Göteborg, Sweden 2013

Adaptive Eyes

Driver Distraction and Inattention Prevention Through Advanced Driver Assistance Systems and Behaviour-Based Safety

Dissertation

submitted in fulfillment of the requirements for the degree of doctor and title

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to the Faculty of Behavioural and Social Sciences of the Chemnitz University of Technology

from

CLAUDIA ANDREA WEGE,

born 13.08.1984 in Burgstädt.

CHEMNITZ UNIVERSITY
OF TECHNOLOGY

Göteborg, Schweden 2013

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Τα πάντα ρει

panta rhei

change is constant

ABSTRACT

Technology pervades our daily living, and is increasingly integrated into the vehicle – directly affecting driving. On the one hand technology such as cell phones provoke driver distraction and inattention, whereas, on the other hand, Advanced Driver Assistance Systems (ADAS) support the driver in the driving task. The question is, can a driver successfully adapt to the ever growing technological advancements?

Thus, this thesis aimed at improving safe driver behaviour by understanding the underlying psychological mechanisms that influence behavioural change. Previous research on ADAS and human attention was reviewed in the context of driver behavioural adaptation. Empirical data from multiple data sources such as driving performance data, visual behaviour data, video footage, and subjective data were analyzed to evaluate two ADAS (a brake-capacity forward collision warning system, B-FCW, and a Visual Distraction Alert System, VDA-System).

Results from a field operational test (EuroFOT) showed that brake-capacity forward collision warnings lead to *immediate attention allocation* toward the roadway and drivers hit the brake, yet change their initial response later on by directing their eyes toward the warning source in the instrument cluster. A similar *phenomenon of drivers changing initial behaviour* was found in a driving simulator study assessing a Visual Distraction Alert System. Analysis showed that a Visual Distraction Alert System successfully assists drivers in redirecting attention to the relevant aspects of the driving task and significantly improves driving performance. The effects are discussed with regard to behavioural adaptation, calibration and system acceptance. Based on these findings a novel assessment for human-machine-interaction (HMI) of ADAS was introduced.

Based on the contribution of this thesis and previous best-practices, a *holistic* safety management model on accident prevention strategies (before, during and after driving) was developed. The *DO-IT BEST Feedback Model* is a comprehensive feedback strategy including driver feedback at various time scales and therefore is expected to provide an added benefit for distraction and inattention prevention.

The central contributions of this work are to advance research in the field of traffic psychology in the context of attention allocation strategies, and to improve the ability to design future safety systems with the human factor in focus.

The thesis consists of the introduction of the conducted research, six publications in full text and a comprehensive conclusion of the publications.

In brief this thesis intends to improve safe driver behaviour by understanding the underlying psychological mechanisms that influence behavioral change, thereby resulting in more attention allocation to the forward roadway, and improved vehicle control.

Keywords: Attention, distraction, behavioural adaptation to Advanced Driver Assistance Systems (ADAS), Visual Distraction Alert System, Forward Collision Warning System, behaviour-based safety, naturalistic driving study, eye-movements, visual behavior, system acceptance, countermeasures

ZUSAMMENFASSUNG

Technologie durchdringt unser tägliches Leben und ist zunehmend integriert in Fahrzeuge – das Resultat sind veränderte Anforderungen an Fahrzeugführer. Einerseits besteht die Gefahr, dass er durch die Bedienung innovativer Technologien (z.B. Mobiltelefone) unachtsam wird und visuell abgelenkt ist, andererseits kann die Nutzung von Fahrerassistenzsystemen die den Fahrer bei der Fahraufgabe unterstützten einen wertvollen Beitrag zur Fahrsicherheit bieten. Die steigende Aktualität beider Problematiken wirft die Frage auf: „Kann der Fahrer sich erfolgreich dem ständig wachsenden technologischen Fortschritt anpassen?“

Das Ziel der vorliegenden Arbeit ist der Erkenntnisgewinn zur Verbesserung des Fahrverhaltens indem der Verhaltensänderungen zugrunde liegende psychologische Mechanismen untersucht werden. Eine Vielzahl an Literatur zu Fahrerassistenzsystemen und Aufmerksamkeitsverteilung wurde vor dem Hintergrund von Verhaltensanpassung der Fahrer recherciert. Daten mehrerer empirischer Quellen, z. B. Fahrverhalten, Blickbewegungen, Videomitschnitte und subjektive Daten dienten zur Datenauswertung zweier Fahrerassistenzsysteme.

Im Rahmen einer Feldstudie zeigte sich, dass Bremskapazitäts-Kollisionswarnungen zur sofortigen visuellen Aufmerksamkeitsverteilung zur Fahrbahn und zum Bremsen führen, Fahrer allerdings ihre Reaktion anpassen indem sie zur Warnanzeige im Kombinationsinstrument schauen. Ein anderes Phänomen der Verhaltensanpassung wurde in einer Fahrsimulatorstudie zur Untersuchung eines Ablenkungswarnsystems, das dabei hilft die Blicke von Autofahrern stets auf die Straße zu lenken, gefunden. Diese Ergebnisse weisen nach, dass solch ein System unterstützt achtsamer zu sein und sicherer zu fahren.

Die vorliegenden Befunde wurden im Zusammenhang zu Vorbefunden zur Verhaltensanpassung zu Fahrerassistenzsystemen, Fahrerkalibrierung und Akzeptanz von Technik diskutiert. Basierend auf den gewonnenen Erkenntnissen wurde ein neues Vorgehen zur Untersuchung von Mensch-Maschine-Interaktion eingeführt. Aufbauend auf den Resultaten der vorliegenden Arbeit wurde ein ganzheitliches Modell zur Fahrsicherheit und -management, das *DO-IT BEST Feedback Modell*, entwickelt. Das Modell bezieht sich auf multitemporale Fahrer-Feedbackstrategien und soll somit einen entscheidenden Beitrag zur Verkehrssicherheit und dem Umgang mit Fahrerunaufmerksamkeit leisten.

Die zentralen Beiträge dieser Arbeit sind die Gewinnung neuer Erkenntnisse in den Bereichen der Angewandten Psychologie und der Verkehrspsychologie in den Kontexten der Aufmerksamkeitsverteilung und der Verbesserung der Gestaltung von Fahrerassistenzsystemen fokusierend auf den Bediener.

Die Dissertation besteht aus einem Einleitungsteil, drei empirischen Beiträgen sowie drei Buchkapiteln und einer abschliessenden Zusammenfassung.

Schlagwörter: Aufmerksamkeitsverteilung, Ablenkung, Verhaltensanpassung durch Fahrerassistenzsysteme, Ablenkungswarnsystem, Kollisionswarnsystem, verhaltensbasierende Verkehrssicherheit, Feldstudie, Blickbewegungen, Akzeptanz von Systemen, Gegenmaßnahmen

LIST OF INCLUDED PUBLICATIONS

This thesis is based on the work contained in the following publications, referred to by Roman numerals in the text.

Paper I

Wege, C., Pereira, M., Victor, T., & Krems, J. (2013). Behavioural adaptation in response to driving assistance technologies - A literature review. In A. Stevens, C. Brusque, & J. Krems (Eds). *Driver adaptation to information and assistance systems*. IET published book. ISBN: 978-1-84919-639-0; E-ISBN: 978-1-84919-640-6.

Paper II

Wege, C., Will, S., & Victor, T. (2013). Eye movement and brake reactions to real world brake-capacity forward collision warnings — A naturalistic driving study. *Accident Analysis and Prevention, 58*(9), 259-270. DOI: 10.1016/j.aap.2012.09.013.

Paper III

Wege, C., & Victor, T. (in review). Subjective vs actual performance improvement with a real-time Visual Distraction Alert System. *Human Factors*.

Paper IV

Wege, C., & Victor, T. (in review). Safer Distraction – Assisting Distracted Drivers with a Visual Distraction Alert System. *Human Factors*.

Paper V

Wege, C., & Victor, T. (2013). Distraction and Inattention Prevention by Combining Behaviour-Based Safety with Advanced Driver Assistance Systems. In A. Stevens, C. Brusque, & J. Krems (Eds). *Driver adaptation to information and assistance systems*. IET published book. ISBN: 978-1-84919-639-0; E-ISBN: 978-1-84919-640-6.

Paper VI

Wege, C., & Victor, T. (2013). *The DO-IT BEST Feedback Model - Distracted Driver Behaviour Management and Prevention Before, While And After Driving*. Proceedings of the Third International Conference on Driver Distraction and Inattention. Göteborg, Sweden.
Full text also accepted for publication In M Regan, J Lee, & T Victor (Eds). *Driver Distraction and Inattention. Advances in Research and Countermeasures Volume II*. Ashgate Publishing Limited. 2013.

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Claudia Wege, Göteborg October, 2013

PREVIOUSLY PUBLISHED WORK

Partial results of the thesis have been previously published in the following context.

Journal articles

Ahlström, C., Victor, T., Wege, C., & Steinmetz, E. (2012). Processing of Eye/Head-Tracking Data in Large-Scale Naturalistic Driving Data Sets. *Intelligent Transportation Systems, IEEE Transactions, 13*(2), 553-564.

Public Deliverables

Wege, C., Victor, T., Brusque, C., Bueno Garcia, M., Beggiato, M., Berthon-Donk, V., Dotzauer, M., Gouy, M., Hajek, W., Haupt, J., Pereira, M., & Piccinini, G. (2010). *ADAS within the ADAPTATION project - Function selection, benchmark, behavioural adaptation effects and conceptual framework development*. Marie Curie Adaptation Project. EU 7th Framework. Humanist. Public deliverable. Available on www.adaptation-itn.eu.

Conferences

Wege, C., & Victor, T. (2013). *The DO-IT BEST Feedback Model - Distracted Driver Behaviour Management and Prevention Before, While And After Driving*. The Third Driver Distraction and Inattention Conference. Göteborg, Sweden. Oral presentation.

Wege, C., & Victor, T. (2012). *Behavioural adaptation to Visual Distraction Alert Systems.* ICTTP - International Conference on Transport and Traffic behaviour. Groningen, The Netherlands. Oral presentation.

Wege, C., Will, S., & Victor, T. (2012). *Visual behaviour to real-world forward collision warning systems - a EuroFOT study investigating HMI-Design.* ICTTP - International Conference on Transport and Traffic behaviour. Groningen, The Netherlands. Oral presentation.

Wege, C., & Victor, T. (2012). *“OLD HABITS DON`T DIE HARD” - Mitigating visual distraction by a Visual Distraction Alert System*. AHFE - International Conference on Applied Human Factors and Ergonomics. San Francisco, USA. Poster presentation.

Wege, C., & Victor, T. (2012). *Visual Distraction Alert Systems - do they alter driver distraction?* HUMANIST Conference - European Conference on Human Centered Design for Intelligent Transport Systems. Valencia, Spain. Poster presentation.

Wege, C., & Victor, T. (2012). *Adaptivt visuellt beteende.* VTI Transportforum Konferensen. Linköping, Sweden. Oral presentation.

Wege, C., & Victor, T. (2011). *Assisting drivers with a Visual Distraction Alert System.* The Second Driver Distraction and Inattention Conference. Göteborg, Sweden. Oral presentation.

Wege, C., & Victor, T. (2010). *What the eyes “tell” us while driving. How eye tracker providers and eye tracking specialists in research benefit from each other’s work.* Marie Curie Conference. Torino, Italy. Oral presentation.

PREFACE

I was fortunate to be able to conduct my PhD research within the unique European Seventh Framework project ADAPTATION (Marie Curie Training network of excellence) – a research consortium of different academic and industrial partners across European countries. The scientific work was devoted to study drivers' responses to Advanced Driver Assistance Systems (ADAS), drivers' underlying psychological processes and the process development over time. My research was carried out at Volvo Group Trucks Technology in Gothenburg, Sweden from 2010 to 2013. Volvo has a strong focus on accident prevention research with *safety* being its core mission. Volvo's ultimate goal is *zero fatalities and serious injuries* with Volvo Group products in the future. I was inspired by a vision of a collision-free future as a guiding principle of my PhD work. And thus, my vision became to analyze the 'drivers vision', meaning the drivers visual attention allocation.

Despite the recent popularity to study driver behavioural adaptation to ADAS, it is not a well-defined research area. This motivated the initial paper (*paper I),* a literature review paper that will hopefully fuel the debate on clearer terminology and definitions. Thereafter, an analysis of naturalistic driver responses to an on-market ADAS followed *(paper II)*. This analysis involved annotating video footage from real world driving scenarios collected over several months in the European Field Operational Test study EuroFOT. As the work progressed, the focus of my research became the prevention of *driver distraction and inattention* through ADAS and behaviour-based safety. Driver distraction and inattention have evolved to be dangerous "epidemics" in our society. There is a need to investigate the safety potential of countermeasures. One countermeasure is a Visual Distraction Alert System that detects and warns distracted drivers whenever they look away from the road for too long and/or too often. The behaviour of professional truck drivers equipped with such a system (different warning algorithms along with false warnings) was examined in a controlled driving simulator experiment. The results in terms of drivers' acceptance and perceived performance over time (*paper III*) as well as on drivers' visual behaviour and driving performance behaviour (*paper IV*) are reported in two separate empirical papers. One of the main findings is that a Visual Distraction Alert System both enhances driver attention on-road and improves driving performance. However, in order to improve the effectiveness, behaviour-based safety programs should be used as a complement. Until today, the ADAS approach and the behaviour-based safety approach have largely been used independently from each other. *Paper V* shows how both approaches can be combined and applied to further enhance driver attention on-road, and to improve safety behavior in general.

Overall, while investigating the humans' adaptation to changes, I became certain of the *humans' ability to adjust to new situations*. This ability is essential because "*change is constant*" – "*panta rhei*". Ultimately, our *ability to modify behaviour to suit new conditions* became the backbone of this thesis and is therefore addressed in each paper.

Based on the conducted research herein, the need to develop a holistic accident prevention approach became evident. The product is the DO-IT BEST Feedback Model (cover picture and *paper VI*). The model illustrates that it may be the *synthesis* of existing theories rather than developing a single new theory that can make a meaningful contribution to science. The DO-IT BEST Feedback Model came out to be the roadmap of my research journey throughout the three years (with the "stopovers" of my journey – the individual papers – shown in Figure 1). This journey involved building a bridge between accident prevention strategies before, while and after driving. Overall, the aim is that this bridge is a solid ground for today's drivers to guide them safely into the future.

CHAPTER 1 INTRODUCTION

1. Outline

The thesis consists of eight chapters. Chapter 1 introduces the objectives of the thesis along with a review on existing knowledge on behaviour adaption to Advanced Driver Assistance Systems as well as driver distraction and inattention and their countermeasures. Chapters 2 to 7 describe the conducted research of the thesis in detail. Thus, these chapters consist of re-prints of the publications in their original format. Chapter 8 closes with a conjoint summary of the thesis contribution, further research recommendations derived from the results, and the limitations of the thesis. The relation of the chapters of the thesis to the DO-IT BEST Feedback Model (a model that was developed in the thesis, *paper VI*) is shown in Figure 1.

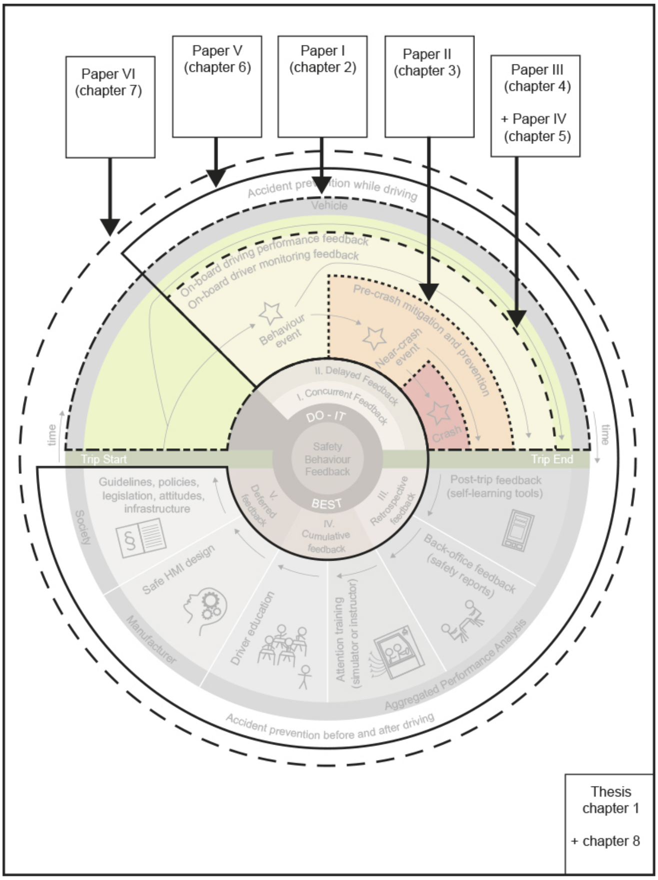

Fig. 1 Thesis chapters and publications in context to the DO-IT BEST Feedback Model

2. Objectives

Understanding and improving safe driver behaviours is important because trends by the World Health Organization indicate that by 2030 road traffic injuries will become the fifth leading cause of death worldwide (compared to now being the eighth leading cause of death) if nothing will be done to prevent crashes (WHO, 2013). One of the greatest traffic safety challenges of our time is to eliminate or moderate crashes that are caused by driver distraction and inattention.

Technology pervades our daily living, and is increasingly integrated into the vehicle – directly affecting driving. Inattention is a long-standing factor related to motor vehicle crashes (Evans, 2004) and was identified as the main contributing factor in 78 percent of all crashes and 65 percent of all near-crashes (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005). Inattention is also a renewed problem associated with modern technology based distractions – both built in and carried in to vehicles. Within the last decade there were fundamental changes in social and communication technology that directly affect driver distraction (Regan, Victor, & Lee, 2013). Angell and Lee (2011, p. 3) have recently predicted that “Cars are quickly becoming mobile Internet devices.” And, as such, the number of people killed in crashes in the US caused by drivers being distracted is continuously increasing (NHTSA, 2013). Because distracted driving accounts for 10 percent of all traffic deaths in the US (NHTSA, 2009), it has been labelled “this generations chronic disease” (Wetzel, 2012; US Centers for Disease Control and Prevention, 2012). Placed high on the political agenda, the strong prevalence of driver distraction and inattention in crash statistics calls for countermeasures.

Simultaneously to technology intensifying driver distraction and inattention, technology is emerging such as Advanced Driver Assistance Systems (ADAS) which are designed to support the driver in the driving task. Recently, ADAS of various kinds – supporting comfort, safety and/or information – have been introduced to the market. In the light of all these flourishing innovations, driver safety is a relevant matter of concern. The question that arises is: “Can a driver adapt to the ever growing technological advances?”

In this context, the *principal aim* of the present work is to address how to improve safe driver behaviour by understanding the underlying psychological mechanisms that influence behavioural change. In order to explore the potentials of improved safe driver behaviour, the current human-machine-interface (HMI) of one existing ADAS was tested, and visual distraction warning algorithms of a future ADAS were examined. Additionally, an assessment of the role of false positive warnings on safe driver behaviours with regard to overall system acceptance was essential. Further research included the examining possibilities to combine ADAS with behaviour-based safety (BBS). These results were then compiled and related to previous literature on ADAS and human attention in the contexts of driver behavioural adaptation. In order to understand the underlying psychological mechanisms that influence safe driving behaviour, performance data (including attention performance, driving performance, subjective performance self-ratings and system acceptance) was coupled to existing scientific knowledge.

The central contributions of this work are related to advancement of research in the field of traffic psychology in the context of attention allocation strategies, and to improve the ability to design future safety systems with the human factor in focus. The contributions of this thesis are presented in more detail in chapters 2 to 7 and are comprehensively discussed in chapter 8.

In general, driver adaption processes become important each time a driving situation embodies one or several unfamiliar components. These processes involve a psychological and a behavioural change of previously established patterns. Empirical research shows that behavioural changes due to ADAS range on a continuum from an increase to a decrease in safety and a few attempts have been made to develop theoretical models and concepts. However, there is a need to develop a conceptual framework capturing the most relevant psychological factors involved in driver behavioural adaptation. The definition of "behavioural adaptation" which underlies current research is the definition by the Organisation for Economic Co-operation and Development (OECD) from 1990. Since then 23 years have passed and new in-vehicle technologies have entered the market, which made it necessary to critically revisit the prerequisites of the OECD definition and discuss its adequacy for on-market and future ADAS applications. Therefore, the *first objective* of this thesis was to review the scientific literature on drivers' behavioural adaptation to ADAS, to critically discuss the adequacy of the OECD definition, to develop a Joint Conceptual Theoretical Framework, and to advance the discussion regarding new terminology and theoretical concepts on behavioural adaptation to ADAS.

The general purpose of ADAS is to enhance driver comfort, entertainment, alertness and/or safety (Huth, Fort, Bueno García, & Brusque, in press). Research in the human factors domain is active to ensure a safe interaction of the user and the ADAS. If ADAS warnings are not designed according to a user's capabilities, the user could fail to obtain critical information which may degrade safety. Some ADAS are designed to prevent forward collisions, like a brake-capacity forward collision warning (B-FCW) system. The intended effects of B-FCW systems are to direct drivers' attention to the forward roadway and to speed up responses in a safety critical event. Such systems can be effective both for attentive and distracted drivers. In a study by Lee, McGehee, Brown, and Reyes (2002), distracted drivers shifted their attention earlier to the driving scene when they received a forward collision warning compared to when they did not receive the warning. However, ADAS warnings - although designed to support the driver - may inadvertently cause inattention to safety critical locations if poorly designed and located (Regan, Lee, & Young, 2008). The expectation is that drivers will learn to interact with ADAS and adapt to a newly installed system in a way that was intended by the system developers (Rudin-Brown, 2010; SIS-ISO/TR 16352, 2006). However, little is known about the actual effects (safety enhancing and/or safety compromising) that come along with ADAS use. This is mainly because of a lack of sufficiently detailed behavioural data on ADAS usage in the real world. As an example, the effects of forward collision warnings on vehicle control and driver behaviour have been tested in the driving simulator (e.g. Kidd et al., 2010; Hanowski et al., 2005; Llaneras, 2000; Stutts et al., 2001) and on test-tracks (Ben-Yaacov, Maltz, & Shinar, 2002; Dingus et al., 2006a,b; Lerner et al., 2011) but data from real world usage is scarce. The questions that arise are "Do B-FCWs have the intended effect on drivers' attention allocation to the forward roadway and do they speed up responses?" and "What are the driver's responses right after a warning?" In order to answer these questions, the *second objective* of this thesis was to evaluate an on-market B-FCW system regarding its effects on safe driver behaviours (brake reactions and attention on-road) and their underlying psychological processes.

As stated above, within the last decade there were fundamental changes in communication technology that directly affected driving and driver distraction (Regan, Victor, & Lee, 2013). Research on naturalistic driving data has identified drivers interaction with mobile devices brought into the vehicle (e.g. operating a navigation system, or text messaging on a phone) as the main contributing factor of attention-related failures in crashes (e.g. Olson et al., 2009). According to Olson et al. drivers who text message while driving were 22 times more likely (although note the big confidence intervals in the study) to be involved in a safety-critical event compared to when not text messaging while driving. According to the results of the 100-car study, drivers who had their eyes off the road for more than two seconds (in an analyzed period of six seconds) were twice as likely to be involved in a crash (Klauer, Dingus, Neal Sudweeks, & Ramsey, 2006). These results were supported by Horrey and Wickens (2007) and Young (2011), who found that more than 80 percent of the crashes they investigated were attributable to drivers glancing inside the vehicle for longer than 1.6 seconds. Overall, the strong prevalence of distracted drivers in crash statistics calls for countermeasures. Some countermeasures already exist. Different elements related to the road transport system have been modified to prevent crashes that are due to driver distraction and inattention. These efforts include changes in the road transport infrastructure (e.g. the implementation of rumble strips (Anund, 2005), public campaigns, legislation, and policies (e.g. the recently published NHTSA-guidelines which are voluntary recommendations for vehicle manufacturer to prevent drivers to complete complex interaction with in-vehicle systems, NHTSA, 2013), driver education, training, and driver coaching (e.g. Hickman, & Hanowski, 2010). The design of effective countermeasures is a challenge and the existing countermeasures have not had a fully satisfying impact, with regard to the crash statistics.

