the participants a more holistic impression of driving with the system than provided by the static images presented in Study I.

6.1 Aims and Research Questions

Aim of this driving simulator study was to examine drivers' acceptance of an ARD providing prior information about the right-of-way regulation of approaching intersections. Since ARDs cannot be experienced by potential future users yet, the simulation was chosen as the most realistic setting available, giving drivers an impression of the system throughout an entire drive through an urban environment. In detail, three main questions (Q) were examined, which are explained below:

(Q1) Do older drivers with and without system experience accept ARDs as a support measure?

(Q2) Are there any age-specific acceptance barriers that could prevent older drivers from using the ARD?

(Q3) How is the acceptance of the ARD affected by the duration of displaying prior information?

The aim of Q1 was to clarify if older drivers are open-minded to use the system, which represents a promising support measure from a theoretical perspective, and whether experiencing the ARD influences their attitudes towards this technology. Q2 was integrated to identify user requirements that need to be taken into account to facilitate a successful system development. Q3 was based on the concerns regarding the potentially increased difficulty for drivers to ignore the displayed information if they wish or need to, based on the presentation in their direct field of view instead of a separate display. This might be problematic in complex traffic situations such as intersections, where supplementary information are more likely to be demanding than supporting (Falkenstein & Poschadel, 2008), which might lead to a reduced system acceptance. Based on this consideration, two different forms of display duration were evaluated. In this case, display duration determined whether the ARD remained activated until the driver started to cross the intersection, providing additional information in the complex intersection itself (long ARD-duration), or if it was deactivated half way between the point of activation and the intersection itself (short ARD-duration).

All research questions factored in drivers' age in order to identify older drivers' specific characteristics and requirements regarding the acceptance of ARDs.

6.2 Method

6.2.1 Study Design

The driving simulator study was based on a 2x3-between-subject-design. To investigate age-specific effects of drivers' acceptance, the experiment was conducted with a group of older drivers and a group of younger drivers. Participants from both age groups were distributed to three groups experiencing one of three different ARD-conditions each (experimental group 1: short ARD-duration, experimental group 2: long ARD-duration, control group: no ARD).

6.2.2 Participants

Ninety-three participants took part in the experiment. All of them had successfully completed a separate training session before, which was conducted to familiarise them with the driving simulator and to reduce the occurrence of simulator sickness. However, three of them could not complete the experiment because of minor simulator sickness symptoms, leading to a final sample of 90 persons in

total. Forty-five of them (3 female, 42 male) belonged to the older group (65-80 years of age) with a mean age of 70.9 years (*SD* = 5.3) and a mean driving experience of 49.5 years (*SD* = 6.5). The 45 participants (17 female, 28 male) in the younger group (25-45 years of age) had a mean age of 29.3 years (*SD* = 5.4) and a mean driving experience of 11.1 years (*SD* = 5.4).

All participants needed to currently hold a valid driver's license and to drive an annual minimum of 1,000 kilometres. None of them had previously experienced driving with an ARD. Participation further required a signed informed consent and was monetarily rewarded.

To ensure the comparability of the three ARD-groups among each other, participants of both age groups were equally distributed to these conditions with regard to their number, age, gender, years since obtaining a driver's licence, annual mileage, and information processing speed, which was assessed using a trail making test (Zahlenverbindungstest, ZVT; Oswald & Roth, 1987). The matching of the three ARD-conditions regarding these driver characteristics (with the exceptions of number and gender) was statistically verified using one-factorial ANOVAs, which confirmed the absence of significant differences for both age groups (see Table 3).

Table 3

Distribution of Driver Characteristics between the Experimental Subgroups, Separated by Age Group

Driver Characteristics	No ARD (control group)		Short ARD (experimental group 1)		Long ARD (experimental group 2)		ANOVAs	
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*(2, 42)	*p*
Younger drivers	*n* = 15		*n* = 15		*n* = 15			
Age	28.00	4.95	28.67	4.57	31.27	6.21	1.59	.215
Years since obtaining driver's license	10.13	5.08	9.67	4.73	13.47	5.71	2.39	.104
Annual mileage (1000 km)	14.17	12.66	12.30	5.93	14.40	14.24	.15	.861
ZVT speed value (sec)	61.27	11.29	60.20	14.71	63.05	17.81	.14	.869
Older drivers	*n* = 15		*n* = 15		*n* = 15			
Age	70.67	4.37	72.13	5.72	70.00	5.67	.64	.533
Years since obtaining driver's license	50.60	5.74	51.40	6.25	46.40	6.72	2.77	.074
Annual mileage (1000 km)	10.20	4.16	13.90	6.80	13.20	7.37	1.48	.240
ZVT speed value (sec)	111.55	27.43	110.23	45.98	108.03	42.23	.03	.970

Note. ARD = Augmented Reality Display, ZVT = Zahlenverbindungstest (Trail Making Test; Oswald & Roth, 1987).

6.2.3 Facilities and Simulated Route

All drives were performed in a fixed-base driving simulator consisting of an Audi shell with a fully equipped interior and an automatic gearbox. A 180° field of view was realised by projecting the driving scenarios on three 2.5-meter screens with the help of three LCD-projectors, each with a resolution of 1650 x 1050 pixels. We created the driving scenarios using the SILAB simulation software. For the test drive, an urban track with a total length of about 9 km was simulated, including 13 intersections, which differed in right-of-way regulation, course of the lanes, and traffic density. Among other regular

elements, each intersection contained a direction sign, helping the participants to follow their instructions to drive towards the city of Chemnitz. For the two experimental groups, we additionally simulated the ARD which informed about the right-of-way regulation of each approaching intersection by projecting the respective traffic sign contact-analogously on the road in front of the vehicle (*see* Figure 10). The ARD was activated 150 m in front of every intersection. In experimental group 2 (long ARD duration), the ARD was presented until the beginning of the intersection. In contrast, it was deactivated 75 m in front of the intersection in experimental group 1 (short ARD duration).

Figure 10. Simulated Augmented Reality Display 150 m in front of an intersection where the driver (a) has the right of way or (b) has to yield right of way.

6.2.4 Assessment of Drivers' Acceptance

Drivers' acceptance in terms of attitudes towards the age-specific ARD was assessed using the Van der Laan acceptance scale (Van der Laan et al., 1997), which consists of nine bipolar five-point rating-scale items. The scale was presented to both experimental groups as well as to the control group after the test drive in order to enable a comparison between drivers' evaluations of the ARD with versus without system experience. The authors of the questionnaire explicitly recommend its application to assess a priori acceptability of a system. Members of the control group were introduced to the ARD by means of a written system explanation including Figure 10, which was presented within the framework of the acceptance questionnaire.

To assess additional information on different determinants of drivers' acceptance beyond attitudes, we also applied a German adaption of the questionnaire based on the Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh, Morris, Davis, and Davis (2003). This instrument consists of 31 seven-point agreement-scale items. Since it mainly addresses information systems in a working

context, we adjusted the wording of the items to the driving context during the translation process, if necessary (see Appendix A). The UTAUT-questionnaire was solely applied to the two experimental groups due to the very specific questions regarding the evaluated system, which required at least a minimum level of system experience to be answered.

6.2.5 Procedure

Initially, all candidates took part in a separate driving simulator-training. In this context, demographic data was assessed via a questionnaire and the ZVT was applied to assess information processing speed. Each candidate not showing any simulator sickness symptoms during or after this training session was invited to the experiment. At the beginning of the experimental session, participants signed the consent form. After a ten-minute familiarisation drive, participants completed the test drive with the help of the short ARD (experimental group 1), the long ARD (experimental group 2), or without ARD (control group). Afterwards, they filled in the acceptance questionnaire in either a short (for the control group) or long version (for the two experimental groups). Next to acceptance, this questionnaire included additional dependent variables (situation awareness, workload), which are not reported in this context. Overall, the experimental session took about 90 minutes.

6.3 Results

6.3.1 Drivers' Attitude towards the ARD

In contrast to the two dimensions postulated by Van der Laan, Heino, and de Waard (1997), an analysis of the questionnaire's factorial structure produced only one dimension in our sample. We followed the procedure of Beggiato, Pereira et al. (2015) for this case and calculated the mean value of all nine items, indicating the overall attitude towards the ARD. Internal consistency reliability of this dimension was high (Cronbach's $\alpha = .91$).

Figure 11 shows the mean value of this dimension in all three ARD conditions, separated by age group. Generally, drivers' evaluation of the age-specific ARD achieved positive values in all ARD-conditions and age groups. All ARD-conditions were rated slightly higher by older than by younger drivers. This age effect was significant according to the results of a two-factorial ANOVA, $F(1, 84) = 9.12$, $p = .003$, $\eta_p^2 = .09$. Even though a visual comparison of the three ARD-groups indicates that younger and older

drivers of the two experimental groups reported slightly higher values than those of the baseline group (Q1), including a preference for the short ARD-duration among older drivers (Q3), a two-factorial ANOVA did not reveal any significant differences between the three ARD-conditions, $F(2, 84) = 1.97$, $p = .147$, $\eta_p^2 = .05$, as well as no significant interactions between ARD-condition and age group, $F(2, 84) = 1.13$, $p = .327$, $\eta_p^2 = .03$.

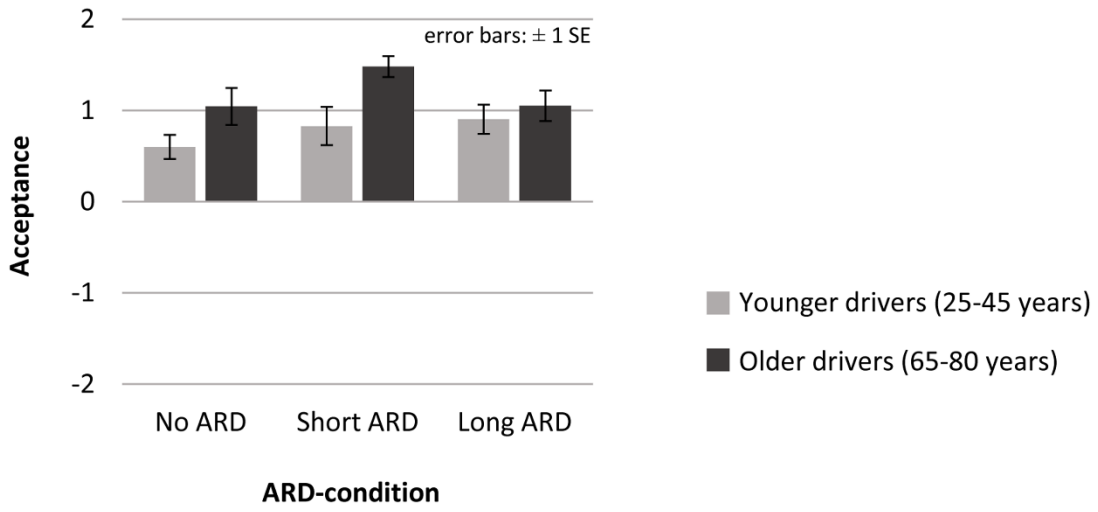

Figure 11. Younger and older drivers' system acceptance (Van der Laan acceptance scale) in the three Augmented Reality Display conditions (ARD-conditions).

6.3.2 Determinants of Drivers' Acceptance

All but one subscales of the UTAUT-questionnaire showed sufficiently high reliability values (Cronbach's α differed between .65 and .92). Reliability of the *facilitating conditions* scale was too low (Cronbach's α = .43), but could be improved substantially (Cronbach's α = .54) by excluding one of the four associated items. The excluded item was the only one with a negative wording throughout the questionnaire, probably leading to vagueness in answering it on an agreement-scale.

Figure 12 displays the mean scores of all eight subscales in both experimental groups, separated by age group (Q2).

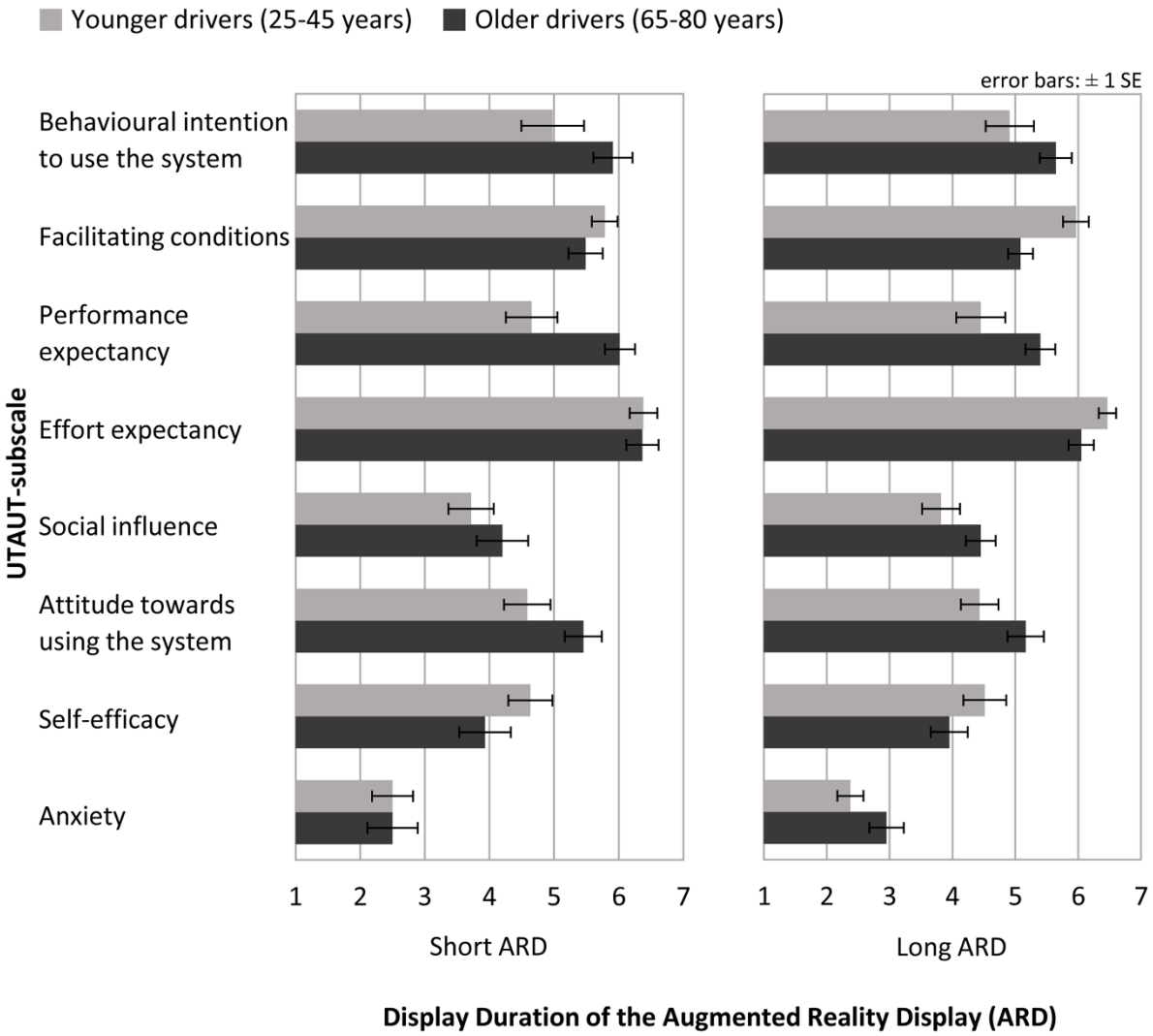

Figure 12. Younger and older drivers' system acceptance after experiencing an Augmented Reality Display (ARD) with a long versus short display duration. UTAUT = Unified Theory of Acceptance and Use of Technology.

Independent of ARD-condition, younger and older drivers reported high ratings on the *behavioural intention to use* scale and the *facilitating conditions* scale, which are both directly linked to actual system usage, according to the UTAUT. Interestingly, older drivers reported a higher *intention to use* the ARD, even though they rated the *facilitating conditions* lower than younger drivers. The generally high ratings on these two scales correspond with the mostly positive values on the direct and indirect determinants of the *behavioural intention to use* the ARD in both ARD-conditions and age groups. The mean values for *performance expectancy*, *social influence* and *attitude towards using* were higher for older than for younger drivers in both ARD-conditions. Considering that lower anxiety ratings correspond to a more positive system evaluation, the mean values for *effort expectancy*, *self-efficacy*

and *anxiety* showed an opposite tendency regarding drivers' age. The evaluations of both age groups appeared to be mostly comparable between both ARD-conditions, with a merely slight tendency to higher ratings regarding the short ARD-duration compared to the long duration.

A two-factorial MANOVA including the eight UTAUT-subscales as dependent variables verified a significant age effect regarding drivers' evaluation of the ARD, *Pillai's trace criterion* = .40, $F(8, 48) = 3.93$, $p = .001$, $\eta_p^2 = .40$. Correspondent post-hoc-tests (see Table 4) confirmed the described age effects on the *behavioural intention to use* the ARD and *facilitating conditions* to be significant. Additional significant age differences were found for *performance expectancy, attitude towards using the system*, and *self-efficacy*. No significant age effects were found for the remaining three scales, indicating a likewise positive ARD-evaluation of older and younger drivers regarding these aspects.

Table 4

Effects of Age on Drivers' Acceptance of the Augmented Reality Display (Independent of Display Duration)

	Younger drivers		Older drivers					
UTAUT-subscale	*M*	*SD*	*M*	*SD*	*F*	*df*	*p*	η_p^2
Behavioral intention to use the system	4.94	1.67	5.78	1.07	5.31	1	.025	.09
Facilitating conditions	5.88	.77	5.29	.91	6.55	1	.013	.11
Anxiety	2.44	1.02	2.73	1.30	.88	1	.353	.02
Self-efficacy	4.57	1.30	3.94	1.34	5.21	1	.030	.06
Attitude towards using the system	4.51	1.26	5.31	1.10	6.81	1	.012	.11
Social influence	3.77	1.25	4.33	1.25	2.23	1	.141	.04
Effort expectancy	6.42	.69	6.21	.87	1.08	1	.304	.02
Performance expectancy	4.55	1.50	5.71	.95	12.56	1	.001	.19

Note. UTAUT = Unified Theory of Unified Theory of Acceptance and Use of Technology.

The described tendencies towards a preference for the short ARD-duration appeared not to be significant according to the results of the two-factorial MANOVA, *Pillai's trace criterion* = .08, $F(8, 48) = .49$, $p = .855$, $\eta_p^2 = .08$. There was no significant interaction between drivers' age and ARD-duration as well, *Pillai's trace criterion* = .05, $F(8, 48) = .31$, $p = .960$, $\eta_p^2 = .05$.

6.4 Discussion

The aim of this study was to assess different age groups' acceptance of an ARD providing prior information about the right-of-way regulation of approaching intersections, which is considered a helpful systems to support older drivers in complex traffic situations. In summary, drivers evaluated the ARD in a positive manner. This applies to both older drivers, who tend to be cautious about new technologies (Lerner et al., 2008), and younger drivers, even though there was a risk of a negative image of a system that was specifically designed for older drivers. This could be shown on the basis of drivers' consistently positive acceptance ratings indicated by the Van der Laan acceptance scale in all three ARD-conditions (experimental group 1: short ARD-duration, experimental group 2: long ARD-duration, control group: no ARD). This general impression was confirmed by the drivers' ratings on the UTAUT-subscales, which were positive as well (with the exception of *social influence* and *self-efficacy*).

Older drivers' attitudes towards the age-specific ARD were slightly more positive than younger drivers' ones, indicated by a significant age effect regarding the Van der Laan acceptance ratings. This impression was strengthened by the results of the UTAUT-questionnaire. Especially older drivers' higher *attitude towards using the system* turned out to be significant. A further significant age effect was found for *performance expectancy*, indicating that older drivers were more convinced that their driving performance would benefit from using the ARD than younger drivers.

Consistent with the age effects on its determinants, the *behavioural intention to use the system*, which is one of the questionnaire's two scales directly linked to actual system usage (Venkatesh et al., 2003), appeared to be significantly higher for older than for younger drivers. These results approve that the age-specific ARD matched the assistance requirements of its target group. With their high ratings, older drivers confirmed the supposed benefit of the ARD-technology out of their perspective. Their higher *behavioural intention to use the system* is even more meaningful considering their significant lower rating on the second direct determinant of actual system usage, *facilitating conditions* (Q2). As this scale convers system-external conditions that could support its usage, this result emphasises the fit between the ARD and the target group, since older drivers are more open-minded to use the system

than younger drivers, even though they feel less facilitated by their environment in doing so. Interestingly, the second UTAUT-scale rated significantly more negatively by older than by younger drivers was *self-efficacy*, representing the only determinant of the *behavioural intention to use the system* not solely referring to characteristics of the ARD itself, but also to drivers' competence of using it. Thus, older drivers' ratings on this scale could be affected by their insecurities concerning innovative technologies or complex traffic situations in urban environments, as those are experienced as difficult especially by members of this age group (Kaiser & Oswald, 2000).

Neither did the study reveal significant differences between the three evaluated ARD-conditions, nor a significant interaction between ARD-condition and drivers' age. The comparison of the Van der Laan acceptance scale ratings stated in the two experimental groups, who experienced the ARD in the driving simulator, and the control group, who was introduced to the system solely via a written explanation, indicated that system experience had no significant effect on drivers' attitudes (Q1). Younger and older drivers in all three ARD-conditions evaluated the ARD in a positive manner. This was not significantly reduced or increased by system experience in the driving simulator. The comparison of the two different ARD-durations revealed no significant effects as well, indicated both by Van der Laan acceptance scale and UTAUT-questionnaire (Q3). This is comprehensible, as none of the two ARD-versions was throughout poorly designed. It was only presumed that the short duration would fit slightly better to older drivers' assistance requirements, as it provides additional information solely in advance of an intersection rather than in this complex situation itself. This assumption was at least rudimentary confirmed by the results, since all drivers' ratings were slightly higher for the short ARD duration. It is conceivable that the comparison between a well and a poor designed ARD would produce significant differences in acceptance. Thus, the orientation of the system development towards older drivers' needs regarding both content and design of the ARD is recommended.

To summarise, the apprehension of older drivers not using a beneficial driver assistance system because of their reservations about new technologies could not be confirmed in the case of an age-specific ARD. Additionally, this study indicates the possibility that such a system would not be refused by other driver groups who could also benefit from its usage as well. Existing acceptance differences between several age groups could potentially be addressed by an adaptive ARD-design allowing for the adjustment of its functionality to individual preferences. Obviously, assessing users' acceptance is not sufficient to evaluate a technological system. However, since it represents a necessary precondition for actual system usage, a substantial potential of age-specific ARDs to support older (and younger) drivers' independent mobility can be assumed based on this study.

7 STUDY III: HIGHLY AUTOMATED DRIVING – PERFORMANCE AND ACCEPTANCE ASPECTS

In parallel with the examination of the potential to support older drivers through Augmented Reality Displays (ARDs) within the framework of Study I and Study II, the evaluation of highly automated driving (HAD) included issues related to driving performance as well as user acceptance. Both perspectives were addressed in Study III, which represents a two-part driving simulator study.

Reflecting the shift of the driver's role from an active driver to a passenger at this level of driving automaton, the system evaluation from the performance perspective focused on the human perception of the driving performance executed by the automated system. Accordingly, the aims of Study III differed from those formulated for the evaluation of ARDs in Study I. Considering the importance of affective components of human-automation interaction, such as driving comfort and enjoyment, in the context of HAD (see Chapter 2.3.4.1), one aim of Study III was to evaluate the theoretical approach to increase driving comfort by implementing familiar highly automated driving styles (HAD-styles) based on drivers individual manual driving styles (MD-styles) (see Chapter 2.3.4.3).

Comparable to Study II, acceptance-related issues in the context of HAD included the effects of system experience on drivers' acceptance as well as potential age-specific acceptance barriers. The aim was to extend previous findings on the acceptance of highly automated vehicles among older drivers, which were mostly limited to studies of their general technology usage or surveys on HAD-acceptability (see Chapter 2.3.5.4). Taking up the issues addressed from the performance perspective, it was additionally examined whether drivers' acceptance of HAD is modifiable by the familiarity of the implemented driving style.

7.1 Aims and Research Questions

Performance- and acceptance-related aspects of HAD were investigated in a two-part driving simulator study. The examination of performance-related aspects focused on the effects of driving automation

and the familiarity of the highly automated driving style on the driving comfort and enjoyment experienced by drivers. This included two main questions:

(Q1) As how comfortable and enjoyable is HAD perceived by drivers compared to MD?
Regarding driving comfort, it should be clarified whether transferring the driving task to a highly automated vehicle is perceived as comfortable facilitation or uncomfortable loss of control. Regarding driving enjoyment, the effect of missing driving-related activities was investigated.

(Q2) Does a familiar HAD-style (i.e. a driving style that corresponds to each driver's individual MD-style) lead to higher driving comfort and enjoyment than an unfamiliar HAD-style (i.e. a driving style that differs from each driver's individual MD-style)?
Aim of this research question was to evaluate the familiarity-approach for HAD-styles. This is of special interest for older drivers whose individual driving styles are characterised by compensation strategies on the regulation level of the driving task.

Regarding drivers' acceptance of HAD, three main questions were examined:

(Q3) How is a priori acceptability of HAD changed by the initial and a subsequent system experience?
The aim of this question was to clarify whether the actual experience of transferring the driving task to a highly automated vehicle leads to an increase or decrease of acceptance compared to the drivers' initial perception of HAD. The study included two subsequent system experiences to examine whether the distinctiveness of the initial system experience identified for Advanced Driver Assistance Systems (ADAS) can be transferred to HAD.

(Q4) Are there any age-specific acceptance barriers that could prevent older drivers from using HAD and are they affected by increasing system experience?
The aim of this question was to identify user requirements that need to be taken into account to facilitate a successful development and introduction of HAD.

(Q5) Does a familiar HAD-style (i.e. a driving style that corresponds to each driver's individual MD-style) also lead to a higher system acceptance of HAD than an unfamiliar HAD-style (i.e. a driving style that differs from each driver's individual MD-style)?

In order to identify older drivers' specific characteristics and requirements regarding HAD, all of these research questions were examined for older drivers as well as a comparison group of younger drivers.

7.2 Method

7.2.1 Study Design

These research questions were examined in a driving simulator study in order to give the participants an impression of the full potential of HAD. This environment enabled a safe and technically unrestricted system experience throughout an entire trip, including different driving scenarios and interactions with other road users. The study consisted of two sessions. In Session 1, we compared driving comfort and enjoyment between two levels of driving automation (manual versus highly automated) (Q1) and examined the impact of the initial system experience on the acceptance of HAD (Q3). Further details on acceptance (Q3, Q4) as well as the effects of HAD-style familiarity (familiar versus unfamiliar) on driving comfort, driving enjoyment (Q2), and acceptance (Q5) were investigated in Session 2. Drivers' age was included as a between-subjects factor by conducting the study with drivers of two age groups (younger versus older drivers), creating a 2 x 2 mixed design for each experimental session.

7.2.2 Participants

The sample consisted of 46 participants from a database of simulator-trained drivers who had already taken part in at least one prior driving simulator experiment consisting of a training drive and at least one manual test drive in the driving simulator that was used in this study. After reporting symptoms of simulator sickness in Session 1, six of them were excluded, leading to a final sample of 40 participants in total. Twenty of them (10 female, 10 male) belonged to the younger driver group (25-35 years of age) with a mean age of 27.8 years (*SD* = 2.1) and a mean number of years since obtaining a driver's license of 9.5 years (*SD* = 2.3). The older driver group (65-84 years of age) consisted of 20 participants (9 female, 11 male) with a mean age of 72.1 years (*SD* = 6.0) and a mean number of years since obtaining a driver's license of 47.4 years (*SD* = 10.7). All participants needed to currently hold a valid driver's license and to drive an annual minimum of 1,000 kilometres. None of them had previously experienced HAD (neither in a vehicle nor in a previous driving simulator study). Participation further required a signed informed consent. Upon study completion, participants were compensated with 30 €.

7.2.3 Facilities and Simulated Route

All drives took place in a static driving simulator with a fully equipped interior and a 180° horizontal field of view, including a rear-view mirror and two side mirrors. Using the SILAB 4.0 simulation environment, we created a 7.5 km long test track (2.5 km one-lane rural road, 5.0 km two-lane highway). The route included 11 driving scenarios which could have been handled differently by various driving styles and required various driving manoeuvres as well as interactions with other road users. The rural road section consisted of five scenarios (speed limits are presented in parentheses after each scenario): driving on a rural road (70 – 100 km/h), having the right of way at an intersection with cross traffic (70 km/h), making a lane change to avoid an obstacle (100 km/h), stopping at a red traffic light (70 km/h), and driving behind another vehicle (70 km/h). This section was followed by a highway section including six scenarios: entering a highway (70 km/h), driving on a highway (no speed limit; maximum speed driven: 170 km/h), highway narrowing from two lanes to one lane (100 km/h – 130 km/h), approaching a slower vehicle ahead (80 km/h), leaving a highway (50 km/h – 80 km/h), and stopping at a stop sign at the end of the highway exit (50 km/h). Turning manoeuvres were reduced to a minimum in order to avoid simulator sickness.