Thus, research on new in-vehicle technologies such as camera-based real-time on-board driver alert systems has evolved (e.g. Engström and Victor, 82008, Croke, & Cerneaz, 2009; Lee et al., 2013; Victor, 2011; Kircher, & Ahlström, 2013; Fors et al., 2011). One ADAS that has the potential to capture moments when driver distraction occurs is a Visual Distraction Alert System (VDA System). A VDA System is based on eye-/head-tracking including software capable of detecting visual distraction in real-time and immediately warning the driver. VDA Systems have the main purpose to provide feedback to help the driver shift attention back to driving when s/he is judged as being "too distracted" according to predetermined criteria set by the system, the driver, or the owner (Engström, & Victor, 2008). To date, the knowledge regarding VDA Systems can be traced to projects like VISREC (Victor, 1999), SAVE-IT (Donmez, Boyle, & Lee, 2002) and AIDE (Engström et al., 2006). In the VISREC project visual distraction warning functions were mainly assessed with respect to user acceptance, showing that drivers noticed the alerts and responded to them by looking up at the road center. From the SAVE-IT project it is known that distraction feedback led to a significant reduction of glance frequency to the an in-vehicle display as well as longer glances to the road. The study also found that drivers accepted the system and found it useful (Donmez, Boyle, Lee, & McGehee, 2006; Donmez, Boyle, & Lee, 2007). However, the same study observed that there were no significant benefits for braking and steering behavior, which confirmed results from an earlier study by *(*Karlsson, 2005). Essential for a VDA System is the warning algorithm that detects and warns for glances away from the road. Research on finding an optimal warning algorithm is effective. In a recent study by Lee et al. (2012, 2013) four progressively more complex distraction detection algorithms were compared on their ability to detect visual distraction during a simulated highway drive. It was found that the an algorithm warning for both single long glances as well as a series of accumulated glances (glance history) (Victor, 2010; Victor, & Larsson, 2010*)* identified distracting visual behaviour better than the three other algorithms (a more detailed description of the characteristics of these algorithms can be found in a later section of this thesis).

Although these results are very positive, further research is needed to understand the influence of algorithm characteristics and to understand how best to influence behaviour. Is a similar warning algorithm also effective in enhancing (perceived and actual) attention and driving performance?

In particular, it is interesting to determine the improvement effect of simplifying the above warning algorithm to become more transparent. Can a warning algorithm that is transparent to the driver (warning for every single long glance) influence the desired behavioural change more than a less transparent (more complex) warning algorithm (combined single long glance and glance history warning)? And which warning algorithm is more accepted? A VDA System can only reduce distraction and inattention if drivers accept the system. In the automotive domain, the importance of users´ acceptance of a system has an undeniable relevance to its successful implementation. Related to this is the user's perception of performance enhancement: if the user perceives the increase of attention on-road then a system will most likely be more accepted and more used. Which warning has an influence on perceived performance enhancement? Are drivers well calibrated to the performance enhancement that a VDA System provides? It is therefore recommendable to include an assessment of user acceptance and an analysis of perceived vs actual performance at an early stage in the development process of ADAS. Related to this is the fact that little is known about *the psychological factors that influence the desired behavioural changes* (e.g. attention, increase in driving performance). And, the influence of false positive warnings has never been investigated for VDA Systems. The effects of imperfect systems are well researched for other ADAS (e.g. FCW, see Bueno et al, 2012), which give speculation about the importance of reliable warnings for VDA Systems. One study from the SAVE-IT project demonstrated that drivers accept "task lock-out" distraction mitigation technology even when it operates imperfectly (Donmez, Boyle, Lee, & McGehee, 2006). Thus, can even an imperfect VDA System be accepted and be rated as useful? The lack of research concerning the above questions motivated *objectives three and four* of this thesis. The *third objective* was to assess two usefulness with the aim to guide technology development to enhance driver safety. In this context, the *forth objective* was to investigate which of the two warning algorithms improves attention allocation towards longer and more frequent glances to the roadway, improves driving performance, and decreases engagement in distracting secondary tasks. Moreover, it was of particular interest whether false positive warnings affect driving performance, visual behaviour and engagement in distracting tasks.

From a general view point, it is expected that ADAS can decrease the number of crashes by 40 percent (Thalen, 2006). Some ADAS are already on the market, but the true safety effect is still largely unknown. Is it possible to increase the expected safety effects of ADAS?

In safety research outside the driving domain, behaviour-based safety programmes (BBS) have been proven to be successful in reducing safety-related incidents from 60 percent up to 97 percent (e.g. Krause, Robin, & Knipling, 1999; Sulzer-Azaroff, & Austin, 2000; Guastello, 1993). Is it possible to influence attention enhancement strategies not only through the above mentioned existing countermeasures but also through BBS? The ADAS and the BBS approaches have been largely carried out independent from each other. Little is known about the transferability of BBS principles and ADAS principles into *one* approach. Thus, the need for an *integration of the existing ADAS and BBS countermeasures* becomes apparent. Warning the driver in a particularly risky situation by ADAS, and to combine these warnings with BBS could emerge into an accident prevention approach beyond existing effects. In this context, the *fifth objective of the thesis* was to review ADAS and BBS characteristics, compile the existing knowledge and explore the possibility to combine the independent ADAS and BBS approaches by evaluating their common principles.

A variety of different accident prevention strategies exist. Previous research has suggested to cluster existing distraction and inattention countermeasures into pre-drive, drive and post-drive countermeasures (Victor, 2012). Independently, research on driver feedback time scales ranging from immediate feedback to delayed feedback has evolved (Donmez, Boyle, & Lee, 2008). However, a holistic comprehensive strategy integrating accident prevention and mitigation by focusing on safety behaviour feedback to the driver while distraction occurs in the vehicle, before and after it has occurred is still missing. The existing countermeasures vary in operation, capabilities and features and – most importantly – varying in provided feedback timing. Feedback timing can vary from immediate feedback with the purpose to immediately redirect drivers' attention to the roadway to delayed feedback with the purpose of shifting driver attitudes and willingness to engage in distracting activities. Today, the diversity of various accident prevention strategies seems lacking with regard to countermeasures related to delayed, aggregated feedback focused on attitudes and decisions. Thus, the s*ixth objective* was to develop a holistic safety behaviour feedback model.

This thesis addresses the research gaps identified above by systematically evaluating the effects of existing distraction and inattention countermeasures in the context of behavioural change.

In sum, this thesis has one general aim and six associated objectives. The *general aim* of the thesis is to improve safe driver behaviours by understanding their underlying psychological processes. Associated with this aim are *six objectives*:

- To provide a review on the scientific literature on driver behavioural adaptation to ADAS including a critical discussion on the adequacy of the OECD definition, the development of a conceptual framework, by advancing the discussion on new terminology and theoretical concepts (*paper I*)
- To test an on-market B-FCW system regarding its effects on safe driver behaviours (attention on-road and brake responses) and their underlying psychological processes embedded in an assessment of driver distraction and warning predictability (*paper II)*
- To analyze the (actual and perceived) performance benefits and system acceptance of two real-time driver distraction warning algorithms, which varied with respect to transparency (warning algorithm understandability) and reliability (number of false positive warnings) (*paper III*)
- To examine the effects of two real-time driver distraction warning algorithms on attention allocation on-road, driving performance and engagement in distracting tasks. The algorithms varied with respect to transparency (warning algorithm understandability) and reliability (number of false positive warnings) (*paper IV*)
- To review characteristics, principles, and safety contributions of ADAS and BBS, and to explore the possibility to combine both independent approaches into one comprehensive BBS-ADAS approach (*paper V*)
- To develop a holistic user-centered safety behaviour feedback model which can be applied to traffic safety management (*paper VI*)

Data collection and analysis included *multiple datasets* from the following sources:

- Literature reviews
- Driving performance data (e.g. CAN signals from a field operational test study and from a driving simulator study)
- Visual behaviour data (e.g. eye-tracker signals from a driving simulator study),
- Video footage (e.g. logged video footage obtained from installed cameras inside the vehicle during a field operational test study) and
- Subjective data (e.g. system perception and acceptance questionnaires and perceived performance questionnaires from a driving simulator study).

The thesis can be summarized in brief: The thesis intends to improve safe driver behaviour by the underlying of psychological mechanisms that influence behavioral change, thereby resulting in more attention allocation to the forward roadway, and improved vehicle control.

3. Background

In this section the general background of the thesis will be presented. First, an overview of behavioural adaptation to ADAS is summarized. Next, background information is provided about the main focus of the thesis, driver distraction and inattention prevention and mitigation. Thereafter, driver attention, inattention and distraction are defined, working mechanisms of attention are briefly presented and contributing factors are described in relation to crash risks. In closing, descriptions of the two ADAS assessed in this thesis are provided with a novel countermeasure approach (behaviour-based safety).

Our decade is the Decade of Action for Road Safety (2011–2020) in over 110 countries, with the aim of saving millions of lives by improving the safety of roads and vehicles (United Nations General Assembly, 2011). According to global status reports, road traffic injuries were the eighth leading cause of death worldwide in 2012 (WHO, 2013). Trends by the World Health Organization suggest that by 2030 road traffic injuries will become the fifth leading cause of death worldwide, if nothing will be done to prevent traffic accidents. In the EU27 countries there were about 39,300 fatalities in traffic accidents in 2011 (EC, 2013). Heavy trucks (>3.5 tons) are involved in about 17 percent of the fatalities, in 15 percent of all slight and serious injuries and in 7 percent of all casualties (Wrige et al., 2011). Fatal highway incidents remained the leading type of fatal work-related event, accounting for nearly two-fifths of all fatal work injuries (Bureau of Labor Statistics, 2010). The consequences of traffic accidents carry tremendous personal, social, and economic costs (e.g. NHTSA, 2006, Horrey, Lesch, Dainoff, Robertson, & Noy, 2012).

1.3.1 Behavioural adaption to ADAS

The Oxford Dictionary defines *Adaptation* as “the action or process of adapting or being adapted.” To adapt is defined as “To become adjusted to new conditions”. The ability to adapt to novel situations, meaning to modify behaviour to suit new conditions, is intrinsic to human nature and from an evolutionary perspective improves human chances of survival. As Smiley (2007, p.48) states “Adaptation … is one of our most valuable characteristics and the reason that a human presence is desirable to monitor even the most highly automated systems – to deal with the unexpected.” She further argues that “Adaptation is a manifestation of intelligent behaviour” and “… that adaptation will occur is predictable – we should be more surprised by its absence.”. The introduction of ADAS to the (car, truck and bus) market has been implemented at an increasing rate and speed in recent years. According to drivers´ needs and requirements, the general purpose of ADAS is to enhance safety, comfort, entertainment and awareness of the driver by optimising the driving task with the overall objective of avoiding drivers’ errors and accidents. Albeit the overall purpose of ADAS is a positive effect on safety and comfort, drivers adapt to new systems in unexpected ways that can compromise safety.

In 1990 a report prepared by the Organisation for Economic Co-operation and Development (OECD) further developed the understanding of behavioural adaptation in a compilation of research. The OECD report aimed at examining the “evidence of road user behaviours that occur in response to road safety programmes” (p.13). The term ‘behavioural adaptation’ was presented and defined as follows: “Behavioural adaptations are those behaviours which may occur following the introduction of the changes to the road-vehicle-user system and which were not intended by the initiators of the change.” (p. 23). A review on existing research effects ranging from a continuum of positive increase in safety to a decrease in safety as well as attempts to develop models and theoretical concepts on behavioural adaptations is included in *paper I.* In the same paper the OECD definition was also critically discussed as well as novel conceptualizations and terminologies on behavioural adaption was developed.

Adaption processes become important each time a driving situation embodies one or several unfamiliar components. These processes involve a behavioural change emerging into previously established behavioural patterns. A variety of concepts, theoretical models as well as empirical research regarding the concept of ’behavioural changes’ exist. For a review of the literature see Wege, Pereira, Victor and Krems (in press). In general, it is the role of feedback in changing behaviour that is of importance because ‘behavioural change’ is largely based on human learning theories and their underlying cognitive, motivational and energetic processes. The important role of feedback was defined already in the theory of operant condition by Skinner (1953). Skinner influenced the “behavioural approach” which assumes that once behaviour can be operationally defined, and reliably tracked, it can be influenced. The behavioural influence is based on consequences (feedback) that may reinforce or inhibit the recurrence of that behaviour.

1.3.2 Driver distraction and inattention

Communication, information, and entertainment technology pervades our daily living, and is increasingly integrated into the vehicle, where it has the potential to distract drivers. Consequently, there is a critical need to better understand distraction and the limits of attention while driving. Distraction includes instances where drivers take their eyes off the road—visual distraction—, and instances where drivers take their mind off the road—cognitive distraction. The focus of this thesis is visual driver distraction.

Driver inattention is a long-standing major factor related to morbidity and mortality in motor vehicle crashes (Evans, 2004). Distracted driving was labelled “this generations chronic disease” (Wetzel, 2012; US Centers for Disease Control and Prevention, 2012). One of the greatest traffic safety challenges of our time is to eliminate or moderate crashes that are caused by driver inattention. In 2009 distraction was involved in crashes causing 5,474 deaths and leading to 448,000 traffic injuries across the US (NHTSA, 2010). The number of people killed in crashes caused by distractions rose in 2011, but fewer were injured (NHTSA, 2013). According to the U.S. Transportation Department 15 people are killed each day in the US due to distracted driving, accounting for 10 percent of all traffic deaths (NHTSA, 2009).”Inattention to forward roadway”, including secondary tasks engagement, driving-related inattention to the forward roadway, non-specific eye glances, and fatigue, was identified as the primary contributing factor to 78 percent of all crashes, 93 percent of rear-end crashes, and 65 percent of near-crashes in naturalistic driving studies (Dingus, et al., 2006 Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005; Hanowski et al., 2009). A speech at a NHTSA board meeting from a mother losing her daughter in a car accident caused by a distracted driver shows the unimaginable tragedy behind these figures (White, 2010).

1.3.2.1 Definition

Despite the recent popularity of studying driver attention, inattention and distraction, there remains little consensus about consistent definitions. The difference is large between William James´ (1890, p. 403) famously claimed statement in his classic *Principles of Psychology* “Everyone knows what attention is” in comparison to definition in literature of the past years which shows that “attention”, either being one factor or one process, is a rather slippery concept with vague and ambiguous meanings (e.g. Victor, 2006; Regan, Hallet, & Gordon, 2011). Pettit et al. (2005) suggested that “[…] the result of driver distraction is inattentive driving. However, inattention is not always caused by distraction” (p. 4).

A number of key experts launched since 2009 in the US-EU Driver distraction and HMI Working Group with the objective of establishing a conceptualisation and taxonomy for understanding and categorizing driver attention, inattention and distraction (Engström et al., 2013). This collaboration is currently the most promising action to establish a commonly agreed definition of driver attention, inattention and distraction. The current status of their work is that *attention* can be viewed as *the allocation of resource to activities*, where resources can be divided into sensory (e.g., the eyes), actuator (e.g., the hands), perceptual (e.g., visual cortex), motor (e.g., motor cortex) and cognitive resources (e.g., brain networks, in particular frontal and parietal regions, implementing cognitive control/executive attention). Inattention can be understood in terms of whether this allocation of resources matches the resource allocation required to deal with activities critical for safe driving. In other words, *inattention* is defined as a *mismatch* between the current attention allocation (distribution) and that demanded by activities critical for safe driving, where “activities critical for safe driving” are defined as those activities required for the control of safety margins. *Misdirected attention* relates to the selective aspect of attention, that is *how* resources are distributed between activities. Hence, misdirected attention occurs when the demands of activities currently critical for safe driving are not matched due to the allocation of resources to other safety critical or non-critical activities. *Driver distraction* is a sub-category of misdirected attention. *Driver distraction* refers to situations where *the driver allocates resources to a non-safety critical activity while the resources allocated to activities critical for safe driving do not match the demands of these activities*. In other words, the driver diverts attention away from activities critical for safe driving to one or more activities that are not critical for safe driving (Lee et al., 2009). One example of distraction is the case when a driver writes a text message on a mobile device and looks away from the road towards the display, resulting in insufficient resources being allocated to the safety critical activity of monitoring the headway to a lead vehicle. The overall structure of the taxonomy of driver inattention is summarised in Figure 2 which shows the current status of the taxonomy report by the US-EU Driver distraction and HMI Working Group (Engström et al., 2013).

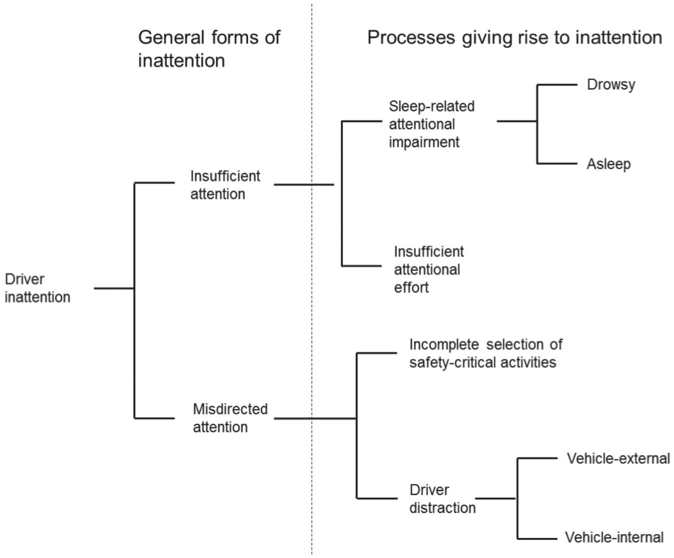

Fig. 2 Graphical representation of the driver inattention taxonomy by Engström et al. (2013) [printed with permission]

The focus of this thesis is visual distraction and inattention. Vision is a critical element of driving. Wierda and Aasman (1992, p. 5) stated "Driving is seeing" and "The eyes have it all". Eye movement metrics have also been shown to be the most sensitive metrics for measuring visual inattention and for studying traffic safety (e.g. Ahlström, Victor, Wege, & Steinmetz in the SeMi-FOT project, 2012; Angell et al., 2006 in the CAMP project; Victor, Engström, & Harbluk, 2009 in the HASTE project; Zhang, & Smith, 2004 in the SAVE-IT project). Visual distraction is mainly caused by drivers taking their eyes off the road for an extended period of time resulting in a behavioural event and/or near-crash event compromising safety.

1.3.2.2 Working mechanisms of attention

Research has aimed at identifying *why* driver inattention causes traffic accidents. Attention is a resource with limited capacity (e.g. Wickens, 1984; Zwahlen, 1985; Norman, 1968; Treisman, & Riley, 1969). Limited visual capacity is one risk factor in the probability of road accidents. As stated above one essential resource for driving is visual attention to perceive the roadway situation. Visual secondary tasks also demand this type of resource. Multiple resource theory suggests that secondary tasks that compete for the same resources required by driving degrade driver performance (Wickens, 2002). Wickens' theory on '*multitasking'* was recently supported by Dingus et al. (2011) and Elvik (2009) who identified risk factors that are statistically associated with road accident occurrence. One risk factor is the *visual overload* when driving and texting simultaneously. This risk factor is described as the "*law of complexity*" which states that the more units of information per unit of time a road user must attend to, the higher becomes the probability that an error will be made (Elvik, 2006).

The concept of attention as a finite resource was also recently reviewed by Engström (2012). Engström proposed a *conceptual model of attention selection and multitasking* in driving with attributing a key function to attention selection. Attention selection is to enable an appropriate balance between goal achievement and the maintenance of acceptable safety margins in everyday driving. In the conceptual model a central role is devoted to basic schemata and attention selection further conceptualized as the selection of schemata. As discussed by the US-EU Bilateral ITS TF working group (Engström et al., in press), driver attention can generally be understood in terms of the selection of activities (both of information and actions).

1.3.2.3 Contributing factors

Driver inattention is a long-standing major factor related to morbidity and mortality in motor vehicle crashes (Evans, 2004). One of the most common human related factors that contribute to heavy truck accidents are “failure to look properly” (Wrige et al., 2011). Most often drivers are capable of anticipating the criticality of a traffic situation and adapt their behaviour, for example paying more attention to avoid an accident. However, even though drivers have a powerful adaptive capacity, if attention is misallocated traffic fatalities occur.

Driver inattention is also a renewed problem associated with modern technology-based distractions such as the cell phone (NHTSA, 2010a) that capture a driver’s visual attention and therefore disrupt the allocation of attention to the driving scene (Victor, Harbluck, & Engström, 2005). Throughout the last decade mobile technologies (e.g. phones, tablets) have been introduced to the market continuously and this fundamental change in social and communication technology has directly affected driving and driver distraction (Regan, Victor, & Lee, 2013). Research on naturalistic driving data identified driver interaction with mobile devices brought into the vehicle as the main contributing factor of attention-related failures. According to Olson et al. (2009) drivers who text message while driving were 22 times more likely to be involved in a safety-critical event, compared to when they did not text message while driving. Although the number of annual fatalities caused by text messaging is unclear (Yager, Cooper, & Chrysler, 2012), the potential scope of the problem can be estimated by the fact that in December 2012, approximately 171.3 billion text messages were sent/received in the United States (CTIA, 2013). Regan, Victor and Lee (2013) summarized the fundamental changes of the last decade in social and communication technology that directly affect driving and driver distraction such as “[…] the advent of Facebook (in 2004), Twitter (in 2006), the iPhone (in 2007), and third-party applications (apps) for the iPhone increasing to over 5000,000 in 2012 from none in 2008” (p. 3). Angell and Lee (2011, p. 3) have recently predicted that “Cars are quickly becoming mobile Internet devices. Drivers’ desire to converse in social media while driving has increased (Forbes, 2009). Recent research has identified factors related to driver’s *willingness* to engage in distracting tasks. A user survey (N=872) found that the majority of in-vehicle navigation system users have interacted with a navigation system while driving (e.g. to enter a destination), and that some do so frequently (Forbes, 2009). In a recent self-report survey in the United States (Harris Poll, 2012)

84 percent of new car buyers admitted to engage in one or more distracting driving behaviours in the average month. A similar study examined the prevalence of text messaging in self-reports from college students from the United States. Analyses revealed that 91 percent of participants reported having used text messaging while driving (Harrison, 2011). Other sources report that 20 percent of all U.S. drivers have admitted to texting while driving in the past 30 days prior to the survey, however almost 75 percent of the survey respondents had seen drivers in other vehicles texting on a cell phone or other mobile device previous 30 days (Consumers Union Report, 2011). Current investigations demonstrate detrimental effects of text messaging on driving behaviours and shifts of attention, even under relatively ideal and naturalistic driving condictions (e.g. familiar route, good weather, no traffic) (McKeever, Schultheis, Padmanaban, & Blasco, 2013). Landsdown (2012) reported the ratings of severity of engagement with distracting driver behaviours. Survey data from four hundred eighty-two respondents indicated that the three behaviours rated as most distracting when driving were (i) writing text messages (41percent), (ii) reading text messages (62 percent), and (iii) using a cellular telephone hand-held (52 percent).

1.3.2.4 Consequences

Research investigating the relationship between visual distraction and driving control has evolved. A substantial portion of the body of knowledge that currently exists on the relationship between driver distraction and driving control has been synthesized in the literature (e.g. Angell, & Lee, 2011; GHSA, 2011; Regan, Lee, & Young, 2008; Regan, Lee, & Victor, 2013; Robertson, 2011; Rupp, 2011). Young and Salmon (2012) have recently reviewed literature about the relationship between driver distraction and driving errors. In naturalistic driving studies it has become possible to examine the real-world safety effects (e.g. Liang, Lee, & Yekhshatyan, 2012, Olson, Hanowski, Hickman, & Bocanegra, 2009). Distraction was found to be associated with unintentional lane deviations (Olson et al., 2009), abrupt steering wheel corrections (Markkula, & Engström, 2006; Yang, McDonald, & Zheng, 2012), more variance in velocity (McKeever, Schultheis, Padmanaban, & Blasco, 2013; Yang, McDonald, & Zheng, 2012), increased lane deviations (McKeever, Schultheis, Padmanaban, & Blasco, 2013), and slower reaction times to lead vehicle braking (e.g. Angell et al., 2006; Angell, & Lee, 2010; Carsten et al., 2005; Zhang, & Smith, 2004; Castro, 2012; Birrell, & Young, 2011). An overview of off-road glance times associated with different tasks can be found in Kircher (2007), Kircher and Ahlström (2013) and Green and Shah (2004).

1.3.2.5 Drivers glance characteristics and crash risk

Although, in the past few years research has been showing a much clearer association between driver inattention and crash risk, the *specific* mechanisms and indicators of the risk of distraction are unfortunately not definitively quantified. Initial analyses of the 100-car study focused on general relationships, such as the proportion of crashes involving inattention as a contributing factor (Dingus et al., 2006), or the relative and population-attributable risk associated with different inattention-related activities (Klauer et al., 2006). Subsequent analyses have examined the influences of various characteristics such as total eyes-off-road time (glance history), single glance duration, and glance location. Previous work has also focused on calculating the risk associated with (human identified) classifications of distracting tasks, such as dialling, eating, texting, etc (Klauer et al, 2006; and Olson et al, 2009).

The temporal characteristics of glances between road center and a peripheral object is remarkably constant with glance durations typically exhibiting means between 0.6 and 1.6 seconds, and showing a (positively) skewed distribution towards short glances (Victor, 2006; Victor, Harbluk, & Engström, 2005; Werwille, 1993; Green, 1999). For conventional instrument panel functions such as checking the speedometer, radio or clock the longest mean single glance durations range from 1.2 to 1.85 seconds (Rockwell, 1988; Kircher, 2007; Pradhan, 2011). Drivers are generally unwilling to look away from the road for more than 2 seconds (Rockwell, 1972; Vollrath, & Krems, 2011). Often, one short glance is not sufficient when completing a non-driving related task, so the driver looks back and forth to the road, a glance pattern defined as 'visual time sharing' (Victor, Harbluk, & Engström, 2005; Zwahlen, Adams, & de Bald, 1988; Greenberg et al., 2003; Östlund et al., 2004; Merat, & Jamson, 2007). Thus, the glance is temporally "chunked" (i.e. occurs in bursts of glances). It has been determined that drivers choose a series of repeated glances rather than extending one single glance, if the secondary task demands attention for a longer period of time. Drivers tend to "chunk" large tasks into smaller interactions of between 1 and 2 seconds single glance duration (Zwahlen et al., 1988; Wierwille et al., 1988; Dingus et al., 1989).

Klauer et al. (2006) and Olson et al. (2009) show that critical events are associated with high eyes-off-road times during the six second period preceding an event onset. In a re-analysis of the 100-car data, Klauer et al. (2010) showed total Time Eyes Off the Forward Roadway (total TEOR) within a time period is associated with increased crash/near-crash risk. The shortest significant amounts were 20 percent (3 seconds) total TEOR for a 15 second task duration, or 30 percent (2 seconds) total TEOR for a 6 second task duration. It is important to mention that these results refer to a total off road glance time of two seconds or more in a six second period, and do not refer to a single glance duration. In other words, critical events were associated with an extended eyes-off-road time during the six second period preceding a precipitating event onset (e.g. a lead vehicle initiating braking). Overall, these studies indicate that accumulated eyes-off-road time (glance history) is associated with higher crash probability, but they did not test independently the effect of single glance duration or asses how single glance duration combines with glance history to influence crash risk.

Liang, Lee, and Yekhshatyan (2012) used the 100-Car study data to compare different approaches in estimating distraction and established which characteristics of driver eye glance behaviour indicate crash risk. Twenty-four algorithms – that varied according to how they considered glance duration, glance history, and glance location – were compared on how well they predicted crash risk. They found that algorithms estimating risk as a linear function of instantaneous changes of off-road glance duration produce the most sensitive estimation to crash/near-crash risk. That is, instantaneous single off-road glance duration and not glance history, was the best crash predictor. Although algorithms considering both glance history and glance location did not improve estimation above glance duration algorithms alone, they were still predictive of crash/near-crash risk. For example, algorithms that summarized glance measures using a small window led to better performance than those that used a large window.

In the past years there is a growing concern over the driving-compatibility of the ever-increasing functionality available through electronic devices (such as mobile devices brought into the vehicle and intelligent vehicle systems). The safety problem at issue in both these developments centers upon problems related to driver inattention. The vehicle industry is moving fast to respond to both enable the use of electronic functionality in a safe manner and to reduce driver inattention through safety systems which are capable of monitoring it. Scientific research needs to investigate the potential benefits and problems on drivers' attention allocation accompanied by these developments.

1.3.2.6 Countermeasures

Several countermeasures to prevent and mitigate driver distraction and inattention exist, varying significantly in purpose, operation, capabilities and features. Six examples of non-technological countermeasures are:

- changes in the road transport infrastructure (e.g. the implementation of rumble strips (Anund, 2005))
- policies (e.g. the recently published NHTSA-guidelines which are voluntary recommendations for vehicle manufacturer to prevent drivers to complete complex interaction with in-vehicle systems (NHTSA, 2013))
- regulation to ban cell-phone use while driving
- public campaigns (e.g. the "One text or call could wreck it all" campaign (NTHSA, 2010))
- public executive orders (e.g. by US President Barack Obama directing federal employees not to engage in text messaging while driving (The White House, 2009))
- driver education, training and driver coaching

Even the best non-technological countermeasures will be ineffective unless they are properly designed, implemented, and routinely assessed (Regan, Lee, & Young, 2008). The design of effective countermeasures is a challenge and the existing countermeasures have not had a fully satisfying impact, with regard to the crash statistics.

In this thesis the focus is on technological solutions to the visual distraction and inattention problem. Two ADAS, one ADAS already on the market (brake-capacity forward collision warning system), and another ADAS, a Visual Distraction Alert System, are assessed in this thesis. A description of a Visual Distraction Alert system, followed by a description of a brake-capacity forward collision warning system, is presented below. Later, a new strategy to counteract the visual distraction and inattention problem, behaviour-based safety programmes, will be introduced.

1.3.2.7 Visual Distraction Alert Systems

Technological solutions to combat driver distraction are real-time distraction mitigation systems with the main purpose of providing feedback to help the driver shift attention back to driving when s/he is judged as being “too distracted” according to predetermined criteria set by the system, the driver, or the owner (Engström, & Victor, 2008). As such, it alerts the driver to inappropriate behaviour, and does not necessarily have a direct coupling to driving performance deterioration. Engström and Victor (2008) have reviewed various types of distraction alerts (e.g. flashing LEDs, icons, tones, seat vibration, and voice messages). In addition to the immediate effect of redirecting attention towards the critical aspects of the driving situation, real-time distraction feedback may also result in positive long-term behavioural changes, e.g. safer visual allocation strategies. The first efforts in this area can be traced to projects like VISREC (Victor, 1999), SAVE-IT (Donmez, Boyle, & Lee, 2002) and AIDE (Engström et al., 2006).

- *VISREC project (Victor, 1999)*
  In the VISREC project visual distraction was estimated in real-time based on a combination of the following parameters: (1) the percentage of time that gaze falls within a road center area (percent road center; PRC) over a 1-minute running window; (2) a single-glance duration; and (3) detection of visual time-sharing behaviour calculated as a PRC running average using a 10 second time window.
  The visual distraction alert function was evaluated by 30 truck drivers with respect to user acceptance of three types of distraction alerts. All drivers stated that they noticed the alerts and responded to them by looking up at the road center. They ranked the distraction alert highly in comparison to other driving support functions (like a drowsiness alert).

- *Swedish study (Karlsson, 2004)*
  The visual distraction alert prototype systems described in Karlsson (2004) featured two types of distraction feedback: a row of blue flashing LEDs reflected in the windshield at road center position, and a single kinaesthetic brake pulse. The distraction detection algorithm used the concept of an *attentional budget* that runs out if the driver looks away from the road too much, and receives “funding” when the driver looks back at the road. The algorithm had three parameters: (1) initial budget limit; (2) the rate at which the “budget” runs out when looking away; and (3) the rate at which the driver receives “funding” upon looking back to the road. The algorithm is similar to the AttenD-algorithm used by Kircher, & Ahlström (2013). Karlsson conducted an assessment of the potential driving performance enhancements of the system. However, no significant driving performance effects were demonstrated.

- *Australian Study (Fletcher, 2007)*
  Fletcher (2007) used the Percent Road Center metric to reset a counter. Once the driver is observed to have a stable gaze at the road ahead, the counter and the warning is reset until the next diversion. As the driver's gaze diverges, the counter begins. The time period of permitted distraction is an inverse square function of speed. When the gaze has been diverted for more than a specific time period, an audible warning was given.

- *SAVE-IT study I, II (Donmez, Boyle, & Lee, 2006, Donmez, Boyle, & Lee, 2007)*
  Distraction was estimated based on the current off-road glance duration (β_1) and the total off-road glance duration during the past three seconds (β_2), resulting in the function $\gamma = \alpha\beta_1 + (1-\alpha)\,\beta_2$ where α determines the weight of the current glance duration. Alerts were then given on at two levels, defined by thresholds for γ (2 and 2.5 seconds). Visual distraction feedback that was given in two display locations: vehicle-centered (a strip of LEDs on top of the dashboard/steering wheel) and in-vehicle information system-centered (as yellow or orange strips on the top portion of an LCD display mounted on the center console). Results showed significant benefits were not observed for braking and steering behavior. A significant change in drivers' interaction behaviour with s was shown, as drivers looked at the in-vehicle display less frequently. It was concluded that the distraction alert positively altered drivers' engagement in distracting activities, helping them attend to the roadway. Furthermore, the distraction feedback led to a significant reduction of glance frequency to the display as well as longer glances to the road. However, no significant effects were found with respect to driving performance. The study also investigated driver acceptance of the visual distraction alert function, and found positive ratings for both dimensions, but only significantly for usefulness.

In the past years, research on technology based countermeasures has intensified (e.g. Victor, 2011; Donmez et al., 2008; Kircher, & Ahlström, 2013, Angell, & Flanigan, 2011; Donmez, Bolye, & Lee, 2008). A review of distraction monitoring and feedback functions can be found in Engström and Victor (2008) and Kircher and Ahlström (2013). In recent years, so called on-board safety monitoring devices have been developed (e.g. Hickman et al 2007, 2010a). Automobile and aftermarket manufacturers have begun introducing on-board safety monitoring devices to reduce distraction-related crashes. These devices use advances in sensor technologies to detect risk and warn drivers (e.g. Tripmaster®, DriveCam®, Driver Alert Support System® and Transsecurity System®). Victor (2012) has placed 16 emerging technology-based safety countermeasures to a conceptual framework for distraction and inattention countermeasures (Fig. 3). These technologies that vary in product maturity and safety impact, are clustered according to descriptive characteristics and functions.

The method of remote eye tracking has only recently emerged, which enables real time identification of visual distraction (Kircher, & Ahlström, 2013; Ahlström, Victor, Wege, &

Steinmetz, 2012). The real time identification of visual distraction was of particular interest in this thesis. An ADAS which can not only identify visual distraction, but also warn the distracted drivers in real-time is a Visual Distraction Alert (VDA-) System. In general, a VDA System has the intended effect to assist distracted drivers in redirecting attention to the relevant aspects of the driving task. The VDA System in this study is based on driver glance and/or head movement monitoring. It provides auditory alerts (a short "beep"-sound) to redirect distracted drivers' attention to the forward roadway. Lee et al (2013) have summarized the safety benefits of VDA Systems which can accrue by discouraging drivers from 1) *enabling* distracting devices, 2) *engaging* in distracting activities, and 3) *persisting* in distracting activities when distractions put them in crash-imminent situations.

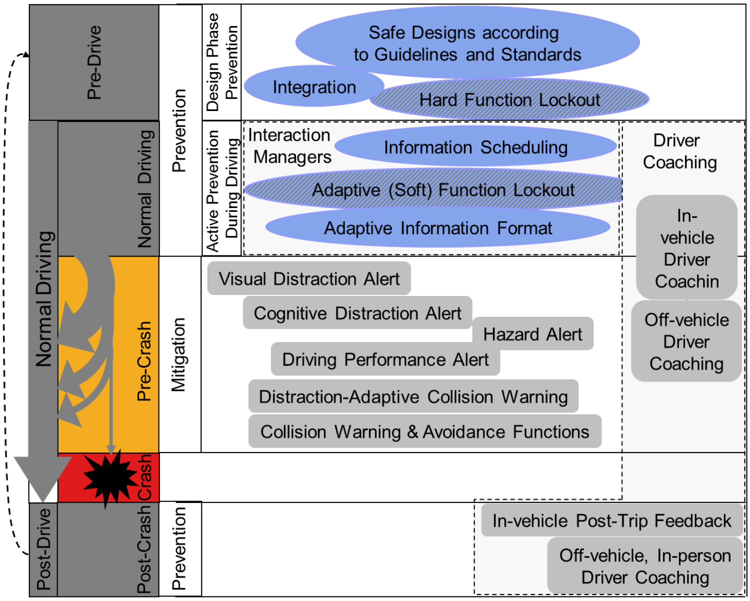

Fig. 3 A conceptual framework for distraction and inattention countermeasures by Victor (2012) [printed with permission]

The drivers glances are continuously tracked, the driver only receives a warning when the system detects an inappropriate glance behaviour. This depends on the pre-set warning threshold set by the system. Attending the road at all times, will avoid a warning. Thus, the interference of the system is kept minimal, restricted to situations where the individual attention allocation to the forward roadway is at risk. In short, a tone was presented to the driver whenever the eyes-off-road time exceeded 2.4 seconds (SG- warning algorithm) or 2.4 seconds and a threshold for accumulated glances (GHSG-warning algorithm). A more detailed description of the system is the distraction warning algorithms are included in *paper III* and *IV*.

VDA Systems that detect visual distraction are based on distraction detection algorithms. The main characteristics of four main published distraction detection algorithms can be found below, although others exist (e.g. Croke, & Cerneaz, 2009). The VDA System assessed in the present thesis is based on the Multi Distraction Detection algorithm (although slightly modified) and therefore its characteristics are described in more detail.

> *Eyes off forward roadway (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006:*
>
> The algorithm accounts for the results from Klauer et al. (2006) of the 100-car study that a cumulative glance time (i.e. comprised of several glances - of two seconds or more within a six second window is defined as visual distraction and significantly increases crash risk.
>
> *Risky scanning patterns (Donmez, Boyle, & Lee, 2007, 2008):*
>
> The algorithm considers the duration of the current glance and the cumulative glances away from the forward roadway within the last three seconds. The current glance is weighed with a factor and multiplied by the cumulative glance duration, wherein the value of this equation represents the risk of a crash (values above two are considered a moderate risk, values above 2.5 are considered a high crash risk.)
>
> *Attend (Kircher, Kircher, & Ahlström, 2009; Kircher, Kircher, & Claezon, 2009):*
>
> As with the risky scanning pattern algorithm single long glances away from the road are risky, the algorithm uses a buffer to represent the amount of road information the driver possesses. The buffer decrements over time as the drivers look away from the road beginning from 2 seconds. When the buffer reaches a buffer value of zero, the driver receives a warning.
>
> *Multi Distraction Detection (Victor, 2010;* Victor, & Larsson, 2010*):*
>
> This algorithm was developed for production applications, and therefore is designed to be robust and reliable. The finer points of the algorithm, such as data pre-processing and calibration are presented in descriptions available in theses (Victor, 2005; Larsson, 2003) and a patent application (Larsson, & Victor, 2008). For a more detailed description of the algorithm setting parameters see Victor (2010). In Figure 4 a schemata visualizes the warning procedure. The *Multi Distraction Detection* algorithm uses the Percent Road Centre (PRC) measure as its basis. As defined by Victor (2005) PRC is the percentage of gaze- or head angle data points that fall within a road center area. The algorithm relies on the notion that drivers should spend a certain amount of time glancing towards the road center area. The road center area is defined as a circle of 10 degrees radius centered on the road center. When eye glance data is unavailable, the algorithm uses head pose data to calculate PRC. The size of the road center cone adjusts to the sensor signal, increasing from 10 to 20 degrees when sensor input shifts from eye glance to head pose signals. A visual time sharing (VTS) PRC window is calculated to improve the consistency and reliability of distraction detection by resetting the visual PRC window when glances return to road center after a brief time off the road (PRC less than 65 percent in a 4 second

window). Resets are used as a mechanism to saturate the maximum value of the medium length window (17.3 s) to 80 percent, and the minimum value of the long window (60 s) to 60 percent. Additionally, whenever a VTS event is detected, all the PRC windows are reset.

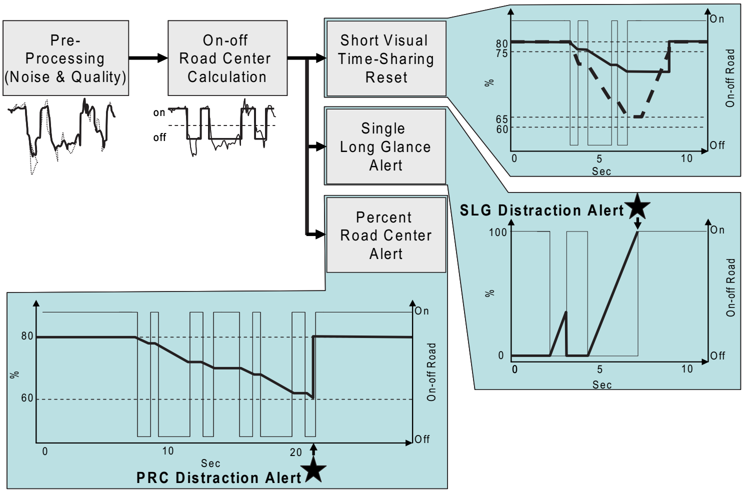

Fig 4. The driver visual distraction detection algorithm of the Visual Distraction Alert System by Victor (2010) [printed with permission]

In a recent study by Lee et al. (2013) these four detection algorithms were compared on their ability to detect visual distraction during a simulated highway drive. It was found that the Multi Distraction Detection algorithm (Victor, 2010; Victor, & Larsson, 2010) identified distracting visual behaviour better than the three other algorithms. The results from the study by Lee et al. (2013) were re-printed with permission in Figure 5. Although these results are very positive, further research is needed to understand the influence of algorithm characteristics. In particular, it is interesting to determine the improvement effect of simplifying the algorithm to become more transparent and the role of false positive warnings.

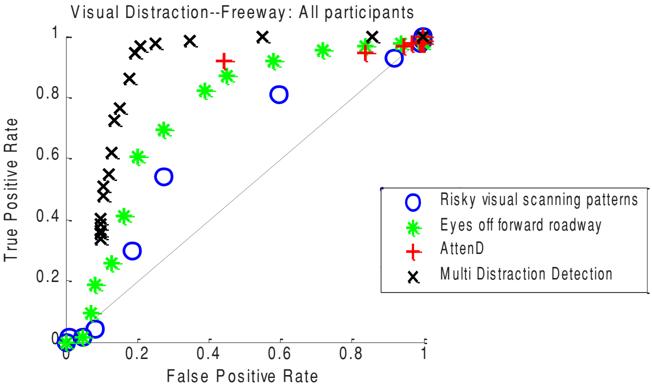

Fig 5. ROC plot for each vision-based algorithm for visual distraction in the freeway environment assessed by Lee et al. (2010) and Lee et al. (2013) [printed with permission]

1.3.2.8 Brake-capacity forward collision warning systems

Rear-end truck collisions account for more than 19 percent of all truck accidents and 91 percent of all rear-end collisions in Sweden (STRADA database, Wrige Berling et al., 2011). Results from naturalistic driving studies show that 75 percent of the drivers are non-attentive to the forward roadway right before a frontal collision occurs (Dingus et al., 2006a,b; Olson et al., 2009). Driver distraction has been identified as the most important contributing factor (60 percent) in rear-end collisions. In this context, forward collision warnings (FCW) have the potential to reduce the number of rear-end crashes by warning drivers of potential rear-end collisions (Lee et al., 2002; Zhu, 2001). The benefits of FCW systems are that drivers attend more to the forward roadway (Ho, & Spence, 2009), brake faster (Abe, & Richardson, 2009) and maintain longer and safer headways (Ben-Yaacov, 2002)

Currently, there are two types of forward collision warning systems on the market: a full FCW system (mostly in passenger cars) and a brake-capacity forward collision warning (B-FCW) system (mostly in trucks). A full FCW operates independent from an Adaptive Cruise Control (ACC) system and issues a high-priority warning (EC, 2011) alerting the driver of a potential collision with another vehicle in the forward path on straight roads (ISO 15623, 2002). A B-FCW is connected to the ACC system. If a truck catches up with a vehicle that is traveling slowly and the ACC cannot manage to brake sufficiently, then a collision warning is issued. The difference between a FCW system and a B-FCW system is that the full FCW is specifically designed to detect a crash in more severe situations whereas the B-FCW system may warn in a collision impending situation if that situation causes the brake-capacity of the ACC system to be exceeded. A B-FCW informs the driver to use the foot brake to reduce speed sufficiently. Thus, the warning signals the driver to react. The intention is to make drivers look immediately forward and assess the threat to make an important safety decision: either to hit the brake pedal or to continue driving at the same speed. A thorough statistical analysis of the intended effects of a B-FCW system is presented in *paper II*.

1.3.2.9 Behaviour-based safety

The general behavior-based safety (BBS) principle is that behaviours followed by desirable consequences are more likely to be repeated in the future and those followed by undesirable consequences are less likely to be repeated in the future (Geller, 2001). This principle is adapted from Skinner's (1953) operant conditioning learning theory. As Knipling and Hyten (2013) state "The scientific basis and effectiveness of BBS are unquestionable." (p.1)

Geller (2001) was among the first who introduced the BBS concept into industrial work safety and occupational behaviour research. The original BBS process is a four-step process called DO-IT process which was developed by Geller (2001). DO-IT is an acronym for the following terms: (1) Define the critical target behaviour(s) to increase or decrease, (2) Observe the target behaviour(s) during a pre-invention baseline period to set behaviour-change goals and, perhaps, to understand natural environments or social factors influencing the target behaviour(s), (3) Intervene to change the target behaviour(s) in desired directions, and (4) Test the impact of the intervention procedure by continuing to observe and record the target behaviour(s) during the intervention program. According to Geller safety feedback is most effective when given immediately or as soon as possible after the occurrence of the behaviour.

Safety program techniques following the BBS principle have proven to be relatively easy to implement, cost-effective and highly efficient for reducing occupational injuries and fatalities in a variety of industrial domains. Meta-analysis of health and safety BBS studies has found a significant reduction in injuries ranging from 96.6 percent (Sulzer-Azaroff, & Austin, 2000), to 59.6 percent (Guastello, 1993), to 69 percent (Krause, Robin, & Knipling, 1999). Krause, Seymour and Sloat (1999) compared the pre- to post-feedback incident levels of 73 companies in 5 years. The average reduction in occupational incidents amounted to 26 percent in the first year increasing to 69 percent by the fifth year. It was concluded that safety-related behavioural feedback in the workplace (e.g. chemical working plants, paper mills or petroleum industries) improved. Knipling and Hyten identify three barriers when applying changing behaviour in commercial fleets: observation difficulties, infrequency of crashes and violations, and feedback and consequences may be delayed and tied to outcomes rather than to behaviour. These barriers can be overcome when using on-board safety monitoring (devices) that continuously measure and record safety-related driving performance (speed, accelation, and breaking force) and driver behaviour (e.g. off-road glances). A more detailed description of the main principles of BBS together with the barriers to application in the automotive domain were identified in *paper V*.

CHAPTER 2 PAPER I

Paper I

Behavioural adaptation in response to driving assistance technologies - A literature review

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Chapter 2

Behavioural adaptation in response to driving assistance technologies: A literature review

Claudia A. Wege[1], Marta-Sofia Pereira[2], Trent W. Victor[1] and Josef Krems[2]

Abstract

Adaption processes become important each time a driving situation embodies one or several unfamiliar components. These processes involve a behavioural change emerging into previously established behavioural patterns. Research shows that behavioural changes due to Advanced Driver Assistance Systems (ADAS) are on a continuum ranging from an increase to a decrease in safety. This chapter reviews concepts, theoretical models as well as empirical research regarding these behavioural changes. The literature reviews showed the need for a Model capturing the most relevant factors inducing behavioural adaptation which resulted in the development of a '*Joint Conceptual Theoretical Framework (JCTF) of Behavioural Adaptation in Response to Advanced Driver Assistance Systems*'. Alongside, the traditional OECD definition of behavioural adaptation to driving assistance technologies is critically discussed by investigating its main assumptions and its adequacy for current on-market and future ADAS applications.

2.1 Introduction

The philosopher Khalil Gibran (1883–1931) once said, 'It takes a minute to have a crush on someone, an hour to like someone, and a day to love someone . . . but it takes a lifetime to forget someone.' Is this idea of 'adaptation to suit new life conditions' transferable to modern transport analysis research? How long does it take to get familiar with driving assistance technologies? How lasting is the behavioural adaption effect? And, how persistent is an effect once the technology is taken away from the driver? After getting used to a certain routine, is it almost impossible to adapt to changes in the traffic system? This chapter provides a

[1] Volvo Group Trucks Technology (GTT), Sweden
[2] Chemnitz University of Technology, Germany

literature review of the concept of behavioural adaptation in response to driving assistance technologies. In particular, the chapter presents the scope of the state-of-the-art knowledge that guided the ADAPTATION project. It was found that a conceptual framework including the most relevant characteristics of behavioural adaptation (short-, medium- and long-term) is still missing. Therefore, a framework that collects evidence of the most important factors and underlying psychological processes that affect behavioural adaptation was developed and is introduced in this chapter.

The Oxford Dictionary [1] defines *Adaptation* as 'the action or process of adapting or being adapted'. To adapt is defined as 'to become adjusted to new conditions'. The ability to adapt to novel situations, meaning to modify behaviour to suit new conditions, is intrinsic to human nature [2] and from an evolutionary perspective improves human chances of survival. As Smiley [2, p. 47] states 'Adaptation … is one of our most valuable characteristics and the reason that a human presence is desirable to monitor even the most highly automated systems – to deal with the unexpected.' She further argues that 'Adaptation is a manifestation of intelligent behavior' and '… that adaptation will occur is predictable – we should be more surprised by its absence' [2, p. 48].