To simulate HAD, driving data was recorded at a frequency of 60 Hz during MD and replayed in the simulator while the participants sat in the driver's seat. The pedals and steering wheel were inoperative during HAD.

7.2.4 Questionnaires and Online Assessment of Driving Comfort

In addition to demographic information, we applied standardised questionnaires for the assessment of comfort, enjoyment, and acceptance of HAD. Discomfort was additionally recorded with an online assessment during HAD.

To assess acceptance in terms of attitudes, we used the Van der Laan acceptance scale (Van der Laan et al., 1997). It allows evaluating drivers' *satisfaction* with a system as well as its perceived *usefulness* with a total of nine five-point rating-scale items. The scale was presented before and after the participants' initial experience with HAD as well as after each of the following highly automated drives. As proposed by Van der Laan et al. (1997), the participants rated HAD before their first system experience based on a written system description. After each system experience, the participants were instructed to rate the HAD-system they just finished to drive with. Determinants of acceptance beyond attitudes were assessed using the questionnaire based on the Unified Theory of Acceptance and Use

of Technology (UTAUT) (Venkatesh et al., 2003). It includes a total of 31 seven-point agreement-scale items representing the eight predictors of usage behaviour regarding a new technology provided by the UTAUT: *facilitating conditions* and *behavioural intention to use the system* as well as the latter's three direct determinants (*performance expectancy*, *effort expectancy*, *social influence*) and three indirect determinants (*attitude towards using the technology*, *self-efficacy*, *anxiety*). As the questionnaire originally addressed information systems in a working context, the item wording was adjusted to the HAD-context if necessary (see Appendix B). The UTAUT-questionnaire was applied after two highly automated drives, but not prior to the first system experience due to the very specific questions regarding the evaluated system.

Driving comfort and enjoyment were assessed after each drive with a questionnaire developed by Engelbrecht (2013) to evaluate both variables under different driving assistance conditions. It consists of 32 five-point agreement-scale items that represent the following four dimensions based on the Joy and Convenience in Activities Model (Engeln et al., 2008): *convenience* (or comfort) and *joy* (or enjoyment) as well as their contrary states *lack of convenience* and *lack of joy*.

Driving discomfort was assessed continuously during all highly automated drives with a professional handset control (ACD pro 10; see Figure 13) integrated into the driving simulator. In accordance with Engelbrecht's (2013) definition of comfort as relaxation and a lack of comfort as stress, discomfort was operationalised as a state of driving-related psychological tension or stress in moments of a restricted harmony between driver and environment. To address the psychological facets of discomfort associated with the loss of control in the context of HAD (Elbanhawi et al., 2015), we focussed on states of tension or stress resulting from unexpected, unpredictable, or unclear actions of the automated system. Accordingly, the participants' were instructed to indicate each moment of perceived tension or stress associated with the driving behaviour of the automated vehicle or the driving situation. Therefore, they were asked to indicate their current level of discomfort throughout an entire drive on a 0-to-100-scale (0 = *comfortable*, 100 = *uncomfortable*). Stronger button presses on the controller corresponded to higher discomfort, which parallels the natural reaction of cramping the hands in an uncomfortable or stressful situation. The handset control input was recorded synchronously with the driving data. A display in the dashboard supplied the participants with visual feedback of the currently entered value on the 0-to-100-scale. Secondary tasks were not allowed aside from using the handset control.

Figure 13. Handset control (left) for the online assessment of comfort while driving highly automated in the driving simulator (right).

This online measure allows for a detailed analysis of situational influences and is less influenced by memory effects than an overall post-hoc evaluation (Kopiez, Dressel, Lehmann, & Platz, 2011). Continuous, nonverbal self-reporting via manual input devices (Continuous Response Digital Interface, CRDI; Geringer, Madsen, & Gregory, 2004) is well established in the fields of music and clinical psychology, for instance to examine perceived musical tension (Fredrickson, 2000; Hackworth & Fredrickson, 2010) or aesthetic responses to music (Geringer & Madsen, 2003). In these fields, the values indicated via CRDI highly correlate to post-hoc Likert-scale ratings of the same constructs (Goins, 1998; Madsen & Geringer, 1999). In transportation research, this method has already been applied to the assessment of driver's workload (Totzke, Rauch, Ufer, Krüger, & Rothe, 2008).

7.2.5 Procedure

The two experimental sessions occurred on separate dates with a gap of approximately six weeks in between them.

After signing the informed consent at the beginning of Session 1, participants completed a questionnaire assessing demographic variables. They were informed about simulator sickness and instructed to report every possible symptom as soon as possible. This was followed by three simulator drives in fixed order: a manual training drive, a manual drive on the test track, and a highly automated drive on the test track. The purpose of the training drive was to familiarise the participants to the driving simulator. The training track required lane changing, braking, accelerating, and driving at different speeds.

The manual drive happened immediately after the training. Participants were instructed to drive naturally and follow the road signs. It took approximately 10 minutes to complete the drive. Afterwards, comfort, enjoyment and a priori acceptability of HAD were assessed via a questionnaire. For the subsequent highly automated drive, participants sat in the driver's seat and were informed that they were not required to drive themselves as the vehicle would now operate automatically. They were introduced to the handset control and instructed to press the button in accordance with the extent of their perceived discomfort throughout the entire drive. Participants then experienced their own driving style as HAD by watching the replay of their respective manual drives. Details on drivers' reasons for pressing the button of the handset control and their needs to change driving style and in order to improve comfort were discussed in a subsequent interview. Afterwards, comfort, enjoyment, and acceptance were assessed again via a questionnaire. Overall, this session lasted approximately 90 minutes. In case a participant reported any symptoms of simulator sickness, the session was immediately cancelled and the participant was excluded from Session 2.

In Session 2, participants experienced three highly automated simulator drives based on different driving style familiarity in a randomised order: one familiar style and two different unfamiliar styles. For the familiar drive, participants experienced the replay of their Session 1 manual drive again. For three participants, who missed the highway exit at the end of the test track during their manual drives, their own drives were replaced by the most similar drives of other participants (based on the cumulative absolute speed difference) in order to present the identical test track in all three drives of Session 2. The two unfamiliar drives were based on the manual drives of the study's other participants. Therefore, all Session 1 manual drives without any driving behaviour implausible for HAD (i.e. driving slightly faster than permitted, driving unnecessarily slowly, or missing the highway exit) were selected, leading to a pool of 16 drives. In Session 2, each participant experienced two randomly chosen drives out of this pool as unfamiliar automated drives. It was ensured that none of the participants observed their own drive again or the same drive two times. In this manner, the unfamiliar drives represented natural driving styles of varying difference from each participants' own driving style. To allow for an analysis of the relations between driving style familiarity and all dependent variables despite presenting different driving styles to each participant, we calculated a distance measure based on driving parameters to quantify the driving style difference between each driver's own (familiar) drive and the other (unfamiliar) drives presented to him in this session. All details on this distance measure are provided in Chapter 7.3.4. During each drive, discomfort was assessed online via the handset control. To ensure that the handset control was used to indicate discomfort instead of potentially confounding variables, such as impatience or boredom, drivers' reasons for pressing the button were assessed in interviews after each drive. Questionnaires on comfort, enjoyment, and acceptance

followed each interview. At the end of Session 2, participants received their compensation for their participation. This session took approximately 100 minutes to complete. Figure 14 gives an overview of the procedure of both sessions.

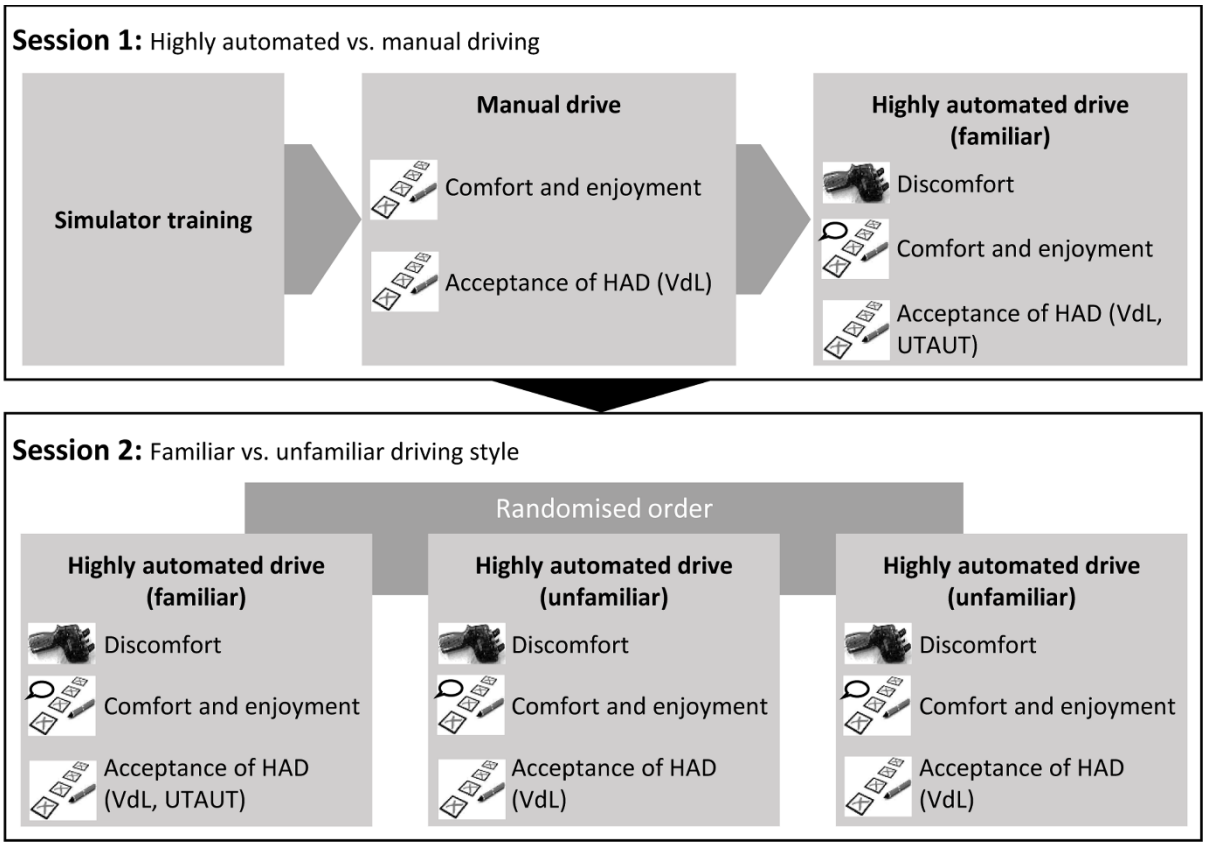

Figure 14. Procedure of the driving simulator study, including assessment of the dependent variables. HAD = Highly automated driving, VdL = Van der Laan acceptance scale, UTAUT = Unified Theory of Acceptance and Use of Technology.

7.3 Results

7.3.1 Data Preparation

In accordance with Engelbrecht (2013), the driving comfort and enjoyment scores were calculated by averaging all questionnaire items of each scale. However, a factor analysis, which as conducted to examine the questionnaire's factorial structure in our sample, produced only two dimensions at all points of assessment rather than the four dimensions postulated by its authors. Based on these results,

we reverse coded the *lack of convenience* items and averaged them with the *convenience* items to derive driving comfort. Further, we reverse coded the *lack of joy* items and averaged them with the joy items to derive driving enjoyment. Internal consistency reliability was high for both dimensions, with Cronbach's α values ranging between .91 and .97 (comfort) and between .87 and .94 (enjoyment) for all times of assessment.

Discomfort was estimated for each highly automated drive of Session 2 by summing up the values of all handset control responses over time for each entire drive per participant. To compare the discomfort experienced during the different drives independent of the drivers' differences in their sensibility to uncomfortable situations (i.e. using the handset control excessively versus seldom) and to prevent group mean values from being distorted by those drivers who used the handset control more often, this sum score was standardised by the total sum of all discomfort values rated by the same participant during all three highly automated drives. Therefore, the sum scores of the three highly automated drives were summarised per participant. This total sum equalled 100 % of the discomfort experienced by one participant in Session 2. To standardise a participant's sum score of one drive, its percentage of this total sum was calculated by using the formula $\%_{drive\ 1} = \sum_{drive\ 1} / (\sum_{drive\ 1} + \sum_{drive\ 2} + \sum_{drive\ 3}) * 100$. Thus, the standardised discomfort value calculated per participant and drive indicates this drive's percentage of the discomfort experienced by this participant during all highly automated drives of Session 2.

A priori and a posterior acceptance of HAD were derived from the Van der Laan ratings made before the initial system experience as well as after each highly automated drive. In contrast to the two postulated dimensions *satisfaction* and *usefulness* (Van der Laan et al., 1997), an analysis of the questionnaire's factorial structure produced only one dimension in our sample. Based on this finding, we followed the procedure of Beggiato, Pereira, et al. (2015) for this case and calculated the mean value of all nine items, indicating the overall attitude towards HAD. Internal consistency reliability of this dimension was high, with Cronbach's α values ranging between .92 and .96 for all times of assessment.

The eight subscales of the UTAUT-questionnaire indicating determinants of acceptance were calculated in accordance with Venkatesh et al. (2003). For both points of assessment, Cronbach's α values of the subscales ranged between .56 and .97.

Based on these dependent variables, the four research questions were analysed using inferential statistics to test each of the implicit two-tailed null hypotheses.

7.3.2 Effects of System Experience on Drivers' Acceptance

Younger and older drivers' Van der Laan acceptance scale ratings made before (a priori) and after the initial highly automated drive (a posteriori 1) as well as after the second highly automated drive based on drivers' own driving style (a posterior 2) were compared in a mixed ANOVA (Greenhous-Geisser-corrected) (Q3). The mean values for both age groups are presented in Figure 15.

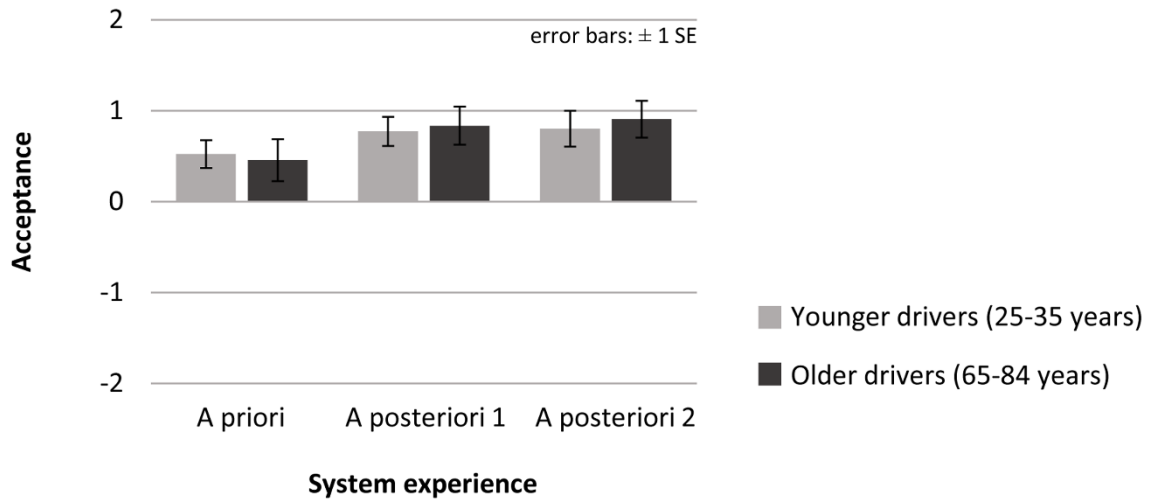

Figure 15. Drivers' a priori acceptability of highly automated driving compared to their system acceptance after the initial (a posteriori 1) and a subsequent (a posteriori 2) system experience.

Drivers from both age groups reported slightly positive a priori attitudes towards HAD. System experience significantly increased this level of acceptance, $F(1.41, 53.75) = 8.24$, $p = .002$, $\eta_p^2 = .18$. Based on post-hoc pairwise comparisons, the a priori ratings were significant lower than the ratings made after the first ($p < .001$) and second highly automated drive ($p = .005$), despite the absence of a significant difference between the two latter ratings ($p = .894$). These experience effects are relevant for both age groups given the absence of an age effect, $F(1, 38) = 0.11$, $p = .746$, $\eta_p^2 = .00$, or an interaction effect between age group and system experience, $F(1.41, 53.75) = 0.89$, $p = .386$, $\eta_p^2 = .02$.

Comparing further aspects of acceptance based on applying the UTAUT-questionnaire after experiencing HAD confirmed the stability of drivers' acceptance after the initial system experience. Figure 16 shows younger and older drivers' mean values across the eight subscales after the first (Session 1) and the second (Session 2) highly automated drive based on drivers' own driving styles.

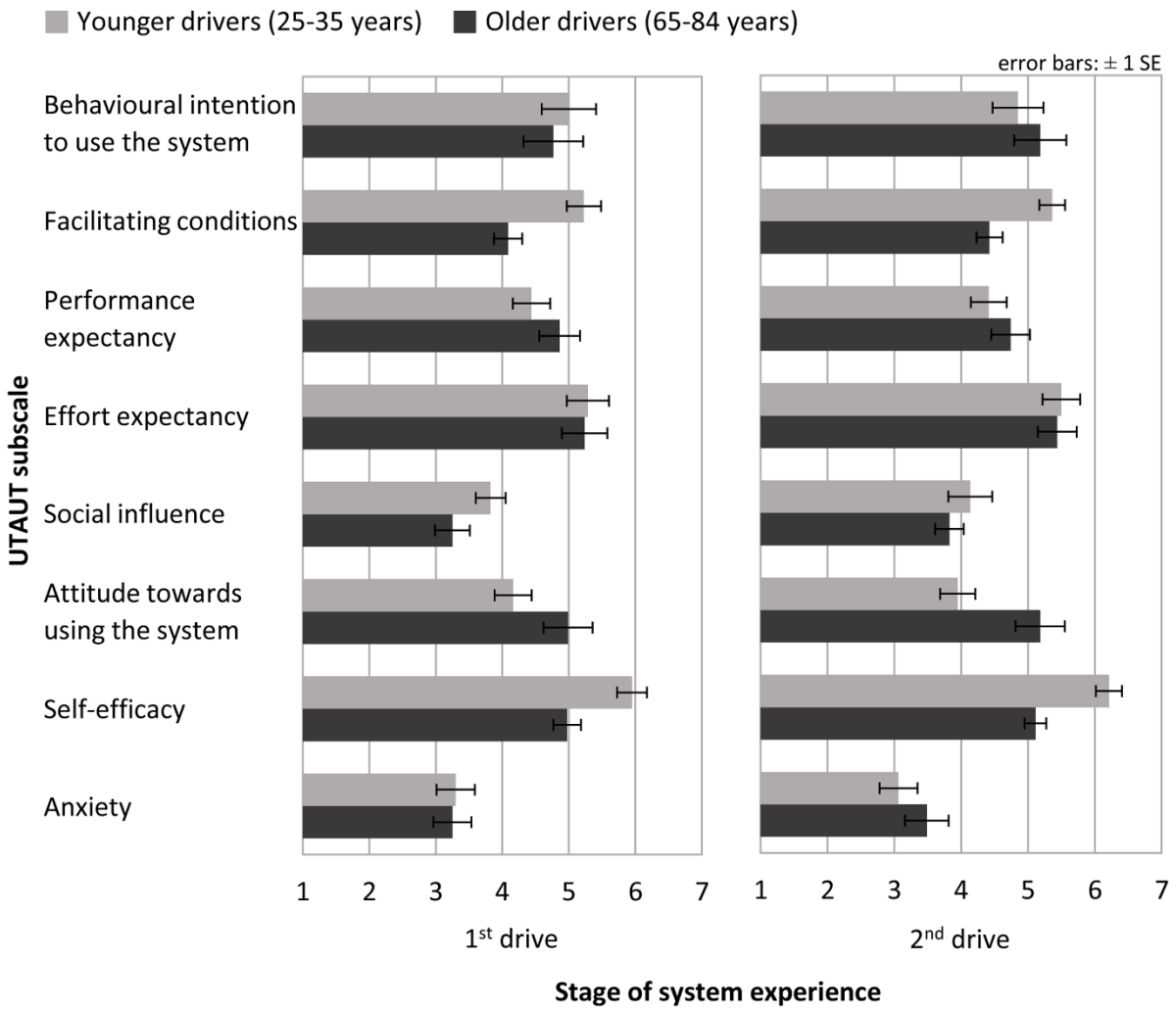

Figure 16. Younger and older drivers' system acceptance after their first and a subsequent highly automated drive. UTAUT = Unified Theory of Acceptance and Use of Technology.

Considering that lower *anxiety* ratings correspond to a more positive system evaluation, seven of eight predictors of system usage were rated on the positive side of the scale on average by both age groups at both times of assessment. The exception was *social influence*, which older drivers evaluated marginally negative at both times of assessment, as did younger drivers after the first highly automated drive.

With the exception of *social influence* increasing in both age groups, $F(1, 38) = 5.93$, $p = .020$, $\eta_p^2 = .14$, experiencing HAD for a second time did not make a significant difference on the UTAUT-subscales, according to mixed ANOVAs. There was not a significant interaction between age group and system experience regarding all UTAUT-subscales. However, there was a significant difference between the

two age groups regarding their ratings on three subscales: while older drivers reported a more positive *attitude towards using* HAD, $F(1, 38) = 5.60$, $p = .023$, $\eta_p^2 = .13$, they indicated less positive values regarding *facilitating conditions*, $F(1, 38) = 16.05$, $p < .001$, $\eta_p^2 = .30$, and *self-efficacy*, $F(1, 38) = 16.45$, $p < .001$, $\eta_p^2 = .30$, than younger drivers.

7.3.3 Effects of Driving Automation on Driving Comfort and Enjoyment

Based on the questionnaire ratings made after both drives in Session 1, comfort and enjoyment of MD and HAD were compared using a mixed ANOVA for each dependent variable (Q1). Figure 17 shows younger and older drivers' mean values on both dimensions.

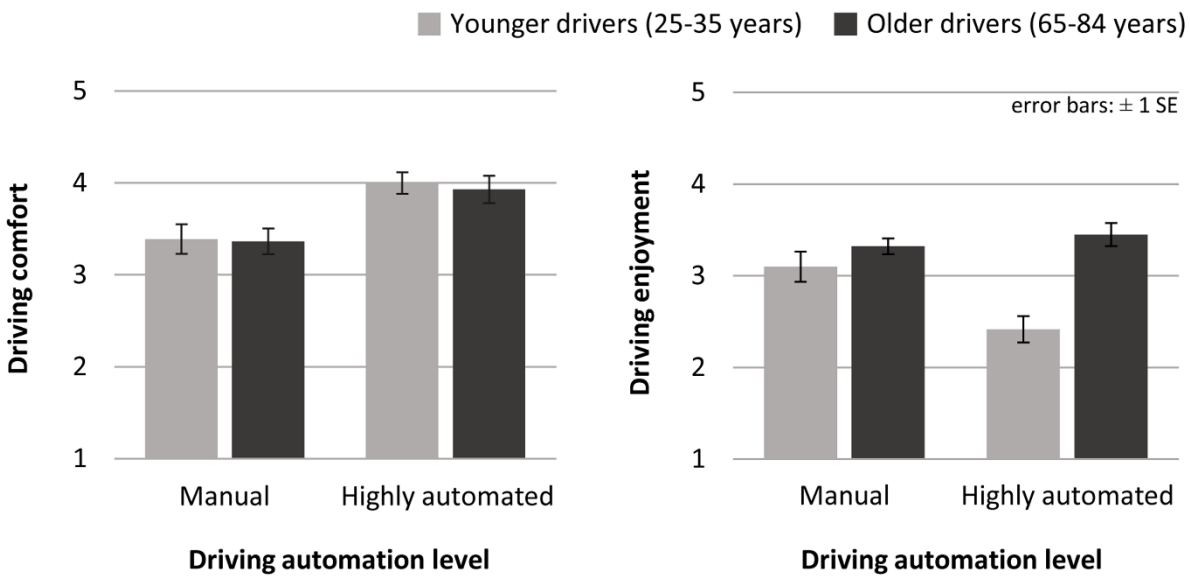

Figure 17. Driving comfort and enjoyment rated by younger and older drivers after the manual and the first highly automated drive.

Participants reported experiencing significantly more comfort when driving highly automated than manually, $F(1, 38) = 34.81$, $p < .001$, $\eta_p^2 = .48$. This effect can be assumed for younger as well as older drivers given the absence of an age effect, $F(1, 38) = 0.12$, $p = .735$, $\eta_p^2 = .00$, and the absence of an interaction between age group and automation level, $F(1, 38) = 0.01$, $p = .935$, $\eta_p^2 = .00$.

In contrast to driving comfort, there were different effects revealed with the enjoyment perceived by younger and older drivers. Even though the significant effect of automation level implies that it is more

enjoyable to drive manually than highly automated, $F(1, 38) = 8.37$, $p = .006$, $\eta_p^2 = .18$, the significant interaction between age group and automation level, $F(1, 38) = 18.22$, $p < .001$, $\eta_p^2 = .32$, clarifies that this effect can only be assumed for younger drivers, who evaluated HAD as relatively unenjoyable. Regarding the group of older drivers, this interaction comprises moderately higher enjoyment values for HAD than for MD. There was a significant age effect as well, with older drivers experiencing driving in general as more enjoyable than younger drivers, $F(1, 38) = 13.21$, $p = .001$, $\eta_p^2 = .26$. However, taking into account the significant interaction effect, this effect can mainly be assumed for HAD.

Both driving comfort, $r = .71$, $p < .001$, and enjoyment, $r = .38$, $p = .017$, reported after this first highly automated drive correlated significantly with a posteriori system acceptance.

7.3.4 Effects of Driving Style Familiarity on Driving Comfort, Enjoyment, and Acceptance

To investigate how driving comfort, driving enjoyment (Q2), and acceptance of HAD (Q5) are influenced by the familiarity of the implemented driving style, the comfort, enjoyment, and Van der Laan acceptance scale ratings made after the three drives of Session 2 as well as the discomfort values indicated during each of these drives were compared using a mixed ANOVA for each dependent variable. For all ANOVAs, the ratings from the two unfamiliar drives were averaged into one score as they both represented driving styles other than the drivers' own.

The mean values for comfort and enjoyment from both younger and older drivers are shown in Figure 18 (Q2). Comfort was rated positively by both age groups in both driving style conditions, thus there was neither an HAD-style effect, $F(1, 38) = 0.29$, $p = .592$, $\eta_p^2 = .01$, nor was there an age effect, $F(1, 38) = 0.11$, $p = .744$, $\eta_p^2 = .00$. However, a significant interaction between age group and HAD-style familiarity indicates different driving style evaluations of younger compared to older drivers, $F(1, 38) = 7.97$, $p = .008$, $\eta_p^2 = .17$. More specifically, while younger drivers experienced the familiar driving style as more comfortable than the unfamiliar driving styles, this effect was opposite for older drivers, who experienced more comfort with an unfamiliar driving style.

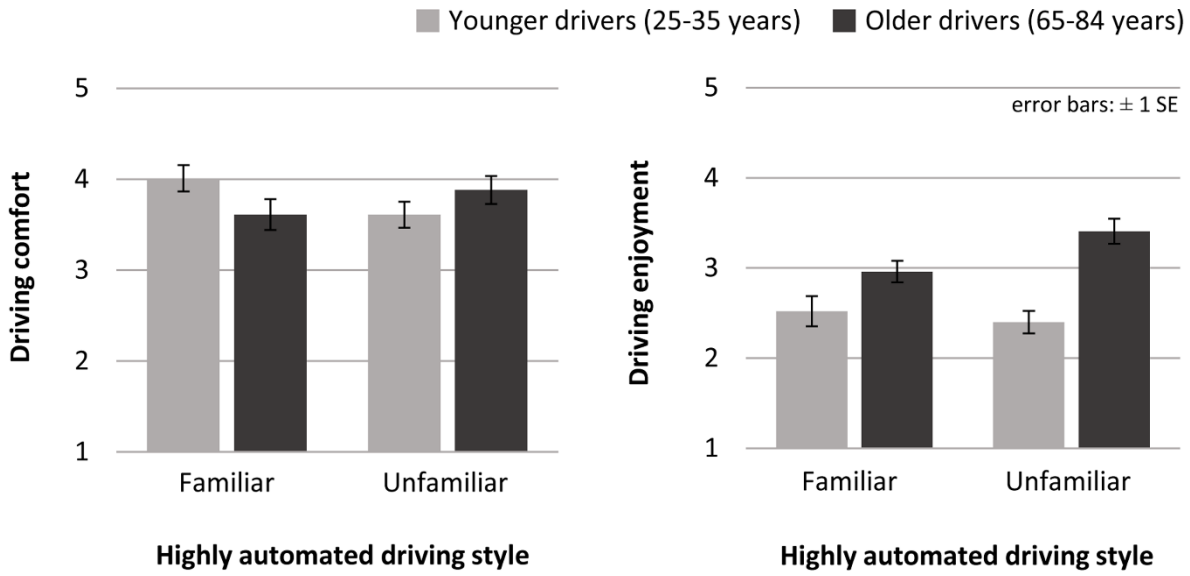

Figure 18. Effects of highly automated driving style familiarity on driving comfort and enjoyment rated by younger and older drivers after each drive.