The introduction of ADAS to the (car, truck and bus) market has been implemented at an increasing rate and speed in recent years. According to drivers' needs and requirements, the general purpose of ADAS is to enhance safety, comfort, entertainment and awareness of the driver by optimising the driving task with the overall objective of avoiding drivers' errors and accidents. Albeit the overall purpose of ADAS is a positive effect on safety and comfort, drivers adapt to new systems in unexpected ways that can compromise safety. According to Rudin-Brown [3] it is these negative effects of behavioural adaptation that are of most interest to road safety professionals. These negative effects have not been studied to a full extent yet, especially in regards to the diversity of safety systems. As research has demonstrated, there is a tendency for behavioural adaptation to develop differently for different ADAS [4–7] (for an overview, see Rudin-Brown [3]). Despite recent efforts in developing theoretical models and experimental studies, research is still at an early stage. This chapter outlines the progress of research from its early stages to the present and aims to advance the scientific debate for future researchers.

2.2 Historical background

Although the number of fatalities caused by road accidents has decreased in Europe over the last two decades (from 75,426 fatalities in 1991 in the 27 member states to about 39,300 in 2011 [8]), the current number of traffic deaths and injuries is still regarded as unacceptable. Various measures have been implemented to increase road safety, e.g. Vision Zero initiative [9]. However, both manufacturers and researchers have already identified potential problems with current countermeasures, as the safety effects of certain measures have been lower than initially expected. Aiming to identify the phenomenon responsible for this discrepancy, the interaction between the human and the different elements of the road transport system has been brought into focus. To convey that the implementation of safety changes might be inducing modifications in driver behaviour, terms like risk compensation [10], human behaviour feedback [11], behavioural adaptation [12], danger compensation [13], adverse behavioural change [14], and driver-behavioural barrier [15] were used. These phenomena are now frequently jointly called behavioural adaptation. Evans [11] stated that the earliest explicit reference to behavioural adaptation was by Gibson and Cooks in 1938 [16]. Gibson and Cooks mentioned in a footnote that ‘except for emergencies, more efficient brakes on an automobile will not in themselves make driving the automobile any safer. Better brakes will reduce the absolute size of the minimum stopping zone, it is true, but the driver soon learns this new zone and, since it is his field-zone ratio which remains constant, he allows only the same relative margin between field and zone as before’ (p. 458). Over a decade later, Smeed [17] considered the existence of a ‘regressive tendency’ that led drivers to drive faster as a result of improved sight distances and better roads. Wilde’s work on the risk homeostasis theory contributed to further explain and theoretically support this phenomenon [10]. Wilde’s work was based on the idea that road users tend to maintain the same level of risk, independent of changes made to the road system. To achieve the same level of risk, drivers compare their perceived subjective risk with the target level of risk (i.e. the level of risk desired to accept) and adjust their behaviour accordingly. In other words, individuals are hypothesised to modify their behaviour when perceived risk deviates from the target risk level in order to keep risk at the preferred level. The target level of subjective accident risk is assumed by Wilde as very important, as it is the variable capable of influencing accident rate, thus matching the expected safety effects with the real ones. A model following Wilde’s homeostasis theory [10] is the task–capability interface model by Fuller [18]. It focuses on the possibility of task demands to exceed the driver’s available capability. Where capability exceeds demand, the task is easy; where capability equals demand, the driver is operating at the capability limits, which makes the (driving) task difficult. As in Wilde’s risk homeostasis theory, individuals are hypothesised to modify their behaviour when task demand exceeds capability in order not to fail at a task that would result in the loss of control, potentially precipitating a near-crash.

Evans [11] collected information on different approaches that tried to understand and reduce the toll from traffic accidents. Evans included the notion that, when a system is modified, the user usually does not ignore it, but instead responds with some type of behavioural change, which he defined as ‘alteration in behaviour in response to changing external physical conditions’ (p. 558). This change can be on a continuum of possibilities, suggesting that the outcome of a safety program can vary between two extremes: from (a) changes even greater than expected, to (b) safety changes in opposition to what was expected, i.e. decrease in safety. The term ‘feedback’ was used as a key element that not only characterises the degree to which there is feedback provided by a system, but also defines the difference between the estimated safety change and the actual safety benefit. This means that a change that is perceived by road users will result in a change of behaviour, and might lead to different safety outcomes when compared with what was originally planned. However, Evans reported not to have addressed the important issue of feedback variations over time.

2.3 Definition and assumptions

In 1990 a report prepared by the Organisation for Economic Co-operation and Development (OECD) further developed the understanding of behavioural adaptation in a compilation of research [12]. The OECD report aimed at examining the 'evidence of road user behaviours that occur in response to road safety programmes' (p. 13). The term 'behavioural adaptation' was presented and defined as follows: 'Behavioural adaptations are those behaviours which may occur following the introduction of the changes to the road-vehicle-user system and which were not intended by the initiators of the change. Behavioural adaptations occur as road users respond to changes in the road transport system such that their personal needs are achieved as a result, they create a continuum of effects ranging from a positive increase in safety to a decrease in safety' (p. 23). When considering the OECD definition, one aspect is clearly different from the formalism presented by Evans. Not all behavioural changes are covered, but only the ones that are *not* consistent with the purpose of the change. It is defined that both positive and negative effects are included in the definition, not only negative effects. The important condition to be considered a behavioural adaptation is to be *unexpected*, either unexpectedly positive or negative. The fact that the existence of 'unexpected behaviour' is dependent on the intentions of the initiator has been criticised. Grayson [14], for example, stated that the intentions behind the road safety changes are not always clear and often all that can be said with any degree of certainty is that measures aim to reduce accidents, an aspect that is not easily linked with behavioural changes. Furthermore, any estimates on what will happen after a change is complex and might neither be predicted nor understood by the initiator of the change [19]. 'Only if reasonable estimates of what should happen are available, would it be possible to compare what actually did happen with these expectations, and hence determine whether there had been any adverse effect' ([14], p. 6). The fact that the change is not necessarily subject to be predicted or understood by the initiator shows that it is yet unclear whether or not behavioural adaptation is a conscious or a subconscious process. In order to evaluate this phenomenon, studies need to investigate the perceived and actual performance change of ADAS users. A further discussion on the level of drivers' awareness of the behavioural change is presented in Section 2.4.2 in connection with compensatory behavioural adaptation.

The adequacy of the OECD definition can be a matter of discussion regarding not only the predictability of the events, but also the type of consequences. Grayson [14] and Rudin-Brown [3] argue that although the OECD definition covers positive, negative or neutral effects on crash risk and overall road safety, the negative consequences of behavioural adaptation are usually the focus of research. Grayson emphasised that a less vague term should be used ('adverse behavioural consequences' was his proposition), focusing on the literal use of the word 'adverse' as opposed to safety. Grayson's vision to some extent has been supported in recent publications as, in certain cases, a reformulation of the term presented by the OECD was used. For example, Dragutinovic, Brookhuis and Marchau [4] focused exclusively on the negative aspects and mentioned that, in the framework of their study, the term 'behavioural adaptation' refers to 'unintended and unwanted changes in driver behaviour'. Likewise, Rudin-Brown [3] stated that for the purpose of the discussion elaborated in her article, behavioural adaptation would be defined as 'unintended behaviour that arises following a change in the road traffic system that has negative consequences on safety' (p. 252).

In spite of the discussions about the adequacy of terminology, the OECD definition has been used by several authors in the context of transportation psychology for studying the occurrence of such phenomenon after the introduction of in-vehicle technology [4, 20–26]. Therefore, it is worth explaining its boundaries in further detail. Additional assumptions about explanatory characteristics regarding the occurrence of behavioural adaptations contribute to a clearer understanding of the proposed concept. The first is the notion of *feedback*. Similarly to the work presented by Evans [11], for behavioural adaptation to occur, feedback from the road system change has to exist and has to be perceived by the road user (though not necessarily consciously). The speed at which behavioural adaptation occurs might be dependent on the feedback, as changes that are perceived quickly might result in faster behavioural changes. Different levels of feedback can be distinguished. For a discussion on the different time characteristics of feedback, see Section 2.5.

Apart from feedback, two other explanatory assumptions were integrated in the behavioural adaptation definition proposed by the OECD: the driver has to be *able to change the behaviour* and also has to have the *motivation to act* upon it. Both assumptions are straightforward. A driver that perceives a change in the system but is not able to change his/her behaviour will not show signs of behavioural adaptation. The same applies to motivation. For behavioural adaptation to occur, users must be motivated to behave differently; for example, they have to recognise the benefit of the behaviour modification. Furthermore, the OECD definition does not identify a temporal or spatial range of behavioural adaptation. The authors justify this due to the limited amount of empirical and theoretical work conducted on this matter. When the OECD definition was formulated, only the existence of the phenomenon and its different effects were able to be gathered. It cannot be expected that behavioural adaptation identified following a certain change will also appear when changes of different nature occur in the road transport system. For example, behavioural changes following the introduction of anti-lock braking systems will be different from behavioural changes following speed control systems. Behavioural adaptation is not only highly system specific but it also varies for different elements of the road transport system. This means that changes to the infrastructure (e.g. lane width, shoulder width edge line markings), changes related to education and enforcement (e.g. publicity campaigns, education and training, legislation and enforcement) and non-automated vehicular modifications in the vehicles (e.g. high-mounted braking lights, studded tyres, seat belts) might lead to such phenomena. Studies have shown that in response to increases in road and lane width, people drive faster [27–29], engage in more erratic manoeuvres (e.g. centre line crossings or steering corrections) [30] and drive closer to the road edge [31]. Other studies have found changes in driver speed related to street lighting [32, 33]. With regard to the previous studies, the introduction of new in-vehicle technologies is expected to change the driving task either by the automation of specific sub-tasks of driving, or by providing extra information to the driver (related or unrelated to the driving task) [34, 35]. The expected consequence of the technical development is the related change of the role of the driver. In the past the driver's role was to control the vehicle; in the future the driver's task will be to monitor the function of the ADAS and to resume manual control in certain situations such as an emergency. On one hand, ADAS replace some of the driver's tasks (e.g. speed choice, distance keeping, detection of relevant traffic information etc.) while on the other hand the management of ADAS is imposed on the driver. The driver needs to gradually develop this 'new role', because otherwise, unintended ADAS effects due to drivers' human capabilities and limitations could emerge. System developers can help to prevent unintended effects by considering the 'human factor' within the complex interaction of driver, vehicle and environment when new systems are introduced.

2.4 Theories accounting for behavioural adaptation effects

A number of theories have been proposed to account for drivers' adaptive changes in response to new technologies [36–40]. The theories place varying amounts of emphasis on different types of processes and influencing factors. They all try to explain, to some extent, the underlying mechanisms of behavioural change found in empirical research. As stated above, researchers [e.g. 3, 5, 7] have reviewed the 'behavioural adaption' debate. All attempts to explain the phenomena can be classified into either *learning theories* or *driver risk theories*. Both approaches are described in more detail below. In order to investigate a more conclusive approach to contribute to the understanding of behavioural adaption, three *integrative models* are presented as well.

2.4.1 Behavioural adaptation and learning theories

Behavioural adaptation is strongly connected to learning effects. In the literature, it is assumed that the exponential learning curve is applicable for changes in human behaviour over time. In the context of skill learning and traffic research, Elvik [41] has identified statistical regularities that refer to 'laws of accident causation'. One of these is the *universal law of learning*, which implies that accident rate per unit of exposure will decline as the amount of exposure increases. Although Elvik refers to a driver's ability to detect and control traffic hazards as the amount of travel increases, the universal law of learning is also appropriate for explaining adaptation effects when exposure to ADAS increases. Thus, the more exposure to ADAS the more learning is involved, which results in fewer accidents.

Another theory in connection to behavioural adaptation and learning is the *Skill-Rules-Knowledge model* [42], which explains how human behaviour changes with practice. This model was developed further from the original model by Fitts and Posner [43], which has also resulted in simulation models such as ACT-R [44, 45]. Fitts and Posner termed the initial stage of skill learning as the cognitive phase followed by the associative phase and finally the autonomous phase. It is assumed that experts can execute certain tasks following automated routines that demand little or no conscious control and/or attention. However, the three processing stages highly depend on the task at hand. As such, an expert driver can all of a sudden become almost novice due to the introduction of an ADAS which might change the task at hand.

The *change in mental representations* is another example of an issue worth mentioning. During interaction with ADAS, drivers build mental representations of the system. These mental representations are internal models formed in a specific context and for a specific aim [46]. They directly influence the modes of cooperation between the driver and the system because they reflect the users' understanding about the functioning principles and the usage conditions of the system. Mental representations can change over time and as they are not true copies of objective reality they may diverge from it considerably. Therefore, when mental representations are not properly formed, they can trigger misuses of the system, leading to possible dangerous situations. Finally, behavioural adaptation and learning is also connected to the *enhancement of perception and attention*. Thus, Smiley [2] suggests that the primary motivations for behavioural adaptation are the intelligent re-allocation of attention and effort. This will not necessarily lead to constant accident rates but may lead to trade-offs between mobility and safety.

2.4.2 Behavioural adaptation and driver risk models

The OECD scientific expert group [12] suggested that Wilde's *risk homeostasis theory* [10] provides the most complete explanation for behavioural adaptation, and although controversial and heavily criticised, this theory has received the greatest amount of attention from researchers. Its basic assumption is that people have a target level of risk that they accept, tolerate, prefer, desire or choose. Whenever road users perceive a discrepancy between the target level of risk and experienced risk in one direction or the other, they will attempt to restore the balance through some kind of behavioural adjustment. This is referred to as risk compensation or behavioural compensation performed by drivers in response to any change in the perceived risk. Two examples of behavioural compensation are first, drivers compensating for the increased cognitive demand of driving while using a mobile phone by driving more slowly and thereby increasing safety margins [47]. And second, Lewis-Evans and Charlton [48] found that drivers reduce speeds on a narrowed road accompanied by increased ratings of risk. The results support a zero perceived risk model of behavioural adaptation to road width as an implicit perceptual process rather than explicit, conscious process. In their study Lewis-Evans and Charlton [48] compared perceived and actual performances in response to traffic changes but not in response to ADAS. When evaluating driver's level of consciousness and self-awareness for compensatory behaviour when using ADAS, a study design should investigate driver's perceived and actual response to ADAS.

Evolving from research on compensatory behaviour is the concept of *counterproductive behavioural adaptation*. Heijer, Brookhuis, Van Winsum and Duynstee [49] define counterproductive behavioural adaptation as a phenomenon where drivers start to behave in riskier ways because they are supported by an ADAS. Contrary to compensatory behavioural adaptation, counterproductive behavioural adaptation only targets behavioural changes that affect safety negatively. Supporting theories on counterproductive behavioural adaptation is a study by Comte [6] comparing measures of safety when driving with and without an 'Intelligent Speed Adaptation System', restricting drivers to the posted speed limit. Results show that drivers were more inclined to engage in riskier behaviour when driving with the 'Intelligent Speed Adaptation System'.

2.4.3 Integrative models on behavioural adaptation

The OECD work [12] criticises most general attempts to model behavioural adaptation as too vague, overly general and only indirectly related to behavioural adaptation. Therefore, recently there were attempts to specifically model behavioural adaption in order to draw more definitive conclusions. One example is the '*Qualitative model of behavioural adaption*' by Rudin-Brown [3] and Rudin-Brown and Noy [38]. Instead of establishing a hierarchical model (static) that would explain behavioural changes due to the use of ADAS, the model is a dynamic model that helps to understand behaviour and the associated changes over time. Through its iterative character, the model offers the opportunity to explore and explain behavioural adaptation over time periods, which can also include changes from an earlier negative displayed behaviour back to a positive driving behaviour. The model includes psychological concepts and their contribution to driver's behaviour and proposes that the driver's dimensions locus of control and sensation-seeking, both being personality factors, contribute to the development of behavioural adaptation. Drivers with an internal locus of control may rely more on their own skills and abilities and, no matter how reliable a safety system, always maintain more direct involvement with the driving task than drivers with an external locus of control. Conversely, drivers with an external locus of control may be more likely to give up control to an external system, relying on it completely, resulting in reacting more slowly when the system fails to perform the task it was designed to do. Furthermore, according to the model, drivers who are high sensation seekers, compared to low sensation seekers, may demonstrate more behavioural adaptation due to their preference for a higher level of risk (assuming that the intended effect of an ADAS is to reduce the level of risk). Additionally, personality factors directly and indirectly (through trust in automation) influence the driver's 'mental model'. Generally, false trust in an ADAS is the primary concern of road safety researchers. False trust is where an operator trusts and uses poor quality automation and shows reduced alertness due to less monitoring of the device. The 'Qualitative model of behavioural adaption' [38] predicts that the degree of behavioural adaptation will be related to the amount of trust a driver has in the system (wherein trust includes 'reliability' and 'competence' of the system), which is determined by the system's characteristics such as feedback timing (immediate vs. delayed), amount of usage (amount of exposure) and persistence.

An example for a static rather than a dynamic model is the '*Process Model of behavioural adaptation*' by Weller and Schlag [40]. In the model behavioural adaptation only occurs when the driver is aware of the new possibilities offered by the system. This may depend on several factors such as an indirect feedback (e.g. media), a direct feedback (e.g. haptic or visual) or driver's characteristics (e.g. experience, age). Furthermore, it is likely that behavioural change may occur even though this change in behaviour is not consciously perceived by the driver. An example of this may be the earlier case of a driver with an external locus of control who subconsciously is more likely to give up control to an external system, resulting in reacting more slowly when the system fails to perform the task it was designed to do. Because this model does not take the effect of time into account, it is questionable whether the variables in the model influence the direction and magnitude of behavioural adaption.

A model that aims to draw attention to the interdependences of relevant variables influencing the driver's behaviour is the '*Conceptual model of driver appropriation*' presented by Cotter and Mogilka [36]. As an extension of existing conceptual models [e.g. 38, 40] an attempt was made to consider the full range of driver's behaviour processes, including behavioural adaption, risk compensation, and changes in information processing in response to the introduction of ADAS. The model takes into account the timely interaction of these processes as well as mediating factors and the relationship between them. The model not only accounts for observable behaviour but also the underlying cognitive, energetic and motivational factors. The central focus of the model is a driver's mental representation of an ADAS. During the initial phases of interaction with a new ADAS, the driver begins to build up a mental representation of the system's behaviour and functioning. This mental representation is continually elaborated and refined, thus getting more and more comprehensive and sophisticated over the time of system use. After some learning and a familiarisation period, the driver will have developed a relatively stable mental representation of the system that subsequently governs behaviour. Nevertheless, the consequences of driver's behaviour will provide feedback and cause the mental representation to be revised and refined accordingly.

In sum, generally a number of theories have been proposed to account for driver's adaptive changes in response to new technologies [36–40]. The theories place varying amounts of emphasis on different types of processes and influencing factors. They all try to explain, to some extent, the underlying mechanisms of behavioural change found in empirical research. As stated earlier, all attempts [e.g. 3, 5, 7] to explain the phenomena can be classified into either *learning* *theories, driver risk theories* or a more conclusive approach, which is *integrative models of behavioural adaptation.*

In the future, in order to investigate underlying behavioural adaptation processes it is necessary to carefully examine behavioural adaptation effects. Survey questionnaires can be an appropriate tool to study the subjective modification of behaviour, which might give valuable insight into less obvious processes. One example of a less obvious process is a user not fully attending to the road ahead when using an in-vehicle navigation system [50]. Questionnaire data can also show ADAS perception and acceptance. For example, questionnaire results of 130 Adaptive Cruise Control system users showed that the longer drivers use the Adaptive Cruise Control system, the more aware of its limitations they become [51].

2.5 Behavioural adaptation over an extended period of time

Long-term ADAS effects can only be studied during long-term usage (e.g. days, weeks, months or years of exposure). One important aspect of ADAS, often asked by system developers, is, how long do drivers take to adapt to a system, e.g. to use a system as intended and to understand a systems functions?

Evans [11] suggested that *the time* taken for behavioural changes to occur depends on the *ability of road users to detect changes*. Using his interpretation, easily perceived changes will result in relatively quick behavioural adaptation (hours, days or weeks). For more subtle changes of a system (e.g. road width modification), it takes longer for both the detection and manifestation of the behavioural adaptation (months or years). The OECD expert group [12] views behavioural adaptation differently. As mentioned before, the OECD postulated three prerequisites for behavioural adaption to occur: (1) the presence of system feedback to the driver, (2) the driver's ability to change the behaviour and (3) the driver's motivation to act accordingly. Though it is possible to distinguish between different levels of feedback and timings for the behavioural change, the OECD report highlighted that the initial response after a change in the road system is not included in the proposed behavioural adaptation definition. The initial response might be required and expected by the promoter of the system change, to elicit the planned goals. Therefore, behavioural adaptation occurs only *after the initial response* and can be characterised by the process during which the driver integrates the behavioural change in their normal behaviour. A similar notion is followed by Saad and colleagues [52], addressing that behavioural adaptation to in-vehicle systems may not always appear immediately when the driving context is changed, but it usually appears after a familiarisation period. Viti, Hoogendoorn, Alkim and Bootsma [53] regarded a 'two' week learning phase to Adaptive Cruise Control systems as 'fast', referring to a study by Weinberger, Winne and Bubb [54] that estimated that 67% of the drivers learn how and when to use an Adaptive Cruise Control system and when to overrule it within two weeks.

Previous studies [55, 56] give evidence that there are different *behavioural adaptation stages*. Overall, the timing of these stages seems as unclear as the

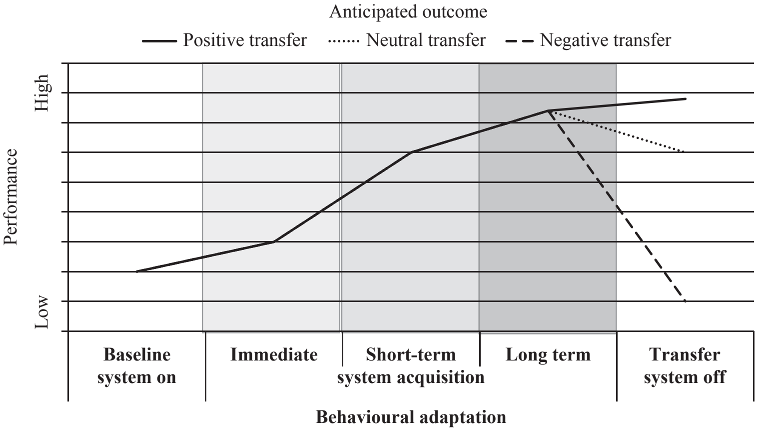

Figure 2.1 Stages of adaptation relative to system use (adapted and printed with permission [55])

definition of these stages. Manser, Crease and Boyle [55] consider adaptation in three stages: immediate (immediately after a driver experiences a change in a safety system), short term (hours, days or weeks after a change in a safety system) and long term (months or years following the change). Manser *et al*. updated the original figure [55] as shown in Figure 2.1. These stages may be considered when examining behavioural adaption relative to safety system use as the quality of the performance is a result of the introduction of a system and its continuous use. According to Manser *et al.* there is always an improvement in performance after the system is activated, a fact that has not always been supported by other researchers.

Some researchers have shown negative behavioural changes that could compromise safety [e.g. 4, 7, 38, 57, 58]. Different effects of studies [59] could be explained by differently defined adaptation time frames (behavioural adaptation stages). A study that systematically investigated two behavioural adaptation stages showed varying driver reactions depending on the time passed after drivers received an ADAS warning, and provided primary empirical evidence for various behavioural adaptation stages following changes in the driving task. Wege, Will and Victor [56] found, using naturalistic driving data, that there is a further adjustment (‘post-threat recovery period’) after the initial response (‘threat-period’) to brake-capability forward collision warnings. The use of Manser *et al.* terms and Wege *et al.* terms represents an important area that needs to be clarified in further literature. An attempt to define the stages or phases of behavioural adaption to new in-vehicle technologies over time has been made by Wheatley [60] in the context of the ‘culture shock concept’ that may help to understand some of the processes involved. ‘Culture shock’ can be defined as ‘the psychological disorientation experienced by people who suddenly find themselves living and working in radically different cultural environments' [61]. Culture shock is characterised by four stages [62], which may apply in similar ways to the process of adaption to new products or systems. These four stages are: the honeymoon stage, the hostility stage, the adjustment stage and the acceptance stage. According to Wheatley the classic stages of culture shock, and its emotional reactions, may be adapted to describe the consequences of driver's behavioural stages following the introduction of ADAS. The first and fourth stages may be associated with positive pleasure experiences while the second and third are associated with negative experiences and stress.

Lately, large field operational test (FOT) studies have investigated behavioural adaption to active safety systems over an extended period of time, e.g. in the Netherlands [53] and across several European countries [63]. One of the first long-term ADAS-related studies presented was an Australian case study reporting a year-long real-world deployment of a driver inattention warning system (DSS) [64]. Results show a trend in the reduction of distraction events during the DSS-alert period. The change in the driver's behaviour is also reflected in the decrease in high acceleration and deceleration events recorded by the DSS. This trend can be attributed to a change in driver's behaviour to avoid actions that trigger distraction alerts, such as long glances away from the road.