The same significant interaction existed for driving enjoyment, showing that younger drivers experienced more enjoyment with a familiar driving style, whereas older drivers evaluated the familiar driving style as less enjoyable than the unfamiliar ones, $F(1, 38) = 15.27$, $p < .001$, $\eta_p^2 = .29$. There was also a significant HAD-style effect, implying that unfamiliar driving styles were rated as more enjoyable in general, $F(1, 38) = 4.88$, $p = .033$, $\eta_p^2 = .11$. However, due to the interaction between age group and driving style, this can only be assumed for older drivers. Additionally, this age group experienced significantly more driving enjoyment than younger drivers independent of HAD-style condition, $F(1, 38) = 16.58$, $p < .001$, $\eta_p^2 = .30$.

Figure 19 illustrates the levels of discomfort indicated via the handset control on a 0-to-100-scale across the entire test track, summed up for all drivers per age group and HAD-style condition (Q2). The variability of discomfort within each condition clarifies that discomfort depended on drivers' age and HAD-style as well as on situational influences, as the peaks of the progression graphs can clearly be associated with complex traffic situations such as intersections or obstacles on the road. Summated discomfort scores present the same data pattern as for comfort and enjoyment: older drivers indicated more discomfort during familiar drives than during unfamiliar driving styles, whereas younger drivers used the handset control considerably more often with unfamiliar than familiar HAD-styles.

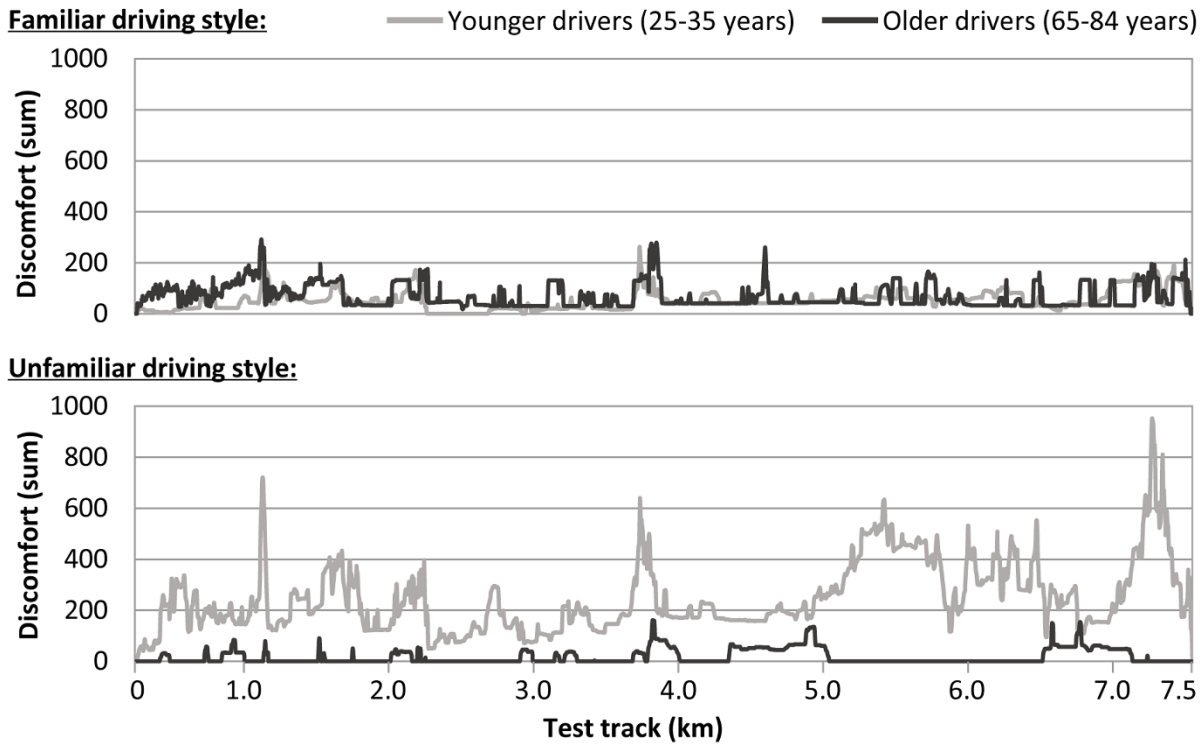

Figure 19. Discomfort values indicated via the handset control by younger and older drivers during familiar and unfamiliar highly automated drives.

For a statistical verification, individual discomfort values were summated and standardised (see Chapter 7.3.1). Figure 20 shows the standardised mean values per age group and HAD-condition.

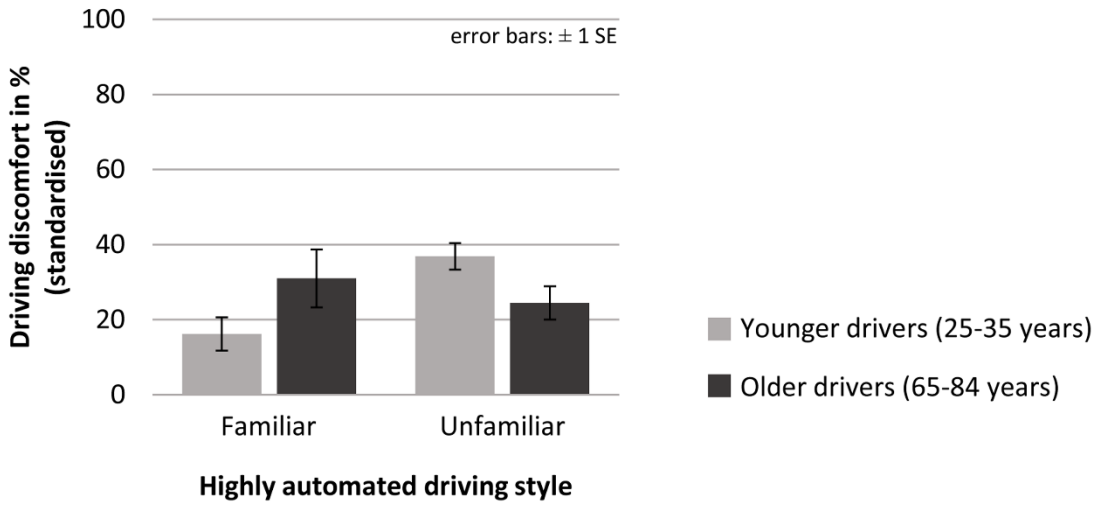

Figure 20. Effects of highly automated driving style familiarity on driving discomfort rated by younger and older drivers during driving. One hundred percent equals the total sum of all discomfort values from the same participant during all highly automated drives.

Neither HAD-style familiarity, $F(1, 38) = 1.36$, $p = .251$, $\eta_p^2 = .03$, nor age group, $F(1, 38) = 0.08$, $p = .781$, $\eta_p^2 = .00$, had a significant effect on driving discomfort. However, again there was a significant interaction between both variables, $F(1, 38) = 4.99$, $p = .032$, $\eta_p^2 = .12$, indicating that while younger drivers rated more discomfort during highly automated drives based on unfamiliar driving styles, older drivers used the handset control more often during familiar drives.

The mean values from the Van der Laan acceptance scale, which are presented in Figure 21, show that the HAD-style familiarity had different effects on drivers' acceptance of HAD among the two age groups as well (Q5). There was neither an overall effect of HAD-style, $F(1, 38) = 0.95$, $p = .336$, $\eta_p^2 = .02$, nor age group, $F(1, 38) = 0.00$, $p = .983$, $\eta_p^2 = .00$, on the Van der Laan ratings. However, a significant interaction between both variables depicts higher acceptance ratings for the familiar compared to the unfamiliar HAD-styles among younger drivers, whereas older drivers had lower acceptance of the familiar HAD-style compared to unfamiliar HAD-styles, $F(1, 38) = 5.10$, $p = .030$, $\eta_p^2 = .12$.

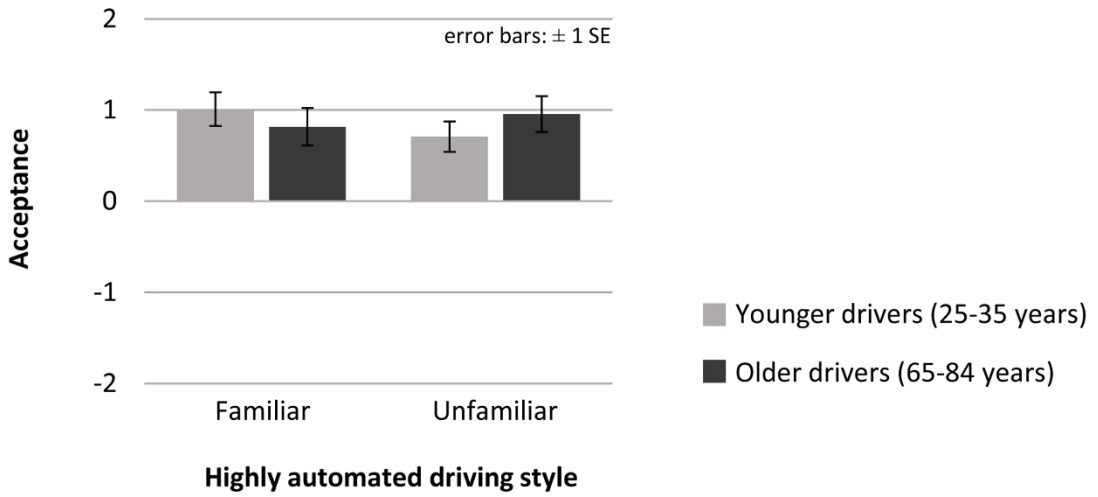

Figure 21. Effects of highly automated driving style familiarity on younger and older drivers' acceptance of highly automated driving.

Acceptance values in Session 2 also correlated significantly with comfort, $\tau = .37$, $p < .001$, discomfort, $\tau = -.13$, $p = .043$, and enjoyment, $\tau = .29$, $p < .001$, rated after the respective drives. Due to the non-normally distributed data (acceptance, discomfort), we calculated Kendall's tau as the correlation coefficient.

To quantify the difference between a participant's MD-style and a driving style presented to him during HAD, a distance measure was calculated to compare different driving styles. Based on the interviews conducted after the first highly automated drive in Session 1, speed, acceleration intensity, as well as onset and intensity of braking were determined as those driving parameters used most often by participants to decide whether the HAD-style was experienced as pleasant or unpleasant over the entire drive as well as in separate driving situations. Therefore, we used the speed profile, which combines those three parameters, as driving style indicator. To compare a specific HAD-style with a participant's MD-style, the area between their speed profiles was calculated as a distance measure between those two driving styles, as illustrated in Figure 22. Therefore, the speed differences between the two driving styles where calculated for each point of measurement and summarised across the entire test track. A larger distance measure corresponds with a less familiar HAD-style in terms of its speed profile.

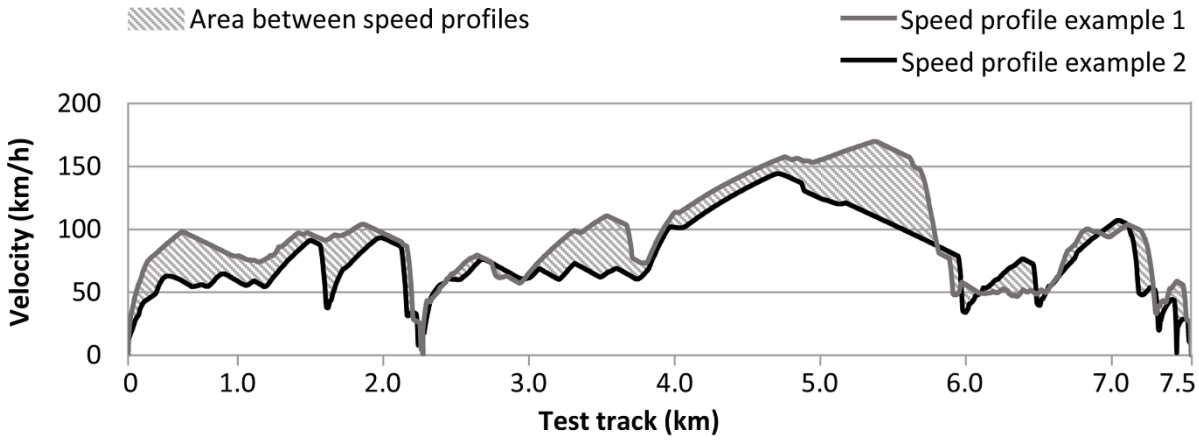

Figure 22. Calculation of the distance between two driving styles based on the area between their speed profiles.

This distance measure was correlated with drivers' ratings of comfort, enjoyment, discomfort, and acceptance across the three highly automated drives in Session 2. Due to the non-normally distributed data (driving style distance, discomfort, acceptance), we calculated Kendall's tau as the correlation coefficient. The results are presented in Table 5 for the entire sample as well as the two age groups.

Table 5

Correlations of Highly Automated Driving Style Familiarity (Area between Speed Profiles of Manual and Highly Automated Drive) with Driving Comfort, Discomfort, Enjoyment, and Acceptance

	Younger drivers (60 drives)		Older drivers (60 drives)		Total sample (120 drives)	
	τ	*p*	τ	*p*	τ	*p*
Driving comfort	-.14	.129	.11	.231	.01	.883
Driving enjoyment	-.04	.705	.35	< .001	.23	.001
Driving discomfort	.20	.037	-.02	.809	.02	.979
Acceptance	-.14	.135	.04	.710	-.01	.940

Across all participants, there was a highly significant correlation between driving enjoyment and driving style distance. Thus, the more different a HAD-style was in comparison to a participant's MD-style, the more enjoyment this participant experienced during the highly automated drive. However, the results of the two age group clarify that this effect only applies to older drivers. For younger drivers, a larger difference between the presented HAD-style and their respective MD-styles significantly corresponded to higher discomfort values indicated during driving.

To specify the effects of speed differences between drivers' respective MD-styles and the presented HAD-styles, we correlated the average speed difference between these driving styles with drivers' ratings of comfort, enjoyment, discomfort, and acceptance across the three highly automated drives in Session 2 (see Table 6). Regarding the average speed difference, a positive value implies that the implemented HAD-style was faster on average than the participant's MD-style. On the other hand, a negative value indicates a slower on average HAD-style.

Table 6

Correlations of the Average Speed Difference between Manual and Highly Automated Driving Style with Driving Comfort, Discomfort, Enjoyment, and Acceptance

	Younger drivers (60 drives)		Older drivers (60 drives)		Total sample (120 drives)	
	τ	*p*	τ	*p*	τ	*p*
Driving comfort	.03	.771	.11	.252	.08	.240
Driving enjoyment	.09	.334	.33	< .001	.31	< .001
Driving discomfort	.15	.101	-.34	.727	.01	.929
Acceptance	.04	.692	.06	.561	.08	.257

None of the correlations between average speed difference and comfort, discomfort, or acceptance were significant. Across all participants, there was a highly significant correlation between driving enjoyment and average speed difference. Thus, the faster a HAD-style was in comparison to a participant's MD-style, the more enjoyment this participant experienced during the highly automated drive. Interestingly, this effect was apparent for older but not for younger drivers.

7.4 Discussion

In a two-stage driving simulator study, performance- and acceptance-related aspects of HAD were investigated. Focusing performance-related aspects on the human perception of the driving performance executed by the automated system, effects of driving automation (Q1) and the familiarity of the highly automated driving style (Q2) on the driving comfort and enjoyment experienced by the drivers were examined. The investigation of acceptance aspects focused on the effects of system experience (Q3) and driving style familiarity (Q5) as well as on the identification of age-specific acceptance barriers (Q4).

Results demonstrate that HAD allows an improvement of affective components of human-automation interaction (Q1). Both younger and older participants' driving comfort as well as older participants' driving enjoyment increased significantly compared to MD. Only a decrease in younger participants' driving enjoyment indicates a negative effect of automation. This finding could support the importance of having active involvement in the driving task to create driving enjoyment (Engeln et al., 2008; Tischler & Renner, 2007). However, it could also be partly explained by the study design, which did not allow for secondary tasks to be completed during the highly automated drives. In a driving simulator study by Beggiato, Hartwich, et al. (2015), participants of the same age group described their experience of automated driving as boring provided they were not allowed to pursue secondary tasks. According to the concept from the questionnaire used to assess driving enjoyment (Engelbrecht, 2013), boredom leads to an absence of enjoyment, which could explain the lower ratings after the highly automated drive. Thus, we expect the decrease in driving enjoyment to be reduced in a realistic setting where drivers are free to choose non-driving activities, such as checking emails or watching a movie, to compensate for the absence of driving-related actions.

Regarding the implemented driving style, the approach to design HAD-manoeuvres to be as familiar to the driver as possible in order to improve driving comfort and enjoyment was evaluated (Q2). Therefore, we compared HAD based on each participants' own manual and thus familiar driving style with randomly chosen other unfamiliar, natural driving styles. We chose this explorative approach based on the lack of preliminary findings on which driving style attributes are relevant for drivers' experience of comfort in HAD and therefore have to be varied to manipulate driving style familiarity based on comfort-relevant parameters. The variance of driving parameters achieved by presenting various unfamiliar driving styles increased the probability to achieve a comfort-relevant manipulation of driving style familiarity. The driving style distance measure provided a method to quantify this driving style familiarity as a basis for the statistical analysis of its effects on the dependent variables.

For all dependent variables, driving style familiarity significantly interacted with drivers' age the same way: while younger drivers preferred a familiar HAD-style, older drivers preferred an unfamiliar HAD-style in terms of comfort, enjoyment, discomfort, and system acceptance. Based on these results, the familiarity approach can be supported at least rudimentary for younger drivers, since these interaction effects comprised higher comfort, lower discomfort, and higher acceptance ratings for familiar compared to unfamiliar HAD-styles in this age group. However, the approach cannot be supported for older drivers, whose MD-styles are characterised by strategies to compensate for age-related impairments of sensory, cognitive, or motor functions. HAD-style preferences of this age group seem to be more influenced by the desire to regain a driving style free from compensation strategies on the

regulation level of the driving task than by a need for familiar driving manoeuvres. Thus, a costly high degree of driving style individualisation does not seem to have a benefit regarding older adults' comfort and enjoyment when driving highly automated. At least for this age group, it is even conceivable that there might be one highly automated driving style perceived as pleasant by the majority of drivers. Detailed specifications of such a driving style need to be addressed in further research.

Quantifying the similarity between MD- and HAD-styles in terms of their speed profiles confirmed the relationship between HAD-style familiarity and the driving discomfort experienced by younger drivers. It further specified older drivers' preferences regarding driving enjoyment. Members of this age group enjoyed HAD the more, the faster the implemented driving style was compared to their MD-styles. It is important to mention that these correlations only apply within the permitted speed limits, which was pointed out by all participants in the interviews. These results support the conclusion concerning older drivers' need to reverse the effects of age-related compensation strategies, such as the reduction of speed, on their driving behaviour. Differences in comfort and acceptance could not be explained by speed profile similarity. This finding supports the additional relevance of driving parameters other than the parameters we combined in the speed profile (overall speed, acceleration intensity, as well as braking intensity and onset), such as lateral position, jerk, or headway distance (Bellem et al., 2016), to drivers' affective reactions to HAD.

The importance of driving comfort and enjoyment for the acceptance of HAD was confirmed by the results of both experimental sessions. Drivers' acceptance of highly automated driving significantly increased after experiencing the technology for the first time in Session 1 (Q3). This increase can be related to their mainly positive evaluation of this drive, as a posteriori acceptance correlated significantly with the comfort and enjoyment ratings reported after this drive. These correlations were replicated in Session 2. Further, acceptance, driving comfort, enjoyment, and discomfort were affected by the same significant interaction of HAD-style and drivers' age. Thus, a more comfortable and joyful driving style was also a more accepted one in each age group (Q5).

While drivers' acceptance of HAD significantly increased after the initial system experience, it was not significantly affected by a subsequent system experience (3). This could be shown based on its commonly used operationalisation in terms of attitudes towards HAD (Van der Laan et al., 1997) and confirmed by further determinants provided by the UTAUT-questionnaire (Venkatesh et al., 2003). Experiencing HAD for a second time did not make a significant difference regarding any of the UTAUT-subscales except for *social influence*, which significantly increased after the repeated system experience. However, this effect may also be explained by the gap of six weeks in between the two

experimental session, which enabled the participants to discuss the experiences they made in Session 1 with their social environment. This may have resulted in a re-evaluation of the degree to which important members of their social environment would approve them driving a highly automated vehicle. Overall, these results parallel previous findings on the nonlinear development of drivers' acceptance of ADAS, depicting a steep growth after the initial system experience and a subsequent stabilisation (Beggiato, Pereira, et al., 2015).

Drivers' age did not significantly affect their system acceptance in terms of attitudes towards HAD. However, significant differences between the two age groups were found for three out of the eight determinants of acceptance provided by the UTAUT (Q4). Older drivers reported a more positive attitude towards using HAD compared to younger drivers, even though they felt less supported by favourable factors, namely their self-efficacy when handling HAD and environmental conditions facilitating its usage. The discrepancy between their positive attitude towards the system usage and their low ratings of encouraging factors could be explained by the high importance older drivers place on driver assistance technology as a compensation strategy for their age-related impairments. Thus, older drivers might show a positive attitude towards using HAD regardless of missing factors encouraging its usage because of their strong need to preserve their individual mobility. In contrast to their usual compensation strategies (see Chapter 2.2.2), HAD could meet this need while simultaneously enhancing older drivers' road safety.

To summarise, HAD is not only an opportunity to improve future traffic safety (Anderson et al., 2016; Lutin et al., 2013; Meyer & Deix, 2014), but also affective components of driving, especially comfort. Therefore, the reduced workload due to the transfer of the complex driving task from the driver to the vehicle (de Winter et al., 2014) seems to affect especially the perceived driving comfort more than the loss of controllability associated with this transfer (Elbanhawi et al., 2015). This corresponds to the findings on ADAS, such as Stop & Go Assistants, showing that drivers appreciated the removal of the uncomfortable driving task (van Driel, Hoedemaeker, & van Arem, 2007). Driving comfort and enjoyment are further modifiable by HAD-style familiarity, with different preferences of different age groups. As assumed, acceptance of HAD was correlated to those affective variables and likewise affected by driving style. Overall, both age groups showed positive attitudes towards using the technology. Although this contradicts the stereotypes of older adults' refusal of innovative technologies (Czaja & Lee, 2012), it is in line with their positive attitudes towards technologies reported for other contexts, such as home, work, or healthcare (Mitzner et al., 2010). Considering the importance of acceptance for the usage of a technology (Regan et al., 2014), these results imply a favourable foundation for the realisation of HAD and the associated benefits regarding traffic safety,

traffic flow, fuel consumption, emissions (Anderson et al., 2016; Meyer & Deix, 2014), and especially older drivers' mobility, well-being, and quality of life (Lutin et al., 2013; Polders et al., 2015).

In addition, the handset control was shown to be a useful online assessment tool of driving discomfort. It produced results comparable to the post-hoc assessment via a questionnaire, but allows for more detailed analyses of situational influences beyond the presented scope. Regarding its validity, it has to be admitted that this measure might not provide a highly selective distinction between driving comfort, perceived safety, and drivers' trust in the automated vehicle's ability to overcome complex traffic situations. However, as outlined in Chapter 2.3.4.3, psychological driving comfort and perceived safety are closely related constructs from a theoretical perspective as well. Thus, psychological driving comfort results from the drivers' trust in the safety of the vehicle and the vehicle guidance (Constantin et al., 2014). Even though these constructs may not be distinguished highly selective by the handset control method, this approach has practical implications for further research and development activities. Identifying uncomfortable situations (that are most likely situations of low perceived safety and/or trust in the automated vehicle) provides the basis for interventions to improve HAD such as driving style adjustment or information design to increase system transparency, which is considered another key factor for successful human-automation interaction (Wolf, 2015).

The results of the study need to be interpreted in consideration of a few methodological limitations. One issue is the operationalisation of HAD through replays of the participants' manual drives along the test track. Due to the limited standardisation of the HAD-styles presented this way, the relationship between driving style familiarity and dependent variables could be confounded by differences in the quality of the participant's driving performance. Limiting the pool of unfamiliar driving styles to the 16 driving styles appearing most plausible for HAD was an attempt to decrease confounding effects of driving performance. However, since all participants' MD-styles were presented as familiar HAD-styles, the variance of driving performance quality may have been larger for the familiar than for the unfamiliar HAD-styles. Therefore, unfamiliar HAD-styles could have appeared more comfortable than familiar HAD-style to some participants due to the preselection of unfamiliar HAD-styles. To avoid this limitation in subsequent studies, future research should focus on methods to extract the characteristics of individual driving styles while keeping the quality of driving performance at a comparable level in order to enable a more standardised approach to compare familiar and unfamiliar HAD-styles.

Another limitation of the study is the fixed-base driving simulator environment that could have affected drivers' perception of comfort and enjoyment. Firstly, the participants may have felt more safe in the driving simulator than they would have felt on road simply based on their awareness that

their driving mistakes as well as failures of the automated driving system would not have had actual safety effects in this environment. Secondly, not having been able to perceive physical motion reduced the participants' perception of driving manoeuvres to visual and acoustic cues. Even though visual cues might be pivotal for drivers' decisions on whether they felt psychologically comfortable or uncomfortable with the parameters (e.g. speed, headway distance, distance to an obstacle at the onset of braking) of a driving manoeuvre, these decisions are intensified by physical vibrations and forces such as jerk (Bellem et al., 2016). Since these physical forces were missing in the fixed-base driving simulator, participants might have experienced less driving discomfort then they would have experienced on road. Further, the missing physical forces might be one explanation for the importance of speed, acceleration intensity as well as braking onset and intensity for the comfort level experienced by the participants (as indicated during the interviews), since these parameters are easily perceptible via visual cues. Summing up these considerations, the missing safety effects of driving failures and the absence of physical motion cues could have influenced participants' situation-specific safety margins (Summala, 2007) and thus produced less conservative driving style preferences than possibly obtained in a field test. There is some first evidence for the validity of the presented results despite these limitations. Firstly, the results of this study were examined for the younger driver group in a subsequent test track study, in which they experienced automated longitudinal driving manoeuvres in a test vehicle under realistic physical conditions. In this setting, the preference for a fast driving style was even more pronounced than in the present driving simulator study (Scherer, Schubert, Dettmann, Hartwich, & Bullinger, 2016). Secondly, drivers' HAD-style preferences for overtaking manoeuvres were investigated in two studies in a dynamic driving simulator by Griesche, Nicolay, Assmann, Dotzauer, and Käthner (2016). The majority of their participants, which correspondent to the younger drivers in our study, preferred their own or a similar driving style in an automated context, as well. Even though these results, which were obtained in different experimental environments, point in the same direction regarding younger drivers' HAD-style preferences, the generalisability of the results presented in this dissertation, especially for older drivers as well as in consideration of the effects of non-driving activities, needs to be addressed in future studies conducted in experimental environments with a higher external validity, such as dynamic driving simulators, test tracks, or on-road traffic.

8 GENERAL DISCUSSION AND CONCLUSIONS

The objective of the present dissertation was to evaluate the potential of emerging in-vehicle technologies as support measures for older drivers. This was realised based on the examples of highly automated driving (HAD) and an Augmented Reality Display (ARD) providing prior information about approaching complex traffic situations. Both are considered suitable for the requirements of this age group, but represent completely different approaches to support the execution of the driving task due to their different levels of driving automation. In three empirical studies, performance- and acceptance-related aspects of both systems were examined for the target group of older drivers (maximum age range: 65-85 years) and a younger comparison group (maximum age range: 25-45 years). The overall aim of these studies was to evaluate whether in-vehicle technologies that appear promising to support older drivers can actually contribute to their individual mobility, which requires an improvement in aspects related to driving performance as well as their acceptance among members of this age group.

The results of these studies as well as their theoretical and practical implications are discussed in Chapter 8.2. Methodological implications are pointed out in Chapter 8.3. However, these results need to be interpreted in consideration of a few methodological limitations, which are presented in Chapter 8.1.

8.1 Limitations

Next to the specific methodological limitation of each study, which have been discussed in the respective chapters (see Chapters 5.4, 6.4, and 7.4), there are a few general limitations associated with the presented research.

The first general limitation concerns the representativeness of the samples acquired for the studies. Even if monetarily compensated, the participation in such studies is obviously based on an individual interest in the evaluated topic or the scientific process. Therefore, the participants may have been more motivated and technology-affine than average drivers. This selection bias represents a generic problem of research, which can only be reduced as best as possible. In the presented studies, this was attempted by excluding drivers with any prior experience with the evaluated systems (including

simulated equivalents) from participation in order to limit the differences between the study samples and the population. Further, it can be argued that some degree of motivation and technology-affinity are likewise required for real customers to take the usage of such systems into consideration at all.