Apart from the potential of FOTs investigating ADAS effects over an extended period of time, FOTs can also shed light on real-world examples of *behavioural adaptation to non-driving related tasks*. For instance, in one in-car study the use of speed regulation assistance systems and mobile phone use over a time period of 4 weeks was investigated. Drivers reported strategies related to the use of speed regulation assistance systems in order to compensate for attentional resource allocation to a phone call [65]. This corresponds to the results of a focus group study that suggested that the use of Adaptive Cruise Control systems may promote the occurrence of non-driving related activities [66]. Rudin-Brown and Parker [21] found that drivers reinvested some of the spare cognitive resources into the cognitively demanding non-driving task, e.g. using a cell phone while driving. Rudin-Brown and Parker argue that the increased comfort level provided by driver support systems is similar to a currency to the driver. The mental (and physical) resources 'saved' by the safety and controllability functions of the system can be used to 'finance' behavioural adaptation by 'purchasing' other secondary activities in conjunction with the primary driving task that satisfy the driver's motives [21, 67]. Once more, naturalistic driving studies are found to be a valuable approach in studying the effects of ADAS on the primary driving task as well as on the secondary non-driving tasks.

2.6 Behavioural change transfer

Research should not only include how long it takes to change behaviour, but also whether the change continues after a safety system is no longer in use. Recently, the first theories on a more extended timespan of behavioural adaptation have been published [55]. Those theories form around the *concept of behavioural change transfer* that identifies 'carry-over' effects after ADAS removal. Three examples of behavioural change transfer are: first, a case when a driver decides to switch off a certain safety device after using it for an extended period of time, or second, when a fleet driver switches to drive from a fleet vehicle equipped with ADAS to drive a fleet vehicle not equipped with ADAS. Third, behavioural adaptation may also change as a result of a change in the configuration of the technology, e.g. improved radar capability. These cases are known from real-world examples from FOT studies [e.g. 63] and show that the experimental design of field or driving simulator studies should include the investigation of behavioural change transfer effects. In the stage schemata [Fig. 2.1], the quality of the performance is not only represented by the result of the introduction of a system and its continuous use, but also after the removal of the safety system. According to Manser *et al.* [55], after the driver has used the system for some time, the anticipated outcome in performance slowly deteriorates and can have three possible outcomes after system removal: a positive transfer (quality of performance is higher than before system use), a neutral transfer (quality of performance is on the same level as before system use) or a negative transfer (quality of performance is worse than before system use). Manser *et al.* state that 'most safety system developers hope that their products would promote neutral transfer in that any behavioural adaptations present would dissipate after safety system use has concluded' [55, p. 344]. In that regard, positive and negative transfer only relates to any carry-over effects without addressing the quality of the effect. This theory is derived from the human motor learning and control literature, wherein positive transfer suggests only those behaviours learned during skill acquisition are exhibited sometime later, whereas negative transfer suggests that opposite behaviours occur. Hence, *positive transfer* is defined as any performance, after system removal, being consistent with the systems intended goals of enhancing safety. Positive carry-over means that an ADAS continues to support safe mobility after system use is discontinued. Because the discussion on possible 'carry-over effects' is very new, the terms used to describe these effects need to be standardised and used in a way that is not contradictory. Also, a *multi-stage* description of adaptation processes will be needed in future literature. Manser and colleagues postulate a '*two-stage adaptation process*' ((1) ADAS use, (2) ADAS disuse). However, in practise there could also be a 'three-stage adaptation process' to technology ((1) ADAS use, (2) ADAS disuse, (3) ADAS re-use) and so forth.

Future research would benefit from the inclusion of 'behavioural adaptation transfer' as an experimental methodological factor, for example using an ABA experimental design (control–treatment–control experimental design). ABA-design studies allow analysing persistent intervention effects such as in a study by Carney, McGehee, Lee, Reyes and Raby [68], who found that an event-triggered video intervention system significantly reduced the number of behavioural events during the intervention and did not significantly increase during the second baseline, which was assessed after the intervention ended. Within the ADAPTATION project, behavioural change transfer was also taken into consideration when designing simulator experiments. For example Dotzauer, Caljouw and Brouwer [69] investigated the effects of an intersection assistant system for older drivers in an ABA experimental design. A similar notion of behavioural adaptation was considered in a study by Gouy [70] on behavioural adaptation of unequipped vehicle drivers to the short time headway maintained by vehicles in a platoon. Unequipped vehicle drivers were found to reduce their time headway while they were driving next to a platoon, but the effect disappeared as soon as they passed the platoon.

In sum, in order to answer the question ‘How lasting is the effect of an ADAS intervention and/or assistance?’, behavioural adaptation studies need to be designed accordingly in the future. It is necessary to consider the different extended time frames of behavioural change, otherwise one might interpret that no behavioural adaptation occurred while it actually takes longer to capture an existing behavioural change [e.g. 24].

2.7 A ‘Joint Conceptual Theoretical Framework (JCTF) of Behavioural Adaptation in Response to Advanced Driver Assistance Systems’

The result of the literature review on behavioural adaptation in response to new technologies showed that there is no model that joins the plurality of factors into one framework. As this chapter outlines, a number of theories have been proposed and each place emphasis on different types of processes and mechanisms that influence behavioural adaptation. Although several theories try to model and explain ADAS effects, they can only partly elucidate the inconsistent results. However, none of them allows for specific predictions of how ADAS will influence the driver’s behaviour and underlying processes dependent on the type of system studied, the design of the driver–system interaction, the context of use and individual driver characteristics. Currently, there is a lack of research programs that have systematically investigated the conjoint short-, medium- and long-term effects of system properties, on driver’s cognitive, energetic and motivational processes underlying behaviour. Thus, one objective of the ADAPTATION project was to develop a conceptual framework [71]. This framework displays the multiple factors acting simultaneously in a complex interplay. Because research on behavioural adaptation to ADAS is still at an early stage, the development of a detailed model is challenging. The aim of the ‘*Joint Conceptual Theoretical Framework (JCTF) of Behavioural Adaptation in Response to Advanced Driver Assistance Systems*’ (Figure 2.2) was to identify the range of relevant internal and external factors associated with behavioural adaptation. The objective of the JCTF was not to develop a model on behavioural adaptation including details on interaction mechanisms, but to show a wide view

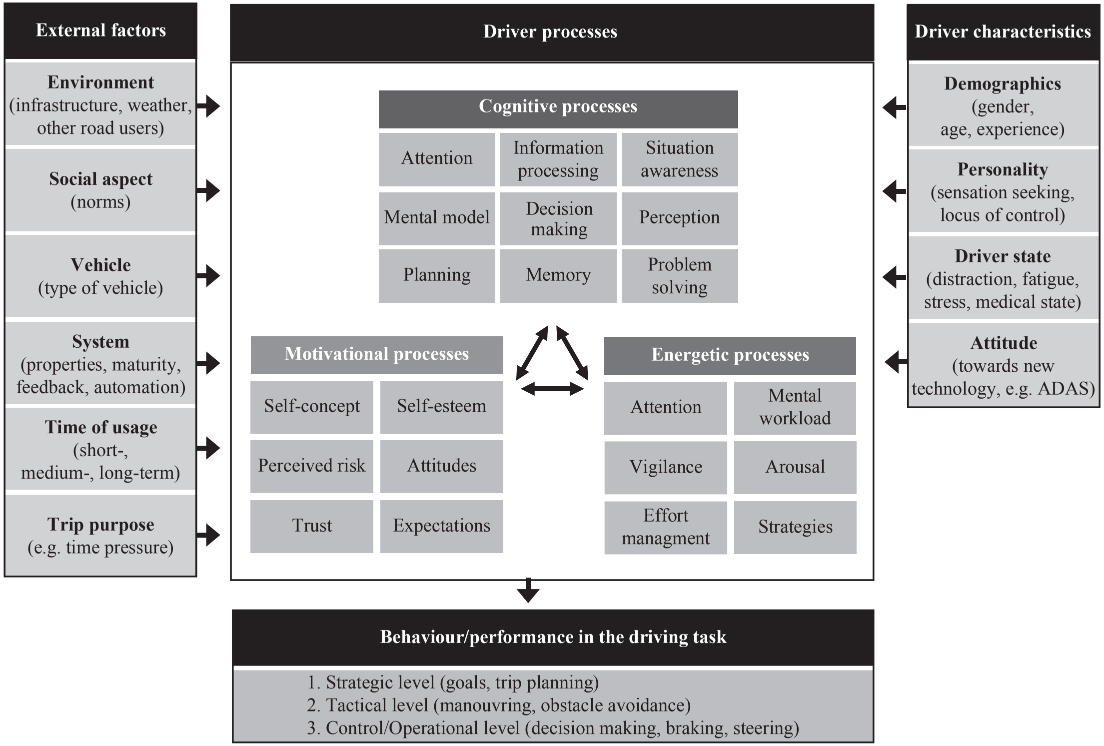

Figure 2.2 Joint Conceptual Theoretical Framework (JCTF) of Behavioural Adaptation in Response to Advanced Driver Assistance Systems

regarding the nature of adaptation processes, emphasising that adaptation does not only include observable behavioural changes, but also psychological driver processes. The definition of behavioural adaptation did not only include unintended changes but also intended changes following ADAS interaction. It is an *integrative* theoretical framework that enables researchers to generate research questions and predictions about the influence of ADAS on different behavioural levels. The JCTF does not target one specific ADAS. It is more a union of various ADAS applications. The behavioural levels, such as strategic, tactical and operational, are adapted from Michon [72]. Furthermore, the JCTF identifies the most relevant external factors and driver characteristics influencing the occurrence and magnitude of behavioural adaptation. External factors such as context variables, e.g. driving task demands, conditions of travel, and driver characteristics, e.g. personality traits such as sensation seeking, locus of control, or a general propensity to trust, as well as attitudes towards ADAS, are expected to influence different psychological processes. The outstanding and innovative characteristic of the JCTF is that it does not only focus on behavioural performance changes but also on their underlying driver internal processes. Those processes are identified as cognitive, energetic and motivational. Each process is characterised by different psychological concepts, which are interrelated with one another without following a hierarchical order.

The *cognitive process* includes:

- Attention [56, 65, 69] and this book Chapters 6, 8, 11 and 12
- Situation awareness [73] and this book Chapter 8
- Mental model [73] and this book Chapter 5
- Information processing [69, 73] and this book Chapters 6 and 12
- Perception [56] and this book Chapter 12
- Problem solving, this book Chapter 12
- Memory, this book Chapter 12
- Planning [65]
- Decision making [65, 69] and this book Chapter 6

The *motivational process* includes:

- Trust [73] and this book Chapters 1 and 5
- Expectations, this book Chapters 5 and 8
- Attitudes, this book Chapter 8
- Perceived risk, this book Chapter 8

The *energetic process* includes:

- Mental workload, this book Chapter 10
- Strategies [65]

In the following chapter of this book some of the collected factors are explained in more detail and in Chapter 17 further research recommendation in regard to the JCTF is given.

2.8 Conclusion and further research needs

In the past decades, behavioural adaptation has received an increasing amount of research attention. Since the OECD [12] definition that postulated the prerequisites of behavioural adaptation: (1) the presence of feedback of the behaviour, (2) the motivation to change behaviour and (3) the human capability to change behaviour, 24 years have passed and new in-vehicle technologies have entered the market. It is time to revisit these prerequisites, to include behavioural transfer into the definition and to advance the development of integrated theoretical models. The ADAPTATION project has expedited this development. The literature review on behavioural adaption to new technologies showed there is a need to advance the debate towards clearer terminology on behavioural adaptation processes.

With the vast progress in automobile technology and the implementation of ADAS, the driving task changes. In the future, the driver's role might become being a 'supervisor of ADAS' rather than the person controlling the vehicle. System designers assume that behavioural adaptation will occur [59] because it is intrinsic to human nature to try to modify behaviour to suit new conditions. Research must identify the nature of these changes in the complex human–machine interplay in order to enhance system design. The results of research on behavioural adaptation should be included in the design of new in-vehicle support systems and in the assessment processes of the associated user interfaces.

Until recently, most research on driving support systems only took a 'snapshot' of behaviour with the system. In order to capture instances of behavioural adaption, studies need to last over longer periods of time. In FOT studies and naturalistic driving studies, a natural behavioural response to ADAS, without the interference of an examiner, can be investigated. The challenge of assessing behavioural change in laboratory settings to naturalistic driving settings is further discussed in Chapter 3.

Empirical research does not yet reveal how lasting the behavioural adaptations during safety system exposure are, and how transient the behavioural adaption effect after system removal is. It is likely that there are immediate, short-term and long-term effects on performance. When designing a study investigating behavioural adaptation, it is necessary to consider the different extended time frames of behavioural change, otherwise one might interpret that no behavioural adaptation occurred while it actually takes longer to capture a change.

Based on the review of existing theories of behavioural adaptation, a '*Joint Conceptual Theoretical Framework (JCTF) of Behavioural Adaptation in Response to Advanced Driver Assistance Systems*' was developed in order to combine multiple aspects of the driver–vehicle–environment concept. The strength of the framework is the identification of important variables associated with behavioural adaptation. In further research, it is necessary to critically analyse the concepts and variables involved, to identify the advantages and disadvantages of a qualitative framework and to find out about the independence or overlapping of different concepts.

Is the initial question in this chapter of Khalil Gibran's idea of 'adaption to new life conditions' transferable to transport research? As this chapter outlined, the answer is complex. However, one fact seems to be certain: 'Change is constant'.

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CHAPTER 3 PAPER II

Paper II

Eye movement and brake reactions to real world brake-capacity forward collision Warnings —
A naturalistic driving study

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Eye movement and brake reactions to real world brake-capacity forward collision warnings—A naturalistic driving study

Claudia Wege[a,*], Sebastian Will[b], Trent Victor[a]

[a] *Volvo Group Trucks Technology (GTT), Sweden*
[b] *University of Wuerzburg, Germany*

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ABSTRACT

The purpose of this field operational test study is to assess visual attention allocation and brake reactions in response to a brake-capacity forward collision warning (B-FCW), which is designed similarly to all forward collision warnings on the market for trucks. Truck drivers' reactions immediately after the warning (threat-period) as well as a few seconds after the warning (post-threat-recovery-period) are analyzed, both with and without taking into consideration the predictability of an event and driver distraction. A B-FCW system interface should immediately direct visual attention toward the threat and allow the driver to make a quick decision about whether or not to brake.

To investigate eye movement reactions, we analyzed glances 30 s before and 15 s after 60 naturally occurring collision warning events. The B-FCW events were extracted from the Volvo euroFOT database, which contains data from 30 Volvo trucks driving for approximately 40 000 h for four million kilometers.

Statistical analyses show that a B-FCW leads to immediate attention allocation toward the roadway and drivers hit the brake. In addition to this intended effect during the threat-period, a rather unexpected effect within the post-threat-recovery-period was discovered in unpredictable events and events with distracted drivers. A few seconds after a warning is issued, eye movements are directed away from the road toward the warning source in the instrument cluster. This potentially indicates that the driver is seeking to understand the circumstances of the warning. Potential reasons for this are discussed: properties relating to the termination of the warning information, the position of the visual and/or audio warning, the conspicuity of the warning, the duration of the warning, and the modality of the warning.

The present results are particularly valuable because all on-market collision warning systems in trucks (and almost all in cars) involve visual warnings positioned in the instrument cluster like the one in this study. Acknowledging the fact that human machine interface (HMI)-design is challenging, the conclusions lead the way toward HMI design recommendations for collision warning systems.

1. Introduction

In 2009, there were about 35 500 fatalities in traffic accidents in the EU27 countries. Heavy trucks are involved in about 17% of these fatalities (Wrige Berling et al., 2011). Due to the big mass of a heavy truck (>12 t) the outcome of an accident with a heavy truck is usually very severe, making it an important research topic for road safety. In this study we focus on rear-end truck collisions, which account for more than 19% of all truck accidents and 91% of all rear-end collisions in Sweden (STRADA database, Wrige Berling et al., 2011).

Forward collision warnings have the potential to reduce the number of rear-end collisions. Currently, there are two types of forward collision warning systems on the market: a full forward-collision warning (FCW) system (mostly in passenger cars) and a brake-capacity forward collision warning (B-FCW) system (mostly in trucks). A full FCW operates independent from an Adaptive Cruise Control (ACC) system and issues a high-priority warning (EC, 2011) alerting the driver of a potential collision with another vehicle in the forward path on straight roads (ISO 15623, 2002). A B-FCW is connected to the ACC system. If a truck catches up with a vehicle that is traveling slowly and the ACC cannot manage to brake sufficiently, then a collision warning is issued.

The difference between a FCW system and a B-FCW system is that the full FCW is specifically designed to detect a crash in more severe situations whereas the B-FCW system may warn in a collision impending situation *if* that situation causes the brake-capacity of the ACC system to be exceeded. A B-FCW informs the driver to use the footbrake to reduce speed sufficiently. Thus, the warning

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[*] Corresponding author at: Volvo Group Trucks Technology (GTT), Advanced Technology & Research, Götaverksgatan 10, SE-40508 Göteborg, Sweden. Tel.: +46 073 90 24082.
E-mail address: claudia.wege@volvo.com (C. Wege).

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signals the driver to react. The intention is to make drivers look immediately forward and assess the threat to make an important safety decision: either to hit the brake pedal or to continue driving at the same speed. A key challenge is to understand exactly the detailed composition of the responses.

Directing glances, and thereby attention, to the road is necessary in two especially dangerous B-FCW scenarios which can cause drivers to react slower. Scenario one is an unpredictable event, for example an unexpected change of the traffic situation associated with a risk of a rear-end crash (e.g. hard braking lead vehicle). Unpredictable events are a particularly important safety threat.

The second scenario is an event when the driver is distracted (e.g. driver is engaged in a secondary task). Distraction has been identified as a primary contributor to rear-end collisions and many studies point to the necessity of including conditions of distraction when studying reactions to collision warnings (Kidd et al., 2010; Hanowski et al., 2005; Llaneras, 2000; Stutts et al., 2001). Results from naturalistic driving studies show that 75% of the drivers are non-attentive to the forward roadway right before a frontal collision occurs (Dingus et al., 2006a,b; Olson et al., 2009).

Currently, all on-market FCW systems in trucks and almost all FCW systems in cars present a visual warning in the instrument cluster (Brockmann and Nawrat, 2010). A few car models present a FCW in a head-up display (Brockmann and Nawrat, 2010). As the primary intention of a forward collision warning is to cause the driver to immediately look forward, the warning needs to be designed optimally so that forward glances are encouraged. Thus, forward glance responses to the warning have implications for the design of the human–machine-interaction (HMI). Although the importance of human factors issues is well known (Campbell et al., 2007; Lee and Kantowitz, 1998; Parasuraman et al., 2000), a definitive understanding of proper FCW design is lacking. The level of current knowledge regarding warning effects in collisions and near-collisions is sketchy primarily because of the difficulties involved in studying in situ reactions to warnings for real safety critical events in the field, and the lack of operational data logged in real world traffic scenarios (SAE J2400, 2003). More research on the effects of different HMI solutions for real-world warnings is needed, thus motivating the current study.

Guidelines and requirements for FCW HMI design are preliminary. The only ISO standard dealing with FCW systems specifically (ISO 15623, 2002) emphasizes details of system sensor capabilities and algorithms rather than HMI requirements. There are some FCW user interface requirements available for voluntary use (SAE J2400, 2003; EC, 2011; Campbell et al., 2007; AAM, 2006; JAMA, 2004). Some recent recommendations indicate that presented information should not impair a driver's visual attention allocation to the road scene (e.g. windshield warnings should not occlude hazards), and a collision warning should not be placed in the conventional dashboard, such as in the instrument cluster by the speedometer (SAE J2400, 2003). Moreover, Lerner et al. (2011) recommend that visual warnings shall be placed within 15° of the driver's forward line of sight. These recommendations are generally in line with previous research stating that a system is visually distracting when the driver spends a significant proportion of time looking at it rather than at the road (Chiang et al., 2004; Noy et al., 2004). In fact, any display that demands visual attention is considered a potential contributor to accidents (Baumann et al., 2004). Nevertheless, it is still unclear if looking at a head up display warning is substantially better than a warning in the instrument cluster.

Data from real world traffic scenarios are a good source for assessing drivers' natural interactions with advanced driver assistant systems such as B-FCW systems. It is questionable whether simulator or test-track set-ups generate authentic responses to warnings (i.e. possess external validity). In particular, due to the repetition of critical events, FCWs become predictable and thus may not be representative of real-world critical FCWs, which are generally unexpected. Ljung Aust (2012) found that a repetition of critical events causes very different behavioral responses to FCWs. Naturalistic observations have strong construct and face validity for the following reasons: first, important information lies within the complex circumstances and scenarios that lead to real world warnings. Second, naturalistic observations are collected in the setting in which the behavior of interest occurs, for example it is difficult to attain "true distraction" in an (semi-) artificial setting (Ahlström et al., 2011). Third, no matter how realistic a simulated setting is, artificial collision events do not replicate the same amount of risk inherent in a collision on an actual highway (Eby, 2011; Lind, 2007). Fourth, in naturalistic driving studies the tested sample of participants is usually an actual system user, for example commercial truck drivers, who show a unique interaction with the device (Hanowski et al., 2005, 2007).

Studying driver behavior in real-life, undisturbed settings can provide useful HMI design-related knowledge. Therefore, HMI interaction data is collected from different field operational tests (e.g. euroFOT (euroFOT, 2012), SeMiFOT (Victor et al., 2010), SHRP2 (Antin et al., 2011)) and naturalistic driving studies (Dingus et al., 2006a,b; Olson et al., 2009). Over a long period of time (e.g. several months) sensor data related to driver behavior (e.g. brake reactions) and video data are recorded. So far, naturalistic on-road driving data have been used to evaluate different collision avoidance algorithms (Abe et al., 2011; Hanowski et al., 2005; McLaughlin et al., 2008; Perez et al., 2009; Zador et al., 2000 in the ACAS program) or different time to collision algorithms as in the NHTSA rear-end crash prevention research program (Kiefer et al., 2003). However, to date, studies investigating the systems' interface were either carried out on test-tracks or have been conducted in driving simulators. Within simulator studies, different warning modes have been tested. Those included for example various visual or audio-visual warnings (Abe and Richardson, 2006; Lee et al., 2002; Liu and Jhuang, 2012; Liu and Wen, 2004; Lind, 2007; Maltz and Shinar, 2007; Mohebbi et al., 2009; Zhong et al., 2011), different haptic alerts in the driver seat (Bella and Russo, 2011; Fitch et al., 2011; Ho et al., 2005, 2006), or tugging seatbelt FCWs (Lerner et al., 2011). Only a few studies have examined the effect of visual warning positions using a mock-up leading vehicle on a test-track (Ben-Yaacov et al., 2002; Dingus et al., 2006a,b; Lerner et al., 2011).

To our knowledge analyses of *visual responses and brake responses* to authentic, naturally occurring B-FCWs, have not yet been published. This study closes this gap, investigating natural visual interactions with B-FCWs and associated brake responses of professional truck drivers. The warning interface of the tested B-FCW system is designed to fulfill its purpose of warning the driver as efficiently as possible when the Adaptive Cruise Control function (ACC) cannot manage to brake sufficiently. However, due to the lack of published real world data, the true effect and efficiency is yet unknown to the research community.

In this study, glance behavior and brake reactions are analyzed immediately after a real world B-FCW occurs and are compared to a silent warning condition where a warning is triggered by the system but no warning is issued to the driver. The immediate reaction to a threat is ultimately the most important one for avoiding a rear-end crash. The first second after a warning is therefore called the threat-period (Fig. 1). The 10 s after a warning is called the post-threat-recovery-period in which the post-warning reactions are analyzed. The particular interest of this study is to assess glance behavior and brake reactions during these two periods after the warning and to compared them to the 10 s prior to the warning. These periods are compared for both the deactivated warning condition ("silent warning") and the activated warning condition and the active warning condition. B-FCW should increase drivers'

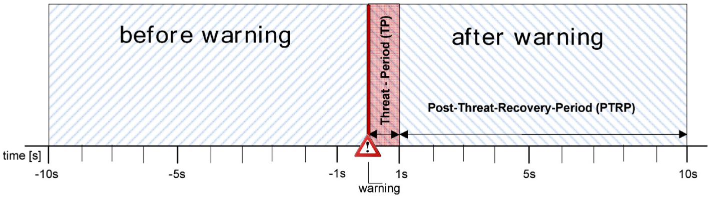

Fig. 1. Threat-period and post-threat-recovery-period.

attention on-road. This should especially be true for unpredictable events and situations when the driver is distracted.