The second general limitation is related to the experimental environment. In general, the settings for the evaluation of in-vehicle technologies can range from laboratory experiments to more realistic naturalistic driving studies. Choosing the most suitable setting out of this continuum involves finding a reasonable offset between the degree of experimental control on the one hand, which decreases with an increasing degree of realism, and the degree of external validity, which increases with an increasing degree of realism (Lietz et al., 2011). To examine the effects of an ARD on drivers' visual processing of complex traffic situations, Study I (see Chapter 5) was designed as a laboratory experiment, since a high degree of experimental control was required. For the evaluation of drivers' acceptance, two driving simulator studies (see Chapter 6 and 7) were conducted in order to provide an extensive impression of ARDs and HAD. Due to their current state of technological development, the driving simulator represented the most suitable opportunity to meet this demand for both systems, based on the inherent opportunities to simulate not yet available systems and to test them without a risk for the participant or other road users. However, considering the limited external validity of the chosen approaches, future a re-evaluations of the presented results in more realistic settings are strongly recommended. As mentioned in Chapter 7.4, first steps in this direction have already been gone by verifying the results of Study III in a subsequent test track study, at least for the younger driver group (Scherer et al., 2016). However, a transfer of this approach to the group of older drivers is still pending.

To narrow the extent of these limitations, it should be considered that the conclusion represented in Chapter 8.2 are not drawn from the absolute values determined in the studies, but from the comparison of the different experimental conditions (e.g. age groups, system conditions). Since all of these conditions were subject to the same methodological limitations, the relative differences between them are supposed to achieve a higher external validity than the absolute values of each condition.

8.2 Theoretical and Practical Implications

The results of the three empirical studies presented in the Chapters 5, 6, and 7 confirm the potential of emerging in-vehicle technologies such as ARDs and HAD to support older drivers from the performance perspective as well as the acceptance perspective.

8.2.1 Performance-Related Aspects

Regarding the performance-related aspects addressed in Study I (Chapter 5), the age-specific ARD improved older drivers' visual processing of complex traffic situations, which is considered a necessary precondition for a safe driving performance (Crundall & Underwood, 2011). After the presentation of prior information about approaching intersections via an ARD, the participants identified a higher percentage of the relevant elements at these intersections without an increase of the required time. On the one hand, this results encourage the approach of supporting older drivers by an age-appropriate presentation of prior information, as realised with the help of an ARD. On the other hand, it also strengthens the theoretical assumption of interactions between the different levels of the driving task established in the Extended Control Model (ECOM; Hollnagel et al., 2003). Supporting drivers on the monitoring level via an ARD positively affected their situation assessment of intersections on the next lower regulation level. According to the ECOM, this improvement will result in a safer driving performance in terms of selecting more appropriate actions of the regulating level (e.g. braking instead of crossing the intersection). This assumption corresponds with previous findings indicating the positive effects of prior information about intersections on older drivers' speed behaviour (Davidse et al., 2009).

Considering the interactive nature of the ECOM, it might even be conceivable that an effective driver support on the monitoring level could also affect the control processes on tracking level of the driving task based on drivers' resources which are set free due to the facilitation on higher levels. Accordingly, the evaluated ARD might even improve older drivers' difficulties on this lowest level, such as their rather inaccurate lane keeping or unstable speed behaviour (Burgard, 2005). However, these theoretical considerations need to be evaluated in future research.

In accordance with the new questions of human-machine interaction arising out of the increasing driving automation, the performance-related aspects of HAD, which were addressed in Study III (Chapter 7), focused on the human perception of the driving performance executed by an automated system. The results of this study confirm the potential of HAD to improve affective components of driving, such as driving comfort and enjoyment, for older drivers. They also indicate the opportunity to further enhance these aspects by means of the implemented driving style. It was assumed that HAD can help older drivers to overcome the limitations associated with strategies that they developed on the targeting level of the driving task to compensate for their age-related functional impairments, such as avoiding demanding driving conditions (e.g. darkness, rain, long distances, unfamiliar areas) and traffic situations (e.g. high-speed roads, complex intersections, rush hour traffic) (Blanchard & Myers, 2010; Eby & Molnar, 2012; Lutin et al., 2013). However, the results of this study point out that these

benefits additionally involve lower levels of the driving task. Thus, older drivers enjoyed HAD especially in cases of a driving style not affected by age-specific compensation strategies on the regulation level, such as their average reduction of driving speed (Burgard, 2005). This was surprising, since the theoretical approach to parametrise a HAD-style familiar to drivers' individual manual driving styles (MD-styles) (Elbanhawi et al., 2015) would have suggested that HAD-styles incorporating these compensation strategies would correspondent to older drivers' individual age-adapted safety margins (Summala, 2007) regarding overall speed, acceleration intensity, and braking intensity and therefore represent the preferred driving styles in this age group. This approach could be confirmed for the group of younger drivers. For older drivers, regaining a driving style unaffected by age-related compensation strategies and therefore a higher level of driving enjoyment seemed to be more important than a familiar driving style. Morris and Guerra (2015) assumed that automated vehicles would have to provide more benefits than just freeing the driver from the driving task to be enjoyable. Re-experiencing a driving style unaffected by age-related deficits could be such a benefit specific to older drivers. This could also explain the missing decrease of driving enjoyment due to the driving automation in this age group, which was found for younger driver. For older drivers, the loss of driving enjoyment due to the missing driving-related activities seems to be outnumber by the enjoyment gain due to the driving style benefit. Accordingly, a costly high degree of driving style individualisation cannot be recommended for older drivers based on the results of Study III, since it would counteract the benefits they could derive from a HAD-style that is unaffected by age-related compensation strategies on the regulation level of the driving task.

The finding that faster driving styles were additionally experienced as more comfortable by older drivers indicates a social component of psychological driving comfort. Thus, being able to drive faster than they would do manually decreases their risk of being perceived as an annoying obstacle by other road users. This explanation was mentioned by several participants of Study III during the interviews that were conducted after the highly automated drives. However, since this assumption does not represent a systematic finding, it needs to be evaluated in future studies.

Considering the importance of independence and mobility for the physiological and psychological well-being at old age (Karthaus & Falkenstein, 2016; Kubitzki & Janitzek, 2009; Lutin et al., 2013), the results of Study III indicate that the contribution of HAD to the quality of life in older adults might be even larger than previously assumed.

To summarise the findings of the performance perspective, both ARDs and HAD can contribute to an improvement in aspects related to driving performance. Interestingly, the majority of these improvements do not only apply to the target group of older drivers, but to the comparison group of

younger drivers as well. The ARD providing prior information about approaching intersections improved younger drivers' visual processing of these intersections to a degree comparable to older drivers' improvement. HAD increased the driving comfort of both age groups to a similar degree, even though it had different effects on their enjoyment of driving. These comparable effects confirm that automotive technologies suggested for older drivers have the potential to support drivers of other age groups as well. This appears plausible, since most of the driving-related difficulties of older drivers are related to traffic situations or driving conditions which are comparably difficult for drivers of all ages (e.g. complex traffic situations).

To conclude, effective approaches to support the independent mobility of older drivers are provided by emerging in-vehicle technologies on different levels of driving automation. Older drivers can benefit from In-Vehicle Information System (IVIS) approaches, such as ARDs, which aid them in executing the driving task manually as well as from HAD, which takes over the monitoring, regulating, and tracking level of the driver task. Apparently, higher levels of automation, such as HAD, provide a rather holistic supportive approach. However, IVIS-approaches, such as ARDs, correspondent more closely with the current development status of in-vehicle technologies and therefore represent and more prompt approach to support older drivers. In addition, future use cases for ARDs even exist in the context of HAD. There, they could be applied to facilitate human-automation interaction, for example by providing information about the system in order to increase transparency. Next to the adaption of the implemented driving style, information design represents another key factor for a successful human-automation interaction (e.g. ensuring driving comfort) in this context (Beggiato, Hartwich, et al., 2015; Wolf, 2015).

8.2.2 Acceptance-Related Aspects

The evaluation of acceptance-related aspects of ARDs an HAD involved general preconditions for their usage as well as system-specific, design-related preferences.

Older drivers' a priori acceptability in terms of their attitudes towards both systems was positive, which was higher than expected considering their general acceptance of new technologies (Czaja & Lee, 2012; Lerner et al., 2008). The initial system experience increased system acceptance. Regarding ARD, this increase did not turn out to be significant, even though a clear tendency was apparent at least for the short version of the ARD. However, this could be partly traced back to the between-subjects design of the study and should therefore be re-examined in subsequent studies using a within-subjects design.

Interestingly, older drivers reported a significantly higher acceptance of the system than younger drivers, indicating the suitability of the age-specific ARD for the specific requirements of this age group.

The effect of the initial system experience on older drivers' acceptance was significant for HAD, which is in line with previous findings on the acceptance of different Advanced Driver Assistance System (ADAS) (Beggiato, Pereira, et al., 2015; Brookhuis et al., 2009; Trösterer et al., 2014). This result emphasises the importance of a positive and realistic initial HAD-experience on drivers' acceptance. Due to the significant increase and rapid stabilisation of acceptance after the initial system experience, the risk of overreliance and thus misuse of HAD should be considered. Research in the fields of aviation and shipping automation provides evidence of how overreliance can lead to fatal consequences such as crashes or loss of navigation (Lee & Sanquist, 2000; Sparaco, 1995). Furthermore, research in medication management systems (Ho, Wheatley, & Scialfa, 2005) and flight simulations (Hardy, Mouloua, Molloy, Dwivedi, & Parasuraman, 1995) indicates that especially older adults tend to overly rely on automated systems, fail to recognise and correct system errors, and thus continue with an inappropriate system usage. In the context of HAD, the risk of an inappropriate reaction to system failures might be intensified by older drivers' preferences for driving styles unaffected by age-related compensation strategies on the regulation level of the driving task. These strategies, such as the overall reduction of speed, are used by older drivers to adapt their MD-styles to age-related declines of sensory, cognitive, and motor functions. In contrast, a HAD-style that does not incorporate such compensation strategies will cause higher demands on an adequate driver's reaction to system errors, such as shorter available time windows for a reaction due to a higher overall speed, which might exceed older drivers' capabilities. Therefore, future research should focus on age-specific design requirements regarding the human-machine interaction in the context of HAD to provide an adequate system experience from the initial phase to an ongoing appropriate usage.

Next to the different designs of Study II and Study III, it is possible that the stronger effect of system experience in the context of HAD is connected to the higher level of driving automation. Thus, older drivers' a priori hesitation might be higher regarding HAD than an ARD, because it might appear more conceivable to use an IVIS than to let an automated system take over full vehicle control. This assumptions is strengthened by older drivers' higher a priori acceptability of the ARD than of HAD, which in turn allows for a greater increase of acceptance after actually experiencing the system.

Regarding drivers' age, both the ARD and HAD were evaluated in a mainly positive manner by both older and younger drivers. As stated in Chapter 8.2.1, this appears plausible out of the performance perspective. However, this does not obviously have to be reflected in acceptance-related aspects, since technologies specifically designed for older adults, such as the ARD, are at risk of being associated with

a negative image among younger age groups (Färber, 2000). In the case of the two systems evaluated in this dissertation, findings suggest that both ARDs and HAD would be accepted by different age groups, which correspondents with the results out of the performance perspective.

Despite the comparable overall acceptance of the ARD and HAD among younger and older drivers, a very interesting pattern was revealed for both systems regarding further aspects of acceptance, which were provided by the Unified Theory of Acceptance and Use of Technology (UTAUT; Venkatesh et al., 2003). Compared to members of the younger group, older drivers reported a significantly more positive attitude towards using both systems, even though they evaluated themselves as being less supported by factors encouraging system usage. In detail, these factors include their own self-efficacy regarding system operation as well as environmental factors facilitating the system usage, such as a technical infrastructure. Revealing this discrepancy for two systems at very different stages of driving automation, such as ARDs and HAD, suggests the existence of underlying general aspects of older adults' acceptance of in-vehicle technologies. Thus, older drivers might show a positive attitude towards using these technologies regardless of missing factors encouraging their usage because of their strong need to preserve their individual mobility. This is supported by previous findings revealing the importance of individual mobility on older adults' well-being and quality of life (Lutin et al., 2013; Polders et al., 2015). In contrast to their usual strategies to compensate for their driving-relevant impairments, emerging in-vehicle technologies could meet this need while simultaneously enhancing older drivers' road safety.

From a theoretical point of view, models that aim at explaining drivers' acceptance of vehicle technologies could benefit from a few extensions, based on these findings, especially if they are focusing on older drivers. Thus, including factors such as the need for individual mobility and the availability of alternative measures to fulfil this need could contribute to the prediction of older drivers' usage of particular systems. Considering the HAD-specific results of Study III, the enjoyment of using a technology could be another predictor. This aspect has meanwhile been addressed in the UTAUT2, in which the original UTAUT (Venkatesh et al., 2003) has been extended by adding *hedonic motivation*, "defined as the fun or pleasure derived from using a technology", as further predictor of system usage (Venkatesh et al., 2012, p. 161). Therefore, the UTAUT2 could represent a suitable theoretical starting point for further investigations of older drivers' acceptance of vehicle technologies.

Practically, these findings indicate potential age-specific acceptance barriers, which need to be taken into account in order to facilitate a successful market introduction of new in-vehicle technologies. Thus, employing strategies to improve older drivers' self-efficacy and facilitating conditions regarding

system usage, such as providing training programs or information about local support infrastructures, could additionally encourage the actual usage of beneficial technologies among older drivers.

To conclude, assessing older drivers' acceptance of ARDs and HAD on the basis of experiencing these systems in the driving simulator provided first extensions of previous findings in this field, which were mainly limited to surveys on a priori acceptability. According to this extended state of knowledge, emerging in-vehicle technologies can be classified as systems which older drivers perceive as useful measures to preserve their individual mobility and therefore will be willing to use, when available. However, in order to generate more specific insights, future research needs to extend the incorporated system experience in parallel with the progressing technological development of these systems.

8.3 Methodological Implications

Next to well-established and validated methodological approaches and instruments, the evaluation of both systems involved the application of new procedures for the assessment of relevant dependent variables. In Study I, drivers' visual processing performance at intersections was assessed using the Surrogate Complexity Method (SCM) (see Chapter 5.2.3). Study III included a handset control for the continuous online assessment of driving discomfort (see Chapter 7.2.4). Both approaches produced findings that corresponded with previous research and could be validated at least rudimentary in the presented studies. However, prior to their application to future research activities, the psychometric criteria of these methods need to be further evaluated. Given their psychometric appropriateness, both method provide several possibilities for the data collection and analysis of future studies.