2. Method

2.1. *The brake-capacity forward collision warning system (B-FCW system)*

The B-FCW system was part of the Adaptive Cruise Control System (ACC) (Model: Volvo ACC2 supplied by TRW Automotive), which only issued a B-FCW when ACC was switched on. The ACC was switched on in approximately 95% of all B-FCW events in the Volvo euroFOT database when a B-FCW was recorded in the log file. The activation of the B-FCW (e.g. the timing of warning onset) was in accordance to regulation No 661 from the European Commission (EC, 2009). The ACC used radar to scan the area in front of a truck. When a target vehicle was detected, it was indicated in the instrument cluster by a green target symbol illuminating, which was located to the left of the speedometer (Fig. 2). According to the Volvo ACC operating instructions (2007), a collision warning occurred when the truck caught up with a vehicle that was traveling so slowly that ACC could not manage to brake sufficiently. A collision warning consisted of a combination of a visual and an audio alert. More precisely, the illuminated green target symbol in the instrument cluster changed its color to red. Simultaneously with the red target symbol, 21 light emitting diodes (LEDs) which were positioned in a half circle on the outer bounds of the speedometer (Fig. 2) lit up in red (lights did not flash). An audio signal was issued simultaneously with the onset of the red LEDs and the target symbol. The audio warning signal (ISO 15006) was produced by a speaker in the forward dashboard. The audio signal had two main peaks at 2465 Hz and 2620 Hz (two different tones played at the same time). There were four pulses which were repeated four times with a silence of 107 ms in between repetitions. The silence within the pulses in a cluster of four was 19 ms, with an onset-onset time of 126 ms. The warning was dynamic in its length and occurred as long as the B-FCW threshold was triggered (dynamic rather than point-warning). The warning was presented continuously until the threat was gone (e.g. distance/time headway falls below certain threshold).

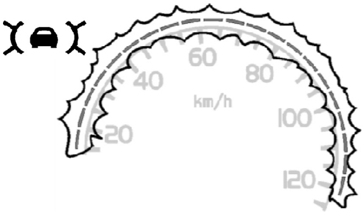

Fig. 2. B-FCW appearance: red LEDs on the outer bounds of the speedometer and an icon lit up when the auxiliary brakes lacked the capacity to reduce speed. Additionally an audible signal was given.

The B-FCW informed the driver to brake the vehicle manually. Usually the collision situation was not as severe as it would have been if it was issued by a full forward collision warning (FCW) system that is set to more specifically detect impending collisions.

2.2. *Experimental design*

The experimental design was a five factor mixed design with system activation (system activated vs. deactivated) as a between-subject factor, time (time period before vs. time period after the B-FCW event) as an intra-subject factor, glance direction (on-road vs. off-road) as an intra-subject factor, predictability of the B-FCW event (predictable vs. unpredictable) as a between-subject factor and secondary task (secondary task engagement vs. no secondary task engagement) as a between-subject factor. The five factors were never analyzed in one ANOVA together, however only in groups of maximum three factors, depending on the relevant research questions. In Table 1 all factors, factor levels, their operationalization and data source are presented.

2.3. *Study design*

All drivers experienced driving first with a deactivated system (baseline) and later with an activated system (treatment). In the baseline condition the warning was not presented to the driver but logged to file. In the treatment condition the warning was both presented to the driver and logged. The baseline condition lasted on average 113 days (SD = 3 days) from the first to the last trip and drivers were driving on average 33 193 km (SD = 7981 km) on Central European roads. The treatment condition lasted on average 174 days (SD = 28 days) from the first to the last trip and drivers were driving on average 55 780 km (SD = 6770 km).

2.4. *Demographic data*

For this study the data of five professional male truck drivers were analyzed. The sample was representative for the population in the heavy vehicle transport occupation: the average age was 50 years (SD = 8 years) and the average yearly kilometers driven in a truck was 135 000 km (SD = 24 000). The truck drivers have held a truck driver's license on average for 30 years (SD = 7 years). One of them was involved in an accident with his truck in the last 3 years. All drivers were stationed in The Netherlands, driving

Table 1
Factors for visual behavior assessment.

Factor	Factor levels	Operationalization	Data source
System activation	Deactivated system (baseline) Activated system (treatment)	B-FCW logged but not issued B-FCW logged and issued	Sensor data-logger
Time	Pre B-FCW	Threat period: 1 s before and after the B-FCW	Determined by a logged video time-stamp for a time period of ten seconds or manual coding for three single long glances
	Post B-FCW	Post-threat-recovery-period: either 10 s segment or three single long glances prior to and after a B-FCW	
Glance location	On road Off road	Forward area of interest Left, right, down, up area of interest	Classified by manual video inspection
B-FCW predictability	Predictable	Driver was pursuing a small forward headway and small TTC to the lead vehicle on purpose, e.g. overtaking maneuver	Classified by manual video inspection
	Unpredictable	Sudden, unexpected change of traffic situation, e.g. path-encroaching vehicle or sudden braking forward vehicle	
Secondary task engagement	No secondary task	Driver focuses exclusively on driving task; no distraction visible	Classified by manual video inspection
	Secondary task	No exclusive focus on driving task, driver uses cell phone, eats, drinks, smokes, etc.; distraction visible	

Pan-European transport missions with a focus to Central Europe at the hauler Nijhof–Wassink.

2.5. Data processing and data selection

Data was extracted from the European Field-Operational Test (euroFOT, 2012) dataset at Volvo on September 1st 2011. The eligible data consisted of 20 professional Dutch truck drivers, having driven approximately 2 million km over a period of 18 months in various European countries in 15 Volvo trucks. All data was recorded in the same model of truck—a Volvo Globetrotter XL cabin placed on a Volvo tractor FH12 6 × 2/4 × 2 truck.

A sample of near-crash events with a B-FCW was extracted. The first selection criteria concerned external trip information and was guided by Wrige Berling et al. (2011) to include daytime highway driving in good weather conditions, on straight roads, with an ego vehicle speed above 70 km/h, and with the driver in the cabin alone. Most forward collision accidents happen in these circumstances in Sweden according to Wrige Berling et al. (2011). The second selection criteria regarded meta-information for each B-FCW-event: (a) drivers with a minimum of eight B-FCWs in the deactivated-warning baseline driving condition and (b) with at least 15 activated warning events in the treatment condition. The very first warnings were explicitly excluded from the current analysis because first warning reactions would not show a representative behavior. After these selection criteria were applied, 126 eligible events were received. Further exclusion criteria like time-synchronization problems between logged data and recorded videos, poor video quality or discontinuous data reduced the number of valid events further. False positive B-FCWs, e.g. when no forward vehicle was present, were excluded by manually annotating the video. Video annotations verified that in all events a lead vehicle was either close to the truck or the truck was traveling in high speed to catch up with a slower vehicle in front, or there was a cut-in vehicle close to the truck. This procedure assured that only relevant B-FCWs were selected. The scope of the paper was not to classify the events into severity categories. As long as the situation met the above criteria of a crash-related relevant situation and a B-FCW was triggered, it was regarded as valid. As a consequence of these selection and exclusion criteria, 60 valid events were included in the analysis. In baseline there were 27 valid events and in treatment 33 valid events.

2.6. Data classification and independent variables

Proprietary data plotting and visualization software was used to review all 60 B-FCW events. The software permits frame-by-frame review of five video perspectives simultaneously (face video, front-view, cabin-view, side-view and pedal-/foot-view). All videos were manually reviewed and annotated. The annotated time period covered 30 s prior and 15 s after each B-FCW event. Additionally each event was classified to be “predictable/unpredictable” and “driver distracted/driver not distracted” by two human coders. All coders were blind to the hypothesis of this study and were extensively and periodically trained according to the Virginia Tech Transportation Institute’s ‘Coder Training and Quality Control Policies’ (Klauer et al., 2011).

Each event was classified into four groups: two factors with two factor levels each were coded (Table 2). The first variable was ‘*B-FCW predictability*’. An event was classified as ‘unpredictable’ if there was a sudden, unexpected change of the traffic situation. This was, for example, the case when the lead vehicle abruptly braked hard or a path-encroaching vehicle suddenly appeared. Otherwise, in all cases when the driver was intentionally pursuing a small forward headway to the lead vehicle, the event was classified as ‘predictable’. This was for example the case for overtaking maneuvers indicated by (a) frequent mirror checks prior to overtaking and (b) video verification of the completion of the overtaking maneuver.

The second variable classifying an event was ‘*secondary task engagement*’. ‘Secondary task engagement present’ was coded whenever the driver was involved in a distracting secondary task (e.g. reaching for an object, talking on a cell phone, eating, smoking, drinking, etc.). Otherwise, when there was no distraction visible, the event was classified as ‘no secondary task engagement’ (similar to VTTI coding scheme from the 100-car naturalistic driving study, Dingus et al., 2006a,b).

To investigate a driver’s glance behavior, video recordings from the in-cabin view as well as the face-view were manually coded. Five target directions, so called ‘areas of interest’ (AOI), were predefined as forward, up, down, left, and right (Fig. 3). An AOI is defined as the target direction to which the eyes are directed (ISO 15007-1, 3.14, 2002). Glances were coded frame-by-frame starting at the transition toward an AOI and ending when leaving that AOI according to the ISO methodology (ISO 15007-1, 3.15). For some data analysis the data from glance directions up, left, right and down

Table 2
Descriptive statistics of all baseline and treatment events (including the factors 'predictability' and 'secondary task engagement').

Events	Baseline					Treatment				
	All	Predictable	Unpredictable	Secondary task	No secondary task	All	Predictable	Unpredictable	Secondary task	No secondary task
N	27	17	10	9	18	33	22	11	6	27
Distance to lead vehicle (m) [M(SD)]	10.9 (9.1)	7.7 (3.8)	16.5 (12.6)	10.3 (5.7)	9.5 (8.8)	9.3 (6.8)	7.5 (4.8)	15.0 (8.9)	14.8 (4.3)	8.7 (6.8)
Minimum time headway (m) [M(SD)]	0.5 (0.53)	0.3 (0.2)	0.9 (0.8)	0.5 (0.4)	0.4 (0.2)	0.45 (0.37)	0.4 (0.3)	0.7 (0.4)	0.7 (0.2)	0.5 (0.3)
Minimum time to collision (s) [M(SD)]	4.5 (1.3)	4.3 (1.2)	4.9 (1.6)	4.2 (1.4)	4.6 (1.2)	4.4 (2.0)	4.3 (1.9)	4.5 (2.3)	6.1 (2.9)	4.1 (1.8)
Warning length (s) [M(SD)]	0.9 (0.7)	0.7 (0.6)	1.2 (0.6)	0.7 (0.6)	1.0 (0.7)	0.9 (0.6)	1.0 (0.7)	0.8 (0.5)	0.8 (0.5)	1.1 (0.9)

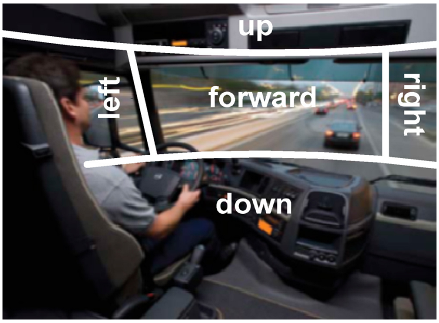

Fig. 3. The five glance target directions (areas of interest 'AOI').

were aggregated into "off-road"-glances, and compared with the forward glances (Table 1).

2.7. Dependent variables

The CAN bus signal *brake pedal position*, measured in percent from 0% to 100% with 100% indicating a fully hit brake pedal, was retrieved from the euroFOT database and used to measure a brake response. According to the definition adopted by Volvo in euroFOT (Malta et al., 2012), only brake pedal positions above 5% were considered an "intentional brake" when measuring reaction time.

Three different dependent variables of glance behavior were used according to standard practice (ISO 15007-1, 2002): *glance transition*, *glance location percentage*, and *glance duration*. *Mean glance transition* (ISO 15007-1, 3.15) is defined as the mean number of changes from one area of interest (AOI) to a different AOI. It was calculated for the two 10-s-time-blocks prior to and after the B-FCW. Mean *glance location percentage* is defined as the value, in percent of all glances, that a glance is directed into a certain AOI at a given point of time whereas the sum of all directions is 100%. This is slightly different than the glance location probability as defined in ISO (ISO 15007-1, 3.9), because it is reported in a percentage [%] value instead of a probability value [0–1]. The mean glance location percentage was analyzed for all five AOIs for various periods of time (e.g. 10-s-time-blocks prior and after the B-FCW). Mean *glance duration* (ISO 15007-1, 3.7) was calculated for three glances prior and three glances after a B-FCW. In order to assess a meaningful duration of a glance, the full length of the glance should be considered without cutting it off (e.g. as a 10 s window would). The consequence of collecting three full glances is that the length of time for each annotated event varies (in this case it can be up to 30 s prior to and 15 s after a B-FCW event).

3. Results

The results related to our research questions are reported in three sections. After showing the descriptive statistics for each event (Table 2), we report the results testing the main effect of a brake-capacity forward collision warning (B-FCW). Then, we assess the two situations during which a fast reaction triggered by a warning is crucial: unexpected events and distraction events. These analyses were carried out separately for the threat-period, in which we assessed glances forward as well as brake reactions, and the post-threat-recovery-period, in which glance behavior was of special interest.

Table 3
Significant effects of ANOVAs on glance location percentage regarding system activation, predictability and time.

Glance location	Effect	*Wilks-λ*	*F*(1,52)	*p*	*Partial* η^2
Forward	Time × predictability	.832	10.477	.002	.168
	Time × system activation × predictability	.904	5.521	.023	.096
Left	Time	.904	5.525	.023	.096
	Time × predictability	.906	5.414	.024	0.94
Right	Time	.902	5.656	.021	.098
	Time × system activation × predictability	.918	4.645	.036	.082
Down	Predictability	–	7.700	.008	.129
	Time × system activation × predictability	.924	4.289	.043	.076

3.1. Effect of the B-FCW [factors: system activation, time and glance location]

3.1.1. Threat-period

To assess the effect of the B-FCW on the *immediate brake reaction*, an ANOVA for the brake pedal position in baseline and treatment comparing 1 s before and after the warning was carried out. Independent of the system activation, drivers brake more after a (potential) warning than before (main effect time: *Wilks-λ* = .764, *F*(1,52) = 16.087, *p* < .001, *partial* η^2 = .236). A 2-proportion test for the brake pedal position rising above 5% immediately after a (potential) warning shows the same effect.

For assessing the effect of *immediately looking forward* when the system was issuing a warning compared to when it was not, a 2-proportion test showed that drivers were 24% more likely to look forward immediately after an issued warning compared to when it was not issued (*p* = .039, 95% CI = .025–.360).

3.1.2. Post-threat-recovery-period

To investigate drivers' glance behavior 10 s before and after a triggered warning, separate ANOVAs for glance location percentage in baseline and treatment were conducted. ANOVAs showed that the B-FCW activation had no effect on glance location percentage on any of the area of interests (AOIs). Independent of the system activation, after a B-FCW event drivers looked significantly less to the left side (*Wilks-λ* = .904, *F*(1,52) = 5.525, *p* = .023, *partial* η^2 = .099) and more to the right side (*Wilks-λ* = .902, *F*(1,52) = 5.656, *p* = .021, *partial* η^2 = .098). None of the interactions were significant. ANOVAs for the dependent variable glance transition regarding the same factors as above showed no effect for either system activation or time. In Fig. 4 the glance location percentage for each AOI and the brake pedal position before and after the warning in baseline (left) and treatment (right) are shown.

3.2. Effects of the B-FCW in predictable and unpredictable events [factors: system activation, time, glance location and B-FCW predictability]

3.2.1. Threat-period

The results of the ANOVA on the brake pedal position did not show any significant effect for predictability of the warning comparing 1 s before and 1 s after the warning in baseline and treatment. A 2-proportion test for the brake pedal position rising above 5% immediately after a warning for unpredictable events compared to when no warning was issued revealed no significant effect. Likewise, there was also no effect for unpredictable warnings compared to predictable warnings.

To assess the effect of *immediately looking forward* when the system issues a warning in unpredictable events compared to when it was not issued, a 2-proportion test showed no significant effect. Likewise, there was also no significant difference between unpredictable events in treatment and predictable events in treatment.

3.2.2. Post-threat-recovery-period

To test our hypothesis that the system should especially support the driver in unpredictable situations, we examined the mean glance duration on and off road surrounding an issued B-FCW (treatment). For this analysis, we took three full glances prior and after the warning into consideration without cutting a glance off (as a 10 s window would). In doing this, the maximum annotated glance period (determined by three whole glances) was 30 s prior to an event and 15 s after an event. In baseline the three full glances prior to a B-FCW event lasted M = 28.03 s on average (SD = 6.02 s) and after a B-FCW M = 17.34 s (SD = 10.09 s) in the treatment condition. The ANOVA on glance duration on and off road revealed significant main effects of the factor glance direction (on vs. off) (*F*(1,20) = 24.824, *p* < .001, *partial* η^2 = .554) and time (*Wilks-λ* = .658, *F*(1,20) = 10.374, *p* = .004, *partial* η^2 = .342). General findings showed that on road glances were longer than off road glances (main effect glance location) and glances prior to the warning were usually longer (main effect time). Despite that, a B-FCW led to shorter on road glances (two-way-interaction time × glance direction: *Wilks-λ* = .628, *F*(1,20) = 11.829, *p* = .003, *partial* η^2 = .372). These results can be seen in Fig. 5.

To investigate the influence of predictability, separate ANOVAs were conducted. ANOVAs included all five AOIs for the effect on glance location percentage (10 s prior and after the B-FCW) regarding the three factors system activation, time and predictability. In Table 3 the statistics for significant effects, wherein glance location up revealed no significant effects at all, were summarized.

The interaction of time, system activation and predictability for forward glances reveals less glance location percentage of forward glances for unpredictable events after a B-FCW is issued. Apart from this three-way interaction the results also showed that the glance location percentage of forward glances also decreases for unpredictable events after a triggered warning (two way interaction time × predictability). The consideration of glances to the side disclosed significant main effects of time. There were more glances to the left prior and to the right after a triggered B-FCW. For downward glances the main effect predictability was significant, indicating more downward glances for unpredictable events. Most importantly, there was a significant three way interaction between system activation, predictability and time for glance location percentage of downward glances (*Wilks-λ* = .924, *F*(1,52) = 4.289, *p* = .043, *partial* η^2 = .076), indicating more downward glances for unpredictable events after a B-FCW was issued. None of the other main effects and interactions reached statistical significance. The above findings were illustrated in Fig. 6 (left).

Apart from glance location percentage, the frequency of glance transitions between the five AOIs, within 10 s prior and after the B-FCW was analyzed. Therefore an ANOVA with the three factors system activation, time and predictability was conducted. This revealed statistical significant two way interactions between time and predictability (*Wilks-λ* = .803, *F*(1,52) = 12.727, *p* = .001, *partial* η^2 = .197) and system activation and predictability

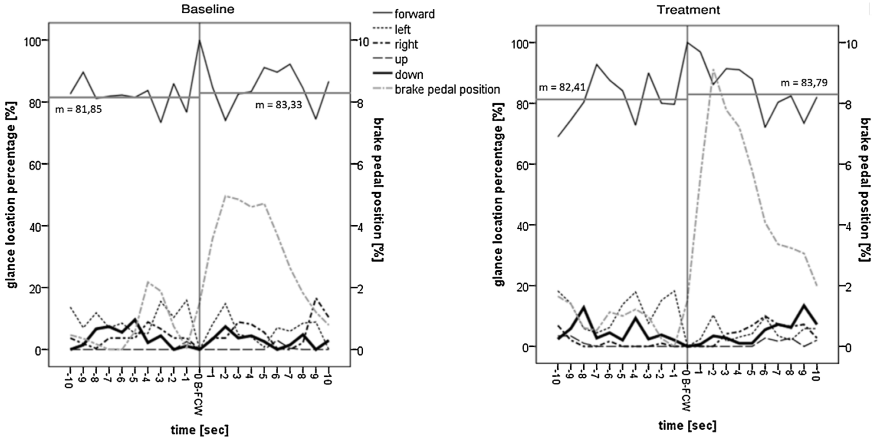

Fig. 4. Glance location percentage for all AOIs and brake pedal position prior and after the B-FCW with B-FCW system deactivated (left) and activated (right).

Table 4
Significant effects of ANOVAs on glance location percentage regarding system activation, secondary task engagement and time.

Glance location	Effect	*Wilks-λ*	*F*(1,52)	*p*	*Partial* η^2
Forward	Time × secondary task	.869	7.871	.007	.131
	Time × system activation × secondary task	.874	7.505	.008	.126
Left	Time	.880	7.086	.010	.120
Right	Time	.858	8.623	.005	.142
	Time × secondary task	.920	4.501	.039	.080
Down	Time × secondary task	.878	7.250	.010	.122
	Time × system activation	.914	4.880	.032	.086
	Time × system activation × secondary task	.819	11.492	.001	.181

($F(1,52) = 5.863$, $p = .019$, *partial* $\eta^2 = .101$). The former reflected more frequent glance transitions for unpredictable events after a triggered warning, while the latter reflected more frequent transitions for unpredictable events with B-FCW system activated. None of the main effects for other interactions were statistically significant.

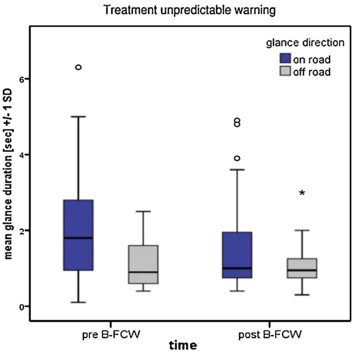

Fig. 5. Mean glance duration prior and after a B-FCW (three glances) for unpredictable events with B-FCW system activated.

Taking a closer look at the increased frequency of glance transitions after a B-FCW event, one could find that especially the frequency of glance transitions toward the down AOI increased for unpredictable events with B-FCW system activated (pre: 6 down changes; post: 15 down changes). To accommodate that and because downward glances to the instrument cluster are especially relevant, an ANOVA for the dependent variable *frequency of glance transitions toward the down AOI* was conducted. Most importantly, it revealed a significant three way interaction between time, system activation and predictability (*Wilks*-$\lambda = .897$, $F(1,52) = 5.955$, $p = .018$, *partial* $\eta^2 = .103$). This means that there were more frequent downward glances after a B-FCW was issued during unpredictable events. This was visualized in Fig. 6 (right). None of the main effects or other interactions were statistically significant.

3.3. *Effects of the B-FCW in non-distracting and distracting events [factors: system activation, time, glance location and secondary task engagement]*

3.3.1. *Threat-period*

The ANOVA conducted on brake pedal position did not show any significant effect for distraction comparing 1 s before and after the warning in baseline and treatment. A 2-proportion test for the brake pedal position rising above 5% immediately after a warning for

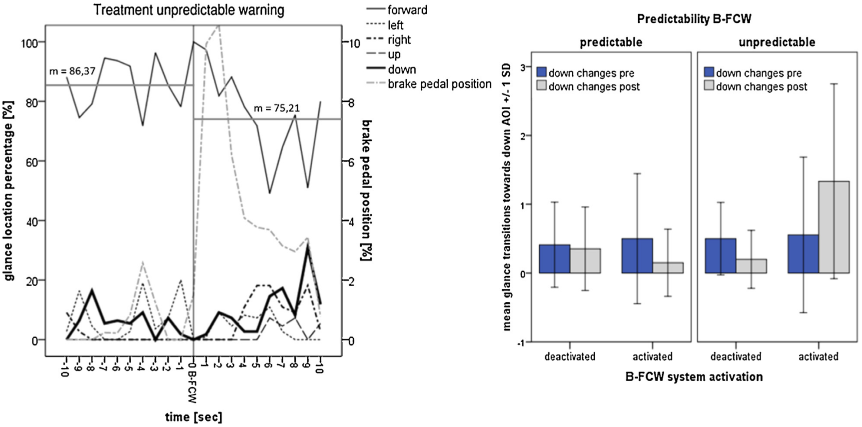

Fig. 6. Glance location percentage for all AOIs and brake pedal position for unpredictable events with B-FCW system activated (left). Mean glance transitions toward the down AOI for the factors system activation and predictability prior and after a FCW event (right).

distracting events compared to when no warning is issued revealed no significant effect. There was also no effect for distracting events compared to non-distracting events.

To assess the effect of *immediately looking forward* when the system was issuing a warning in distracting events compared to when no warning was issued, a 2-proportion test showed no significant effect. There was also no significant difference between distracting events in treatment and non-distracting events in treatment.

3.3.2. Post-threat-recovery-period

Separate ANOVAs for all five AOIs for the effect on *glance location percentage* (10 s prior and after the B-FCW) regarding the three factors system activation, time and secondary task engagement were conducted. The significant effects were summarized in Table 4. Analysis done on glance location ‘up’ revealed no statistical significant results.

The results showed a certain association for glance location percentage between forward and downward glances. While the percentage of forward glances declined both after a potential warning in baseline or issued warning in treatment during secondary task engagement, the percentage of downward glances increased (two way interaction time × secondary task). At the same time the percentage of downward glances increased. Most interestingly, the three way interaction between time, system activation and secondary task engagement showed less forward glances after an issued warning when the driver was engaged in a secondary task. Likewise, there was a significant three way interaction for downward glances indicating more downward glances. There were more glances to the left prior to a B-FCW event and more glances to the right after a triggered warning. These tendencies can be seen in Fig. 7.

An ANOVA conducted for the mean glance transitions between different AOIs (10 s prior and after the B-FCW) revealed significant interactions between time and system activation (*Wilks-*λ = .918, *F*(1,52) = 4.660, *p* = .036, *partial* η^2 = .082) and between time, system activation and secondary task engagement (*Wilks-*λ = .845, *F*(1,52) = 9.506, *p* = .003, *partial* η^2 = .155). The former showed more frequent transitions after an issued warning and less frequent transitions when no B-FCW system was activated. The three-way interaction indicated an increase in the number of transitions for drivers engaged in a secondary task after an issued warning. No other effects reached statistical significance. ANOVA conducted for the mean glance transitions toward the down AOI revealed one significant main effect for secondary task engagement (*F*(1,52) = 8.698, *p* = .005, *partial* η^2 = .143). There were more frequent glance transitions toward the down AOI for drivers engaged in a secondary task. None of the other main effects and interactions were statistically significant.

4. Discussion

The main purpose of the study is to improve real-world knowledge about the effect of brake-capacity forward collision warnings (B-FCWs) on visual attention allocation and brake reactions. The main analysis focus is on assessing reactions within two periods after the warning: the immediate reaction during the threat-period and the following reactions during the post-threat-recovery-period. Unpredictable events are compared to predictable events and distracted drivers are compared to non-distracted drivers.

The first reaction to a B-FCW should be to look forward to observe the road scene and to be able to make decisions about the next actions to take (e.g. to hit the brake or to continue at the same speed without braking). Our results show, that the brake is hit almost simultaneously with the warning (if not before)—an effect that is independent of the system activation. This shows that drivers seem to be aware of the threat and react regardless if a warning is issued or not by hitting the brake in order to maintain a safe distance to the front vehicle. In the exact moment when they hit the brake, they look forward—a reaction triggered by the warning. In conclusion, during the threat-period the warning causes drivers to look on road but they do not brake more than otherwise. This could be an indicator that the assessed events are not as critical to the driver as expected. For severe events, at least for unpredictable events, we would expect the brake reaction to be different after a B-FCW is issued compared to when it is not. Another explanation could be that drivers are very well able to make decisions about the correct timing of hitting the brake pedal. They are able

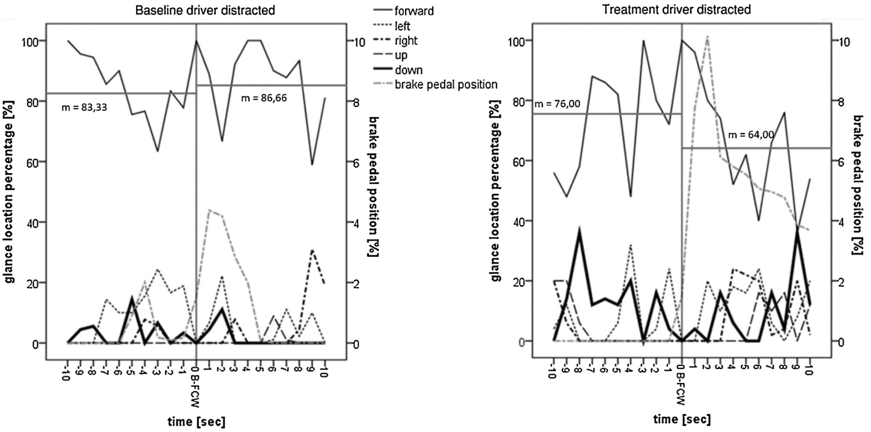

Fig. 7. Glance location percentage for all AOIs and brake pedal position for events with system deactivated (left) and activated (right) with secondary task engagement.

to judge the decreasing distance to the front vehicle very well—an interesting phenomenon because the B-FCW warning occurs when the Adaptive Cruise Control System (ACC) requires the human to take over and brake. In a few cases the driver has already braked before, however not at maximum braking. Our results regarding the braking behavior of drivers support findings from studies validating the *attention-based model of driver performance in rear-end collisions* (ARCAM) developed by Brown et al. (2001). Those studies suggest that the driver adjusts the brake response based upon changes in the driving environment. Drivers do not make a simple step-brake response when they begin braking. This implies that drivers act as a closed-loop system, consistent with ARCAM. The average brake profiles show that maximum braking does not occur until at least 1 s after the warning. This delay reflects, as in Brown et al. (2001), a process of information extraction and judgment.

In contrast to the findings from the threat-period, in the post-threat-recovery-period drivers look forward for the same duration after they received a warning as they do when they do not receive a warning. When we compare the scenarios in which a B-FCW should be especially effective the storyline changes however. In the unpredictable events in the post-threat-recovery-period drivers look less on-road and more down after the warning is issued. Another scenario during which a B-FCW should especially quicken responses is when the driver is distracted. In the threat-period, after an issued warning, drivers look as much forward and brake as much as they did when not receiving a warning. The drivers' first glance after the warning is directed to the forward roadway—an intended effect that is independent of the system activation however. This is in contrast to previous studies for example by Fitch et al. (2011) who showed that distracted drivers, that received a haptic alert through the seat, returned their glances to the forward roadway sooner than distracted drivers who did not receive an alert. These contrasting results could be explained by the fact that already in baseline, drivers were aware of the threat and looked forward, thereby rendering an alert in treatment less necessary. An alternative explanation could be that our sample size of six distracted driver events in treatment is rather small to show a significant effect. In the post-threat-period, similar to unpredictable events, a B-FCW causes distracted drivers to look more down. One might argue that this effect appears due to a biased pre-selection of event. However, the events were randomly chosen and the first B-FCWs were explicitly excluded from the analysis.

In conclusion, after the immediate safety threat has passed, a B-FCW display directs glances toward the location where the visual warning is issued in unpredictable events and when the driver is distracted. Viewing time at the spatial location of the warning in the instrument cluster is increased, and thereby attracts attention that should be directed to the road scene. This is an unintended effect with potential safety consequences.

The "eyes-off-road"-effect in the post-threat-recovery-period is especially interesting because at this time the warning has already disappeared. At this very moment no LEDs are illuminated in the cluster anymore, however drivers seem to be interested in finding out what just happened. Their curiosity takes away their attention from the road. There is a reaction pattern of looking down and up and down again. That is, it is not an initial reaction but happens over time, which indicates a safety critical behavioral adaptation effect. It is likely that the driver sees the visual warning in the visual periphery while fixating the road ahead and feels the need to make a foveal eye movement in order to inspect the location where the warning lights were illuminated, but have now disappeared. After recovering from the immediate threat, the driver allows himself to take the eyes away from the road. This indicates that during the post-threat-recovery-period drivers feel safe enough to shift their attention. The driver feels a "need for comprehension", perhaps as a consequence of the loss of information after the warning disappeared. This "need for comprehension" seems to be greater than the subjective feeling of a safety-risk from looking away from the road. Because the B-FCW was just issued one would expect that a safety-risk may still be present, however the driver's seem to believe it disappears after the threat-period has passed. This can be interpreted as that the subjectively perceived amount of safety-risk decreases during the post-threat-recovery-period.

There can be several reasons for this eyes-off-road effect in the post-threat-recovery period: the display position, the appearance of the warning or the warning duration. One should be careful about attributing blame to the display position. A warning could, even if displayed in a head-up display (HUD), attract the eyes and occlude the background. Even a display position close to the road, e.g. a HUD, can fail in directing drivers' vision toward the roadway due to inattention blindness (Mack and Rock, 1998). In order to assess whether display position is a contributing factor for this eyes-off-road effect found in naturalistic settings, one should design a study that compares different display positions and their effects on visual behavior and brake reaction. Another reason for frequent downward glances could also be the design of the warning icon and LEDs which might not be self-explaining to the driver. The LEDs or/and icon could be too small or the red color of both may not be perfectly visible on the black surface of the dashboard. However, this is highly unlikely as they follow design guidelines (ISO 15008, 2009).

Another speculation about the reason for frequent downward glances is the spatial source of the audio warning. As the sound is issued from the front dashboard, located below the drivers' line of forward sight, the driver might dedicate visual attention to the source of the audio warning. This is in line with previous research (Tan and Lerner, 1996) stating that drivers' perceived location of the auditory alert lead their focus of attention.

Yet another alternative explanation could relate to the variable duration of the warning. The fact that the warning continues as long as the B-FCW threshold is exceeded might be an issue. This may increase comprehension problems especially when either the warning is present for very long (up to 4 s) or the warning disappears after a very short time (e.g. half a second). Alternatively, the driver might expect a reoccurrence of the warning and therefore redirect glances to the source of the previously illuminated warning. In that case the driver could misinterpret the warning as more of a 'distance alert warning' which might not call for the same reaction to hazards as a B-FCW does. Future studies need to investigate whether a point-warning (a warning with a short, fixed duration) causes less downward glances in the post-threat-recovery-period than a variable duration warning does. Thus, further investigations should examine the specific effect of warning duration and the dynamic nature of B-FCWs (visual or audio).

One could argue that we misinterpreted the amount of danger in the unpredictable events and events when the driver is distracted. It could be plausible that these circumstances do not reflect danger to the extent we assumed they would. If drivers do not feel a threat of safety as we expected them to feel, their reaction of 'taking their eyes off road' may be reasonable. On the one hand, the fact that their immediate reaction after the warning is to look forward and to brake weakens this argument. On the other hand, the fact that the assessed system is a B-FCW system rather than a full forward collision warning (FCW) supports the argument that the chosen events might be less severe. Whether or not a full FCW would have warned in the same situation is difficult to determine because of sensor data limitations. In any case, a verified B-FCW was triggered in all events we investigated. Independent video analysts manually verified that the selected situations were true B-FCWs with a vehicle ahead in front of the truck (no false alarm) and were relevant concerning a possible related crash (e.g. cut-in vehicle close to the truck, truck drives full speed toward a very slow vehicle, etc.). The scope of this study was not to classify the events into severity categories. As long as the situations met our criteria of a crash related relevant situation and the B-FCW was triggered, they were included in the analysis. It is important to remember that B-FCWs are issued when there is a crash related relevant situation and therefore eyes-on-road should be the preferred state.

One must be careful, when interpreting the increase of downward glances after a warning as a sign of the driver being confused. Although the drivers were given questionnaires within euroFOT about the perceived usefulness, acceptance and understanding of the B-FCW features, this data could not be included in this study. Only two truck drivers from our sample actually completed the questionnaires. Therefore, in future research, it is advisable to include subjective responses to B-FCWs into any HMI assessment.

4.1. *Implications*

As intended, drivers look more on-road immediately when they receive a warning and assess if it is worth braking or not. However, that is not the full picture. We found that there is an unexpected reaction during the post-threat-recovery-period. Due to the fact that during unpredictable events and during events when the driver is distracted, glances down to the instrument cluster increase, there is reason to consider how current HMIs of on-market B-FCW systems could be redesigned. Our results could have implications on design guidelines for future collision warning displays. Essentially, we conclude that B-FCW warnings contribute to misallocation of attention in the post-threat-recovery-period. After the immediate threat has passed, a B-FCW display may cause some distraction. Because data was collected in the field, the results show high external validity. The results seem to support recommendations to place B-FCWs close to the source of the hazard and not in the instrument-cluster, however there are other plausible explanations such as variable warning duration and sound location (see above).

Furthermore, as our results indicate, the increased amount of eyes-off-road time during the post-threat-recovery-period might be the effect of two causes: (1) comprehension problems and/or (2) confirmation seeking. It can be argued that drivers feel the need for comprehension due to the loss of information after the warning was displayed. It can also be argued that drivers seek confirmation from the system that the threat is over.

The glances back to the display could be removed by taking into account three different implications. The first implication is to display the B-FCW in a head-up display (HUD) superimposed on the windshield. A HUD location seems to provide the best performance according to Lind (2007). In a simulator study comparing four different FCW displays, Lind (2007) showed that a HUD provides the driver with 200 ms lower reaction time and had the least amount of missed warnings out of the tested modalities. The standardized effect between the HUD and the cluster-warning was $d = 0.87$, which constitutes a large difference. However, even HUDs may not solve the problem completely. Although HUD solutions bring glances closer to the source of the hazard, they may not be the only solution for an increased amount of forward glances (see inattention blindness issue above).

The second implication is to let the visual icon linger illuminated for a period to provide the driver with some sort of "post-warning information" (e.g. "You just received a brake-capacity forward collision warning"). The warning may become more transparent to the driver and could ultimately increase trust in the system. Obviously this approach would increase the amount of visual information in the cluster. Therefore, it may be important to let the threat-period (1 s) pass before additional information appears.

The third implication is to reduce the visual content of the warning. To eliminate visual alerts and to issue tactile and audio alerts instead may remove the "eyes-off-road effect" during the post-threat-recovery-period.

Additionally, eyes-off-road time in the post-threat-recovery-period may be avoided by driver training and introduction to advanced driver assistant system features. If truck drivers are informed when and how a B-FCW appears, drivers might show less comprehension difficulty in the usage of the system. In euroFOT this driver training was purposely dismissed, in order to assure a natural usage pattern with the system. Informing drivers that different reactions to B-FCWs could have an influence on traffic safety, could be part of traffic safety education programs. An initial driver training on the appearance of the icon, LEDs and the warning sound during a B-FCW might help to increase transparency with the effect of focusing less on the instrument cluster in the post-threat-recovery-period. To ultimately test comprehension related issues, one needs to conduct a simulator experiment in a controlled environment.

Our results show that the driver clearly experiences two different periods after the warning. This finding can have implications for assessment methodology for other warning systems. It should be relevant to assess if the warning requests foveal attention at a critical point in time (threat-period). An ocular fixation on display features should be avoided in the threat period. The current study provides evidence that future studies on the behavioral effect of warnings should assess the threat-period (about 1 s) *as well as* the post-threat-recovery-period. Only the results of both periods tell the complete story.

One aspect that is left to future FOT studies is the drivers' adaptation effect over time. The question remains as to whether drivers change their behavior of looking down in unpredictable and distracting events during the post-threat-recovery-period over a more extended period of time. They might get used to the appearance and duration of the warnings and adapt. Over time comprehension problems may disappear. However, even if after some time, they do understand the warning and its purpose better, they should ideally not need to look at any other region than the forward roadway at any times.

"After all. . .", as one of the euroFOT truck drivers stated when being asked about the effect of the B-FCW system ". . .[it] remains a machine, so you have to stay focused yourself".

Acknowledgments

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CHAPTER 4 PAPER III

Paper III

Subjective vs actual performance improvement with a real-time Visual Distraction Alert System

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Subjective vs actual performance improvement with a real-time Visual Distraction Alert System

Claudia A. Wege, Trent W. Victor

Volvo Group Trucks Technology (GTT), Götaverksgatan 10, M1.6, 405 08 Göteborg, Sweden

Key words: behavioral adaptation, adoption of new technologies, driver calibration, concurrent driver feedback, system acceptance, driver attitudes towards safety systems

Abstract

Objective: Improvement in driver attention and driving performance when using a Visual Distraction Alert (VDA) System is compared to subjective performance ratings, attitudes, acceptance, usefulness and satisfaction.

Background: Research is active on how to counteract distracted driving using real-time distraction mitigation technology (Lee et al., 2013; Kircher, & Ahlström, 2013) showing positive effects on driving performance , yet it is unclear if drivers perceive these effects and if it influences their acceptance and attitudes to these systems.

Methods: 56 professional drivers were tested in a simulated environment while entering text on a tablet. A VDA System provided real-time audio feedback when distraction was detected according to two warning algorithms (single glances (SG) and glance history combined with single glances (GHSG)). Additionally, warning reliability (false positive warnings) was varied across experimental conditions. Subjective performances as well as a set of attitudes about the system and system acceptance (Van der Laan Scale, 1997) were measured.

Results: Results show that drivers are well calibrated to the attention and driving performance benefits provided by the VDA System. The calibration effect is stable over time. The degree of correspondence of perceived vs actual attention allocation is remarkably constant. Distracted drivers are aware of the performance benefits that the system provides. Acceptance and attitudes of the systems are positive even if they operate imperfectly. Drivers were significantly able to detect unreliable, false positive warnings.

Conclusion: Conclusions indicate that distraction feedback technology can positively alter perceived and actual performance decrements.

1. Introduction

Visual driver distraction and inattention may occur due to a range of factors including interaction with a cell phone (e.g. Olson, Hanowski, Hickman, & Bocanegra, 2009; Yager, Cooper, & Chrysler, 2012), or reaching for an object or person inside the vehicle (Roney, Violano, Klaus, Lofthouse, & Dziura, 2013).

Recent research has identified factors related to the driver's *willingness* to take their eyes off the road for an extended period of time. In a recent self-report survey in the United States (Harris Poll, 2012) 84% of new car buyers admitted to engage in one or more distracting driving behaviors in the average month. According to a NHTSA-survey (N = 6,000) on distracting driving attitudes and behaviors, half of the drivers answer an incoming call, and one-quarter frequently places a call while driving (NHTSA, 2013).

Many studies have documented that distracted driving is associated with degraded driving performance (e.g. Wang et al. 2010). Distraction was found to be the contributing factor in 78 percent of unintentional lane deviations (Olson et al., 2009), inducing abrupt steering wheel corrections (Markkula, & Engström, 2006; Yang, McDonald, Reimer, & Mehler, 2012), creating significant variations in velocity (McKeever, Schultheis, Padmanaban, & Blasco, 2013; Yang et al., 2012), and slowing reaction times to a lead vehicle braking (e.g. Angell et al., 2006; Angell, & Lee, 2011; Carsten, & Brookhuis, 2005; Zhang, & Smith, 2004; Castro, 2009; Birrell, & Young, 2011).

Driver distraction has been identified as a major contributor in crashes (Young, & Salmon, 2012; Klauer, Dingus, Neale, & Sudweeks, 2006). According to NHTSA (2013) as well as the US Centers for Disease Control and Prevention (2012), more than 10 people are killed and more than 1,200 people are injured every day in crashes that involve a distracted driver. Distracted driving is been labeled "this generations chronic disease" (Wetzel, 2012). Klauer et al. (2006) found in a naturalistic driving study that eyes off road time of more than 2 seconds inside the vehicle increased the odds of crashing by three times (Young, & Salmon, 2012). The results refer to a total off road glance time of two seconds or more in a six second period, and do not refer to a single glance duration. Horrey and Wickens (2007) found that over 80 percent of the crashes they studied in a simulator study were attributable to drivers glancing inside the vehicle for longer than 1.6 seconds. Another studies shows that accumulated eyes-off-road time was associated with higher crash probability (Hanowski, Perez, & Dingus, 2005).

1.1. Distraction warning algorithms of a Visual Distraction Alert System

Research on real-time distraction feedback systems that are based on eye or head tracking technology is active (Lee et al., 2013, Kircher, & Ahlström, 2013, Victor, 2012). Real-time distraction feedback systems have the purpose of providing feedback to help the driver shift attention back to driving when s/he is judged as being "too distracted" according to predetermined criteria set by the system, the driver, or the owner (Engström, & Victor, 2008). Review papers from Engström and Victor (2008), Hickman and Hanowski (2010), Horrey, Lesch, Dainoff, Robertson and Noy (2012), Victor (2012) and Kircher and Ahlström (2013) give overviews on a variety of these systems. Lee et al (2013) have summarized the safety benefits of real-time feedback systems which can accrue by 1) discouraging drivers from *enabling* distracting devices, 2) *engaging* in distracting activities, and 3) *persisting* in distracting activities when distractions put them in crash-imminent situations. Tied to the latter safety benefit is the notion that real-time feedback systems have the potential to prevent future distraction. That means that with time, driver attitudes and willingness to engage in distracting activities might shift

One of these real-time distraction feedback systems is a so called Visual Distraction Alert System (VDA System) that uses a visual distraction detection and warning algorithm to warn drivers in real-time. Studies found that when drivers receive real-time feedback, they are less willing to interact with in-vehicle information systems (Donmez, Boyle, & Lee, 2007) and respond faster to lead vehicle braking events in a simulator (Donmez, Boyle, & Lee, 2008). Distraction feedback was found to improve speed maintenance on curve entries and can also improve the braking response for distracted drivers (Donmez, Boyle, & Lee, 2007). However, studies have found mixed results regarding improved visual attention allocation on-road. Donmez, Boyle, & Lee (2008) found that real-time feedback combined with retrospective feedback resulted in longer glances to the road. However Kircher, Ahlström and Kircher (2009), in data obtained in an on-road study, found that although their warning algorithms detected driver distraction, neither an algorithm that relies on the metric "percent road center" nor an algorithm that relies on gaze zones in the vehicle, affected attention performance.

In a recent study Lee et al. (2012; 2013) compared four progressively more complex distraction detection algorithms on their ability to detect distraction during a simulated highway drive while participants performed a secondary task. It was found that the Multi Distraction Detection algorithm identified visual driver distraction better than all three other algorithms. The description of each algorithm along with the AUC values reported by Lee et al. (2012) can be found below (the AUC -area under the curve - values indicate algorithm performance with 1.0 for a perfect algorithm).

- The "*Eyes off forward roadway algorithm"* (Klauer, Dingus, Neale, & Sudweeks, (2006) defines visual distraction as a cumulative glance away from the road of 2 seconds within a 6-second running window) (AUC = 0.75).
- The "*Risky visual scanning patterns algorithm"* (Donmez, Boyle, & Lee, 2007; 2008) considers the history of glances and considers both the duration of the current glance and the cumulative glances away from the road to define risky visual scanning patterns (AUC = 0.67).
- The *"AttenD algorithm"* (Kircher, & Ahlström, 2013) considers long glances away from the road as hazardous, and uses a buffer (begins at 2 seconds and is decremented over time when looking away) to represent the amount of road information the driver possesses (AUC = 0.71).
- The "*Multi Distraction Detection algorithm"* (Victor, 2010; Victor, & Larsson, 2010) identifies visual and cognitive distraction using the percent of glances to the road center (PRC) and long glances away from the road (AUC = 0.87).

Although it was found that the multi distraction detection algorithm *detects* visual distraction best, it is still unclear whether drivers *attend the road more* when they are assisted with either a warning algorithm that detects long single glances *or* a series of off-road glances in combination with long single glances. To test this, in the current study tested two warning algorithms:(1) long single glances (SG-warning algorithm) or (2) a series of off-road glances (accumulated eyes-off-road time) in combination with long single glances (GHSG-warning algorithm). The algorithms were compared regarding their effects on attention on-road, effects on perceived performance benefits, as well as effects on system acceptance. In the present study it was assumed that a SG-warning algorithm is simpler/easier to comprehend, thus more *transparent* to the driver compared to a GHSG-warning algorithm that is less simple/less easy to comprehend and thus non-transparent.

User acceptance of warning systems is a key factor for a positive short- and long term interaction with a system (Adell, 2009). Also, acceptance is a particularly important factor influencing the use of technology (Parasuraman, Hancock, & Olofinboba, 1997; Stearns, Najm, & Boyle, 2002; Lees, 2010; Lee, & See, 2004) and neglect of the system, leading to unwillingness respond to alarms (Wickens, & Dixon, 2007, in Lees 2010). System acceptance depends on various complex behavioral phenomena such as system use, ease of learning, perceived value, advocacy of the system or willingness to endorse, and driving performance (Stearns, Najm, & Boyle, 2002). In Victor et al. (2011) fleet members were asked to what extent various inattention monitoring systems would show a safety benefit in their fleet. Safety attitudes were positive with 63% of all participants believing that VDA Systems in general would reduce crashes. However, a study measuring the acceptance of VDA Systems has been lacking. This current study closes this gap.

1.2. Reliability of a Visual Distraction Alert System

The general principle when designing warning systems is that false warning rate should be low (ECE, 2001). False warnings in a VDA System can be false positive warnings which are warnings provided when the driver is looking on road or false negative warnings which are missed warnings when the driver is looking off-road. False alarms are unintended by the systems designers, do not aid the driver in a given task, and generally appear to be at random from the drivers perspective. The initial response to false positive warnings is usually driver frustration which can also undermine traffic safety (Donmez, Boyle, & Lee). Research shows that unreliable warnings can undermine system acceptance and trust (Lees, 2010; Lee, & See, 2004) which may lead to confusion and neglect of the system such as the driver is unwilling to respond to warnings (Dixon, & Wickens, 2007). System acceptance was in focus in the SAVE-IT program (Zhang, & Smith, 2004) during which various mitigation methods were compared regarding user acceptance. User acceptance was high only when systems were reliable. However, one SAVE-IT study demonstrated that drivers accept "task lock-out" distraction mitigation technology even when it operates imperfectly (Donmez, Boyle, Lee, & McGehee, 2006). However, studies have found that trust can be recovered if the system only provides a small number of errors (Goa, & Lee, 2006). In fact, some studies show that not all false positive warnings are harmful. False positive warnings may also lead to more cautious driving and thereby result in reduced warnings (Parasuma et al., 1997).