In addition to the static stimulus material employed in Study I, the SCM can be applied to driving simulations, as surrogates can also be added to dynamic driving environments instead of static pictures. The order in which the participants name surrogates could be analysed as an additional dependent variable. In this case, the SCM would serve as a low-resolution eye-tracking measure by revealing the visual strategies drivers used to gain an overview of traffic situations. Compared to the eye-tracking method, the SCM would be more economical and exclude limitations such as participants processing traffic elements without focusing directly on them (Underwood & Everatt, 1992) or focusing directly on a stimulus without consciously perceiving its presence (looked-but-failed-to-see-errors; e.g. Hills, 1980). Thematically, this method could address a variety of research topics, such as the effects of IVIS and ADAS, the driver distraction potential of stimuli inside (e.g. entertainment systems,

secondary tasks) or outside (e.g. advertising) of the vehicle, or the necessary time required for the driver to takeover in highly automated vehicles.

The handset control provides the basis for interventions to improve HAD, for example by driving style adjustment or information design. The online detection of driver discomfort during HAD represents a prerequisite for a situation-adaptive application of such intervention. In this context, the handset control represents a research tool, which can applied to the identification and evaluation of discomfort indicators, such as the driver's facial expressions or gestures, that could be used on-road to identify cases of discomfort during HAD and accordingly initiate countermeasures.

Considering the possibilities for the application of the SCM and the handset control, these measures could extend the range of methods deployed by future research activities on the topics pointed out in Chapter 8.2. Thereby, they could contribute to the development and evaluation of emerging in-vehicle technologies, which represent a suitable approach to support an independent and safe mobility of older drivers.

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APPENDIX

Appendix A: German Adaption of the UTAUT-Questionnaire to an Augmented Reality Display (Study II)

Original items	Adapted items	
	English	German
Performance expectancy		
I would find the system useful in my job.	I would find the display useful in my driving.	Ich fände die Anzeige nützlich beim Autofahren.
Using the system enables me to accomplish tasks more quickly.	Using the display would enable me to recognize intersections more quickly.	Die Anzeige würde es mir ermöglichen, Kreuzungen schneller zu überblicken.
Using the system increases my productivity.	Using the display would increase my driving performance.	Mit der Anzeige könnte ich besser Auto fahren.
If I use the system, I will increase my chances of getting a raise.	If I would use the display, I would decrease my risk of being involved in an accident.	Mit der Anzeige könnte ich das Risiko senken, an einem Unfall beteiligt zu sein.
Effort expectancy		
My interaction with the system would be clear and understandable.	The display is clear and understandable for me.	Die Anzeige ist für mich klar und verständlich.
It would be easy for me to become skillful at using the system.	It would be easy for me to get used to driving with the display.	Ich könnte mich leicht daran gewöhnen, die Anzeige beim Autofahren zu nutzen.
I would find the system easy to use.	I would find the display easy to use.	Ich finde, die Anzeige ist einfach zu nutzen.
Learning to operate the system is easy for me.	Learning to understand the display would be easy for me.	Es wäre leicht für mich, die Verwendung der Anzeige zu erlernen.
Attitude towards using the technology		
Using the system is a bad/good idea.	Using the display is a good idea.	Es ist eine gute Idee, die Anzeige zu verwenden.

The system makes work more interesting.	The display makes driving more interesting.	Die Anzeige macht das Autofahren interessanter.
Working with the system is fun.	Driving with the display is fun.	Es macht Spaß, mit der Anzeige Auto zu fahren.
I like working with the system.	I like driving with the display.	Ich mag es, mit der Anzeige Auto zu fahren
Social influence		
People who influence my behavior think that I should use the system.	People who influence my behavior think that I should use the display.	Personen, die Einfluss auf mein Verhalten haben, würden es begrüßen, wenn ich die Anzeige verwenden würde.
People who are important to me think that I should use the system.	People who are important to me think that I should use the display.	Personen, die mir wichtig sind, würden es begrüßen, wenn ich die Anzeige verwenden würde.
The Senior management of this business has been helpful in the use of the system.	People in my environment would be helpful in the use of the display.	Personen in meinem Umfeld würden mich bei der Nutzung einer solchen Anzeige unterstützen.
The organization has supported the use of the system.	People in my environment would support the use of the display.	Personen in meinem Umfeld würden die Nutzung einer solchen Anzeige befürworten.
Facilitating conditions		
I have the resources necessary to use the system.	I have the resources necessary to use the display.	Ich hätte die notwendigen Ressourcen, um die Anzeige nutzen zu können.
I have the knowledge necessary to use the system.	I have the knowledge necessary to use the display.	Ich verfüge über das notwendige Wissen, um die Anzeige nutzen zu können.
The system is not compatible with other systems I use.	The display is not compatible with other in-vehicle technologies I use.	Die Anzeige könnte nicht gemeinsam mit den anderen Systemen in meinem Auto verwendet werden.
A specific person (or group) is available for assistance with system difficulties.	A specific person (or group) would be available for assistance with display difficulties.	Es gäbe in meinem Umfeld Ansprechpartner, an die ich mich bei Schwierigkeiten mit dem Display wenden könnte.
Self-efficacy		
I could complete a job or task using the system, if there was no one around to tell me what to do as I go.	I could use the display, if there was no one around to tell me what to do.	Ich könnte mit der Anzeige Auto fahren, auch wenn niemand dabei wäre, der mir dabei helfen könnte.

I could complete a job or task using the system, if I could call someone for help if I got stuck.	I could use the display, if I could call someone for help if I got stuck.	Ich könnte mit der Anzeige Auto fahren, wenn ich jemanden anrufen könnte, sobald ich Probleme damit hätte.
I could complete a job or task using the system, if I had a lot of time to complete the job for which the software was provided.	I could use the display, if I had enough time to get used to it.	Ich könnte mit der Anzeige Auto fahren, wenn ich sie in Ruhe ausprobieren könnte
I could complete a job or task using the system, if I had just the built-in help facility for assistance.	I could use the display, if I had just a system handbook for assistance.	Ich könnte mit der Anzeige Auto fahren, auch wenn ich nur ein Handbuch zur Hilfe hätte.
Anxiety		
I feel apprehensive about using the system.	I feel apprehensive about using the display.	Es würde mir Sorgen machen, die Anzeige zu verwenden.
It scares me to think that I could lose a lot of information using the system by hitting the wrong key.	It scares me to think that I could overlook important traffic information using the display.	Ich hätte Angst, wichtige Informationen im Straßenverkehr zu übersehen, wenn ich die Anzeige verwenden würde.
I hesitate to use the system for fear of making mistakes I cannot correct.	I hesitate to use the display for fear of making mistakes.	Ich würde zögern, die Anzeige im Straßenverkehr zu verwenden, aus Angst, einen Fehler zu machen.
The system is somewhat intimidating to me.	The display is somewhat intimidating to me.	Die Anzeige schüchtert mich etwas ein.
Behavioral intention to use the system		
I intend to use the system in the next <n> months.	I intend to use the display when it does become available.	Ich würde solch eine Anzeige nutzen, wenn sie verfügbar wäre.
I predict I would use the system in the next <n> months.	I predict I would use the display when it does become available.	Ich könnte mir vorstellen, solch eine Anzeige zu nutzen, wenn sie verfügbar wäre.
I plan to use the system in the next <n> months.	I plan to use the system when it does become available.	Ich habe vor, solch eine Anzeige zu nutzen, wenn sie verfügbar ist.

Appendix B: German Adaption of the UTAUT-Questionnaire to Highly Automated Driving (Study III)

Original items	Adapted items	
	English	German
Performance expectancy		
I would find the system useful in my job.	I would find highly automated driving useful.	Ich fände hochautomatisiertes Fahren nützlich.
Using the system enables me to accomplish tasks more quickly.	Driving highly automated would enable me to be more mobile.	Hochautomatisiertes Fahren würde mich mobiler machen.
Using the system increases my productivity.	Driving highly automated would increase my driving performance.	Mit einem hochautomatisierten Fahrzeug wären Fahrfehler weniger wahrscheinlich.
If I use the system, I will increase my chances of getting a raise.	If I would drive highly automated, I would decrease my risk of being involved in an accident.	Mit einem hochautomatisierten Fahrzeug könnte ich das Risiko senken, an einem Unfall beteiligt zu sein.
Effort expectancy		
My interaction with the system would be clear and understandable.	The driving behaviour of a highly automated vehicle would be clear and understandable to me.	Das Fahrverhalten eines hochautomatisierten Fahrzeuges wäre für mich klar und verständlich.
It would be easy for me to become skillful at using the system.	It would be easy for me to get used to highly automated driving.	Es wäre leicht für mich, mich an hochautomatisiertes Fahren zu gewöhnen.
I would find the system easy to use.	I would find highly automated driving easy to use.	Ich finde, hochautomatisiertes Fahren ist einfach zu nutzen.
Learning to operate the system is easy for me.	Learning to operate a highly automated vehicle would be easy for me.	Es wäre leicht für mich, die Verwendung eines hochautomatisierten Fahrzeuges zu erlernen.
Attitude towards using the technology		
Using the system is a bad/good idea.	Driving highly automated is a good idea.	Es ist eine gute Idee, hochautomatisiert zu fahren.
The system makes work more interesting.	Highly automated driving makes driving more interesting.	Hochautomatisiertes Fahren macht das Autofahren interessanter.

Working with the system is fun.	Driving highly automated is fun.	Es macht Spaß, hochautomatisiert zu fahren.
I like working with the system.	I like driving highly automated.	Ich mag es, hochautomatisiert zu fahren.
Social influence		
People who influence my behavior think that I should use the system.	People who influence my behavior think that I should drive highly automated.	Personen, die Einfluss auf mein Verhalten haben, würden es begrüßen, wenn ich hochautomatisiert fahren würde.
People who are important to me think that I should use the system.	People who are important to me think that I should drive highly automated.	Personen, die mir wichtig sind, würden es begrüßen, wenn ich hochautomatisiert fahren würde.
The Senior management of this business has been helpful in the use of the system.	People in my environment would be helpful in the use of a highly automated vehicle.	Personen in meinem Umfeld würden mich bei der Nutzung eines hochautomatisierten Fahrzeugs unterstützen.
The organization has supported the use of the system.	People in my environment would support the use of a highly automated vehicle.	Personen in meinem Umfeld würden die Nutzung eines hochautomatisierten Fahrzeuges befürworten.
Facilitating conditions		
I have the resources necessary to use the system.	I have the resources necessary to use a highly automated vehicle.	Ich hätte die notwendigen Ressourcen, um hochautomatisiert Fahren zu können.
I have the knowledge necessary to use the system.	I have the knowledge necessary to drive highly automated.	Ich verfüge über das notwendige Wissen, um hochautomatisiert fahren zu können.
The system is not compatible with other systems I use.	Highly automated driving is not compatible with other in-vehicle technologies I use.	Hochautomatisiertes Fahren wäre nicht kompatibel mit anderen Fahrzeugtechnologien, die ich gern verwende.
A specific person (or group) is available for assistance with system difficulties.	A specific person (or group) would be available for assistance difficulties regarding a highly automated vehicle.	Es gäbe in meinem Umfeld Ansprechpartner, an die ich mich bei Schwierigkeiten mit einem hochautomatisierten Fahrzeug wenden könnte.
Self-efficacy		
I could complete a job or task using the system, if there was no one around to tell me what to do as I go.	I could use a highly automated vehicle, if there was no one around to tell me what to do.	Ich wäre in der Lage, ein hochautomatisiertes Fahrzeug zu nutzen, auch wenn niemand dabei wäre, der mir dabei helfen würde.

I could complete a job or task using the system, if I could call someone for help if I got stuck.	I could use a highly automated vehicle, if I could call someone for help if I got stuck.	Ich wäre in der Lage, ein hochautomatisiertes Fahrzeug zu nutzen, wenn ich jemanden anrufen könnte, sobald ich Probleme damit hätte.
I could complete a job or task using the system, if I had a lot of time to complete the job for which the software was provided.	I could use a highly automated vehicle, if I had enough time to get used to it.	Ich wäre in der Lage, ein hochautomatisiertes Fahrzeug zu nutzen, wenn ich es in Ruhe ausprobieren könnte.
I could complete a job or task using the system, if I had just the built-in help facility for assistance.	I could use a highly automated vehicle, if I had just a system handbook for assistance.	Ich wäre in der Lage, ein hochautomatisiertes Fahrzeug zu nutzen, auch wenn ich nur ein Handbuch zur Hilfe hätte.
Anxiety		
I feel apprehensive about using the system.	I feel apprehensive about driving highly automated.	Es würde mir Sorgen machen, hochautomatisiert zu fahren.
It scares me to think that I could lose a lot of information using the system by hitting the wrong key.	It scares me to think that system errors could occur while driving highly automated.	Ich hätte Angst, dass beim hochautomatisierten Fahren Systemfehler auftreten könnten.
I hesitate to use the system for fear of making mistakes I cannot correct.	I hesitate to drive highly automated for fear of making mistakes.	Ich würde zögern, hochautomatisiert zu fahren, aus Angst, einen Fehler zu machen.
The system is somewhat intimidating to me.	Highly automated driving is somewhat intimidating to me.	Hochautomatisiertes Fahren schüchtert mich etwas ein.
Behavioral intention to use the system		
I intend to use the system in the next <n> months.	I intend to drive highly automated when it does become available.	Ich würde ein hochautomatisiertes Fahrzeug nutzen, wenn es verfügbar wäre.
I predict I would use the system in the next <n> months.	I predict I would drive highly automated when it does become available.	Ich könnte mir vorstellen, ein hochautomatisiertes Fahrzeug zu nutzen, wenn es verfügbar wäre.
I plan to use the system in the next <n> months.	I plan to drive highly automated when it does become available.	Ich habe vor, ein hochautomatisiertes Fahrzeug zu nutzen, wenn es verfügbar ist.

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Education

2011 – 2017 **Doctoral studies**
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2005 – 2011 **Psychology major**
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Research Projects

2016 – ComfyDrive **–** Integration von 3D-Fahrzeuginnenraum- und -Umfelderfassung zur Steigerung des Nutzererlebnisses beim hochautomatisierten Fahren [Integration of 3D-detection of vehicle interior and environment for the improvement of driving comfort in highly automated driving]

2015 – 2016 DriveMe **–** Fahrstilmodellierung im hochautomatisierten Fahren auf Basis der Fahrer-Fahrzeug-Interaktion [Driving style modelling in highly automated driving based on the driver-vehicle-interaction]

2014 – 2015 Informationsbedarf in verschiedenen Automatisierungsstufen [Information needs at different levels of driving automation]

2011 – 2014 ViFa 65plus – Visuelle Fahrassistenz für ältere Menschen [Visual driver assistance for senior citizens]

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EIDESSTATTLICHE ERKLÄRUNG

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbstständig verfasst habe und dabei keine anderen als die angegebenen Hilfsmittel verwendet habe.

Franziska Hartwich

Chemnitz, 28.04.2017