Research has shown that false positive warnings can be more detrimental to driver`s performance than false negative warnings (Lee, & See, 2004). The effect of false positive warnings on driving performance has largely been studied on ADAS such as forward collision warning systems (Bueno, Fabrigoule, Deleurence, Ndiaye, & Fort, 2012), however it has not been studied in regards to VDA Systems. Based on the above findings we hypothesize that unreliable warnings reduce the effectiveness (less performance benefit) of a VDA System. And, that a reliable VDA

System is expected to be more accepted than an unreliable VDA System with false positive warnings.

1.3. Hypotheses

In sum, as the above findings suggest, drivers are generally willing to take their eyes off the road. Evidence exists that drivers overestimate their ability to multi-task (Regan, 2010). They do not *realize* the potential hazards created from decisions to engage in a distracting activity and often, do not experience negative consequences (Donmez, Lee, & Boyle, 2008). They believe their driving performance is better than it actually is (Horrey, & Lesch, 2008; Pemco Insurance Poll, 2013). Like a paradox, even though drivers know about the risks involved and report concern about the danger of others engaging in distracting activities while driving (Regan, 2010), recent surveys show that the majority of drivers are willing to interact with in-vehicle devices and some do so frequently (Forbes, 2009).

As shown above, research on real-time attention feedback enhancing both drivers' attention to the forward roadway and their driving performance is ongoing. However, it is still unclear whether drivers perceive the safety benefits a VDA Systems has on driving performance and attention. If the user perceives the increase of attention to the roadway then a VDA System will most likely be more successful in real-world applications. Therefore, the focus of analysis in this study was *driver perceived behavioral control*, which refers to the driver`s perception of their own capability to attend to the road and to control the vehicle.

Further, it is unknown if drivers perceive their performance to be different for different warning algorithms and for different levels of warning reliability (false positives warning). In this study, we hypothesize (H1) that a VDA System increases driver attention allocation on-road, and (H2) enhances driver estimation of performance (perceived behavioral control).

Additionally we hypothesize that (H3) a transparent warning algorithm (SG-warning algorithm) increases drivers attention allocation on-road more than a non-transparent warning algorithm (GHSG-warning algorithm), and (H4) will increase driver estimation of performance more than a non-transparent warning algorithm (GHSG-warning algorithm).

Furthermore, (H5) acceptance of a warning system providing transparent warnings (SG-warning algorithm) is expected to be higher than the acceptance of a warning system issuing non-transparent warnings (GHSG-warning algorithm). This assumption is related to the notion of observability (Rogers 1995) meaning that the driver will rate a system more favorably if its actions are comprehensible and the decision rationale is transparent.

And finally we hypothesize that less reliable VDA Systems (false positive warning algorithms), result in (H6) a decreased estimation of performance and (H7) less system acceptance.

2. Method

A driving simulator study was set up to monitor driver eye movement behavior, driving performance and engagement in secondary tasks at all times. A VDA System detected visual driver distraction. During the deactivated system period the warnings were logged to file, but not issued to the driver. During the activated system period all warnings were logged and issued to the driver.

2.1. Participants

56 participants (14 in each of four experimental groups) between the ages 20 and 59 years (average age of 37 years, SD = 10 years) participated in the study. All drivers were recruited from professional truck companies and were paid a fixed sum of 200 SEK for their time at the end of the test session. No driver had previous experience participating in a driving study. Participants were holding a valid, unrestricted driver’s license, are licensed for an average of 19 years (SD = 10 years) driving a car and licensed for an average of 15 years (SD = 10 years) driving a truck and drive on average 128.000 km/year. They were all in good general health, have had normal vision and hearing and were right handed.

2.2. Driving Simulator

A Volvo Truck FH12 fully equipped chassis was instrumented to collect (sensors for pedals and steering wheel) and record vehicle and visual parameters in a non-moving base driving simulator from Volvo Group Trucks Technology in Sweden. All log data was recorded in 60Hz. Eye-tracker data was logged on a separate machine and merged by synchronization between the driving simulator and the eye-tracker system during each test run.

The cylindrical display system has a 3.5 m radius and a horizontal field-of-view of 180° at which participants did not see any static objects, such as the floor, ceiling or walls. Three Projection Design projectors render three images (1920x1200 at 60Hz) which are blended to form one seamless panorama of simulated road and traffic environment. The rear-views to be integrated using LCDs. Traffic and warning systems sounds are generated by a sound server and a RME Hammerfall multichannel soundcard.

The simulated environment consisted of a two-lane motorway with a W-beam-guardrail to the left and a gravel line to the right (Fig 1). There was a medium traffic density with approximately 23 meeting cars and two passing vehicles per minute when the ego vehicle is travelling at 90 km[h]. Due to the 180 degree wide screen in the driving simulator, drivers did not see any static objects, such as the floor, ceiling or walls.

Figure 1: Simulated driving scenario with ego vehicle (truck on the right hand side)

Figure 2: Positioning of iPad tablet and eye-tracking cameras in experimental set-up

2.3. Visual Distraction Alert System

A non-intrusive Facelab 4.2.2 eye tracking system from Seeing Machines with two analog cameras and two separate infrared lights, installed above the steering wheel in the top center of the instrument cluster (Fig 2), recorded changes in the driver`s ocular and facial features at 60 Hz. The eye-tracker system made it possible to monitor the level of visual driver distraction.

As the drivers' glances were continuously tracked, immediate feedback (an audio alert "short beep") was provided to the driver when the system detected an inappropriate glance behavior. The warning depended on a pre-set warning threshold set by a driver distraction warning algorithm. Attending to the road at all times avoided a warning. The warning algorithm was implemented in Simulink software including data preprocessing and calibration parameters available in a patent (Larsson, & Victor, 2010).

2.3.1. Description of the real-time feedback with two driver distraction warning algorithms

The implementation of the distraction warning was based on the *multi-distraction detection* algorithm (Larsson, & Victor, 2008). Two different warning algorithms, both focusing on different aspects of visual behavior, were tested. The audio alert was the same alert sound for the SG and GHSG-warnings. Both algorithms used the Percent Road Center (PRC) measure as its basis for issuing a warning. PRC is defined as the percentage of gaze- or head angle data points that fall within a road center area. The algorithms rely on the notion that drivers should spend a certain amount of time glancing towards the road center area. The road center area is defined as a circle of 10 degrees radius centered on the road center. The road center is defined as the most frequent gaze angle during normal driving. Each data-point is classified as being either 'eyes within road center area' or 'eyes off road' on the basis of whether it falls within the road center area. A calibration period of 2500 samples at 60Hz (41.7s) was used, after which the on-off road classification started. First there was a "pre-processing" stage where the data quality is checked and noise is filtered. Then the algorithms trigger an off road center calculation.

The warning algorithms were almost identical to the Multi-Distraction Detection algorithm used in Lee et al. (2013), however with refinements (see below). Contrary to the study by Lee et al. (2013), the algorithm did not use vehicle state inputs (i.e., speed) to adjust thresholds for algorithm variables and did not use a seat sensor. This made the algorithm robust and reliable. Drivers were driving above a speed of 80 km/h at all times, and thus algorithm was always engaged after the road center cone was identified. This means that the no mechanism was used to "freeze" the algorithm (e.g. when the speed would have dropped below the minimum threshold). The size of the road center cone was adjusted to the sensor signal, increasing from 10 to 20 degrees when sensor input shifts from eye glance to head pose signals. When eye glance data was unavailable, the algorithm used head pose data to calculate PRC.

The distraction warning algorithms:

> *Single Glance warning algorithm (SG-warning algorithm):* identifies visual distraction from a single long (2.4 second) glance away from the road center area

> *Glance History and Single Glance warning algorithm (GHSG-warning algorithm):* identifies visual distraction from a single long (2.4 second) glance away from the road center area and *additionally* identifies visual distraction from a history of glances away from the road center area. Glance history warnings are provided when drivers' glances fall below a percent road center (PRC) of 60 percent within a 17.3-second running window. In addition to the PRC window, a second PRC window is also calculated to improve reliability and consistency; it is called the visual time sharing (VTS) PRC window. This separate PRC calculation relies on a 4-second running window. When a sink is detected (a PRC value below 65%) followed by a rise (a PRC value above 75%), then the visual distraction PRC windows is reset to 80 percent. Resets are used as a mechanism to saturate the maximum value of the medium length window (17.3 s) to 80 percent, and the minimum value of the long window (60 s) to 60 percent. Whenever a VTS event is detected, all the PRC windows are reset (Victor, 2010).

2.4. Warning reliability manipulation

Within the "reliable warning" condition we gave zero false positive warnings. Within the "unreliable warning condition" we gave initiated, controlled false warnings. This was controlled by an extra algorithm running in parallel to the VDA-algorithms. The computer was programmed to signal a false positive distraction warning (when the driver was looking on-road) randomly one time during every other distracting period and every other non-distracting (normal driving without doing a secondary task). As the length and frequency of the distracting periods varied for each participant, the number of false positive warnings varied among participants between one and seven.

2.5. Distracting task and portable device

Participants were asked to engage in a distracting task which caused them to glance between a secondary task and the forward roadway, thus causing visual time sharing. Thereby the VDA System had the opportunity to detect distraction. The distracting secondary task required an interaction with an iPad tablet equipped with a text entry software that was developed specifically for this experiment. Figure 2 shows the positioning of the iPad tablet in the experimental set-up. The display used for the visual/manual task was positioned spherically 45° clockwise horizontally and 45° clockwise vertically from the center of the steering wheel, re-creating a common position for vehicle-fixated devices in real traffic. The drivers were presented a series of different truck driving work related sentences on the iPad tablet. The driver was asked to read a sentence and to copy it by typing it into a text field. This typing copying task was done at a driver's own pace (without any time pressure). This resulted in the length and frequency of the distracting periods varying for each participant. Pressing the "send message" button indicated the end of the task. 30 seconds after task completion, a voice message indicated the start of the next text-copying task. During the 30 second pause the text field "Keep your eyes on the road" was presented on the iPad tablet screen. After the voice message indicating start, the driver chose whenever it was safe to start writing the message by pressing a "write message" button. If the driver did not press the start button within 10 seconds, another voice message reminded the driver to start the task and so on. The drivers were presented a series of different, truck driving work related, sentences. All sentences were in the drivers' native Swedish language whereas the task demand of writing the text message was controlled by an equal length (83-87 characters including spaces). Text messaging was regarded as a natural source of distraction as it is currently common in a truck driver's interaction with fleet management systems. The sentence to be copied was visible during the task. It needs to be made clear that the purpose of the secondary task was not to encourage drivers how to conduct text messaging while driving, but rather to provide a representative secondary task.

2.6. Experimental Design

The experimental design was a 2x2x2x4x2 mixed experimental design. The *'warning algorithm transparency'* with two transparency levels (high 'SG-warning algorithm' vs low 'GHSG-warning algorithm') and *'system reliability'* with two levels ('reliable system' vs 'unreliable system') as between-subjects factors were compared. Thus, drivers were randomly assigned to one of the four conditions: 'SG-warning algorithm/reliable warnings', 'SG-warning algorithm/unreliable warnings', 'GHSG-warning system/reliable warnings' or 'GHSG-warning system/unreliable warnings'. The within-subjects factor was *'system activation'* with two levels (system deactivated, system activated). All participants drove the deactivated warning condition first, followed by the activated warning condition, the behavioral change was assessed within the activated warning condition. A split of both test sessions was performed to classify a behavioral adaption effect over time which comprised an additional nested four level within-subjects factor *'time'* (beginning and end of deactivated system as well as beginning and end of activated system). The comparison of the actual vs. the perceived performance made it possible to explore another within-subjects factor *´performance measure'* with two levels ('actual performance' vs. 'perceived performance').

2.7. Experimental Procedure

After providing informed consent participants completed a demographic and driving experience survey. They were given basic instructions for the study objective and that the instrumented vehicle in the driving simulator contained specialized equipment to detect and to signal distraction to the driver. Drivers were instructed that the system would alert them using a tone presented in the instrument cluster. Drivers were told that if they felt they could not complete the study they could withdraw at any time without any penalty. The eye tracking system was calibrated and the experimenter evaluated the quality of the eye and head tracking systems prior to beginning of the drive.

The study procedure was the same for each participant and consisted of three practice sessions and two test sessions including breaks for questionnaires (Fig. 3). The first practice session (10 min) consisted of the introduction to the function of the iPad tablet and a walk-through of the iPad tablet task. Next, participants were asked to adjust their seat and steering wheel position in the cab. The eye tracking system was calibrated and the experimenter evaluated the quality of the eye and head tracking systems prior. For the test laps, the drivers were instructed to drive at a speed of 90 km/h at all times. Drivers were informed that they could not hold a conversation with the examiner, however could stop a session at any time if necessary. The second practice session (5 min) was a drive in the driving simulator to get used to steering, accelerating and braking. The third practice session (10 min) was a drive in the simulator while performing the iPad tablet task simultaneously. In order to rule out any practice effects, the practice time of the driving task itself and the secondary task was sufficiently long as indicated by Strayer, Watson and Drews (2011) and Rouzikhah, King, and Rakotonirainy (2013).

During the practice drives no visual distraction alert warning was given. Next, participants completed a series of test session drives according to the group they have been assigned to. The first test session drive was a 12-minute test session drive with a deactivated system (no warnings issued but logged to file) followed by an 18- minutes test-session drive with an activated system (warnings issued and logged to file). In each driving session, after the first 5 m of driving, a prompt automated voice saying "please write message" indicated that the driver should begin engaging in the secondary task. Each test session consisted of completing to write and to send text messages. After the second test session the baseline protocol was repeated: drivers were asked to enter their subjective level of driving and visual performance immediately after the test session. In addition to the performance score ratings, in the post-treatment questionnaire participants were asked about how useful, satisfying and acceptable they found the mitigation, how realistic the simulator was and how they physically felt after the completion of the study.

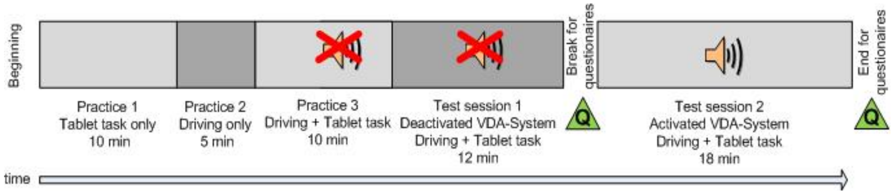

Figure 3: Experimental procedure, Q = Questionnaire

2.8. Dependent Variables and Data Analysis

Univariate ANOVAs were used to test the statistical significance at a 5% level in the dependent variables. Furthermore, paired samples t-tests for the acceptance ratings as well as correlation calculations between actual and perceived performance were performed.

There were time periods when the driver was distracted (during secondary task engagement) and periods when the driver was just driving (30-sec "normal driving" sequences). In the current paper only the distracting periods of the drive are analyzed.

To classify a behavioral adaption effect over time a split of both test sessions was performed (beginning and end of deactivated system as well as beginning and end of activated system). Furthermore, to classify a driver calibration effect, the data from the actual performance was compared to the data of the perceived performance (Horrey, & Lesch, 2008).

A. Actual performance

Actual performance scores from eye movement data were processed and aggregated after the experiment. In order to investigate drivers' actual visual performance during distracting tasks we used the percent road-center (PRC) measure according to (Victor, Harbluck, & Engström, 2005).

B. Perceived performance ratings

Perceived performance was retrieved using a set of performance rating questions (e.g. “How well were you able to keep the vehicle in the lane?”). Driver ratings of the perceived performance included the ability to keep the truck within the lane, the perceived number of lane departures, the perceived ability to keep the posted speed and the perceived ability to keep the eyes on the road during the beginning and the end of the tablet task when driving with and without a VDS-system. After each experimental condition drivers estimated their performance score with a cross on a 10 cm line with the two extremes “very poor” and “very good”. For the estimated PRC values, we asked the specific question “How long (in percent) did you keep your eyes on the road?”

C. System acceptance and system perception

In this study ‘system acceptance’ was used as a between-subjects evaluation (after-measurement only).The acceptance measures were measured using the Van der Laan Scale for acceptance (van der Laan, Heiko, & DeWaard, 1997). The Van der Laan Scale allows a comparison of impact of new devices with other systems by assessing direct attitudes towards that systems. The Van der Laan Scale defines attitudes as respond predispositions, or tendencies in terms of ‘approach/avoidance’ or ‘favourable/unfavourable’ in two dimensions. Possible evaluations can be reflected in the usefulness score reflecting practical aspects and in the satisfying score mirroring pleasantness. The ratings on systems usefulness and pleasantness are considered “sub-measures” of the acceptance scale by taking only parts of the items into consideration (see Table 3).

After each driver used the VDA System, post-drive questionnaires on system perception which reflected the driver’s attitude towards the system and the warning tone on a 7-point Likert-scale (1 – strongly disagree to 7 – strongly agree). The full set of questions is presented in table 4.

3. Results

Univariate ANOVAs were used to test the statistical significance at a 5% level in the actual and subjective ratings of the PRC as well as ratings of system perception and system acceptance. Only the periods when the driver was completing the first and last text message task (distracting periods of the drive) were analyzed. These periods were determined by the experiment.

3.1.Perceived performance over time (driver adaptation)

ANOVAs were calculated for a three factorial design: one behavioral adaptation within-subjects factor “time” (four levels) and two between-subject factors ‘warning algorithm’ (SG vs. GHSG-warning algorithm) and ‘system reliability’ (reliable vs. not reliable). For the within-factor analysis the Huynh-Feldt sources are reported. For the activated test session the influence of the warning algorithm and the reliable warnings was analyzed separately.

Analysis shows that there was a change in subjective ratings over time - subjective performance increases over time. Analysis indicates an increased perceived ability to keep the lane, a decrease in the number of lane departures, an increase in the ability to keep the posted speed and an increase in the ability to keep the eyes on the road. This driver adaption effect is independent of the warning algorithm as well as independent of false positive warnings (see Table 1).

Table 1 Effects of the ANOVA for the factor “time” (behavioral adaptation), “warning algorithm” and “system reliability”

	Effect	***F*(1,52)**	***p***	***partial η²***
Perceived ability to keep within the lane	time	38.932	<.001	.428
	time*warning algorithm	0.330	.801	.006
	time*reliability	1.772	.156	.033
	time*warning algorithm*reliability	0.163	.919	.008
	warning algorithm	1.331	.254	.025
	reliability	2.180	.146	.040
	warning algorithm*reliability	3.854	.055	.069
perceived number of lane departures	time	29.375	<.001	.361
	time*warning algorithm	0.166	.839	.003
	time*reliability	4.720	.012	.083
	time*warning algorithm*reliability	0.173	.833	.003
	warning algorithm	1.318	.254	.025
	reliability	0.061	.807	.001
	warning algorithm*reliability	2.691	.107	.049
perceived ability to keep speed	time	16.865	<.001	.245
	time* warning algorithm	1.280	.283	.024
	time*reliability	0.515	.618	.010
	time*warning algorithm*reliability	2.294	.100	.042
	warning algorithm	0.020	.889	.000
	reliability	0.613	.437	.012
	warning algorithm*reliability	5.646	.021	.098
perceived ability to keep eyes on road	time	38.282	<.001	.424
	time* warning algorithm	0.927	.413	.018
	time*reliability	0.063	.960	.001
	time*warning algorithm*reliability	2.097	.154	.039
	warning algorithm	0.022	.883	.000
	reliability	0.282	.598	.005
	warning algorithm*reliability	0.826	.367	.016
perceived percent eyes on road	time	46.311	<.001	.471
	time*warning algorithm	1.632	.200	.030
	time*reliability	0.951	.391	.018
	time*warning algorithm*reliability	0.534	.468	.010
	warning algorithm	0.140	.710	.003
	reliability	0.008	.929	.000
	warning algorithm*reliability	0.071	.790	.001

Fig. 4 shows the driver ratings of the perceived ability to keep the truck within the lane, the perceived number of lane departures, the perceived ability to keep the posted speed and the perceived ability to keep the eyes on the road during the beginning and the end of the tablet task when driving with and without a VDS-system.

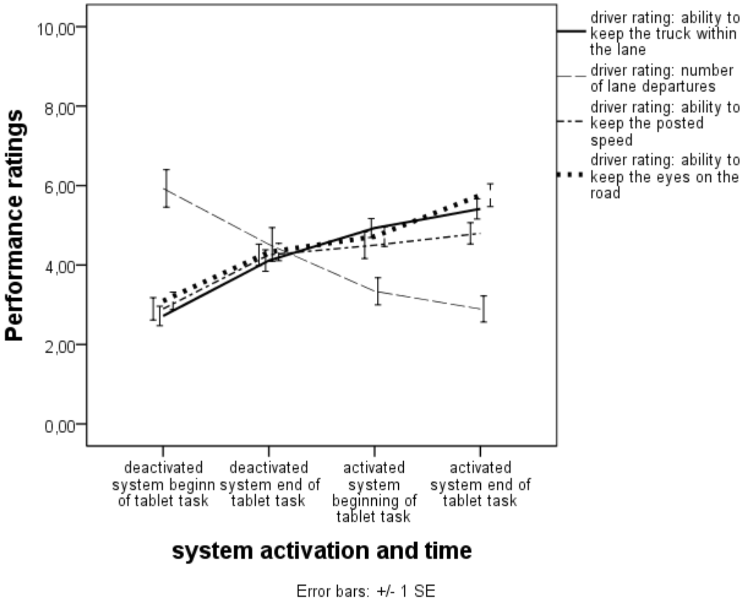

Figure 4: Driver ratings of ability to keep the truck within the lane”, number of lane departures, ability to keep the posted speed and ability to keep the eyes on the road during beginning and end of the tablet task when driving with and without a VDS-system.

3.2.Perceived vs actual performance over time (driver calibration)

To examine drivers’ calibration to distraction effects, we compared drivers’ subjective estimates of effects with actual measured performance effects, based on eyes-on-road percent at four different times throughout the experiment (beginning and end of deactivated system period as well as beginning and end of activated system period).

An ANOVA for the measure PRC with three within-subject factors (performance measure [actual performance vs. perceived performance] and system activation [system deactivated vs. system activated] and time [beginning of tablet task vs. end of tablet task] and two between-subject factors (warning algorithm [SG vs. GHSG] and system reliability [reliable vs. not reliable]) indicated the significant effects as presented in Table 2.

Table 2. Significant effects for PRC with three within-subject factors (performance measure [actual performance vs. perceived performance] and system activation [system deactivated vs. system activated] and time [beginning of tablet task vs. end of tablet task] and two between-subject factors (warning algorithm [SG vs. GHSG] and system reliability [reliable vs. not reliable])

Three main effects	**Two two-way interactions**	**One three-way interaction**
performance measure	System activation*warning algorithm	Performance measure*system activation*warning algorithm
system activation	time *warning algorithm	
time		

According to common practice, only the three-way interaction is interpreted (Bortz, 2005). There is a significant difference between the performance measures (perceived PRC higher than actual PRC), the system activation (VDA System activation increases PRC) and the warning algorithm (GHSG-warning algorithm improves PRC more than SG-warning algorithm) all together. This can be interpreted as both for perceived as well as subjective performance, the GHSG-warning algorithm leads to higher PRC over time when the system is activated (Fig. 5). A correlation for the PRC revealed that actual performance (M = 48.0 %, SD = 15.8 %) and perceived performance (M = 57.1 %, SD = 21.4 %) were significantly related, r = .364, N = 224, p < .01, two tails. Higher actual performance was associated with higher perceived performance. This means that changes in actual performance are correlated with changes in perceived performance.

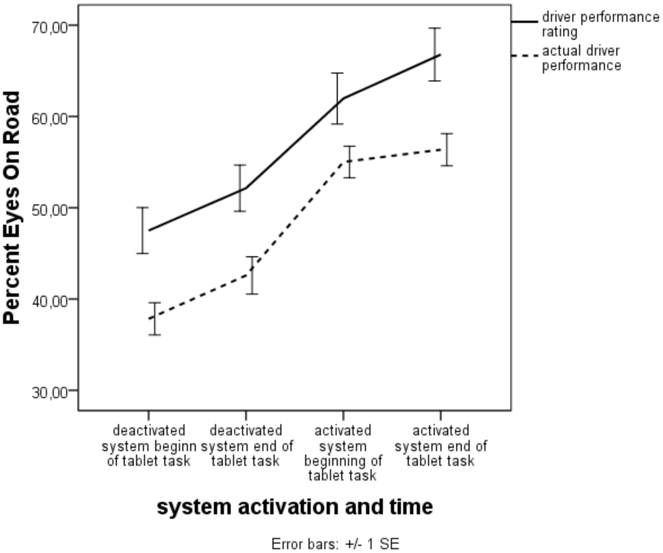

Figure 5: Driver performance ratings and actual driver performance percent eyes on road during the beginning and the end of the tablet task when driving with and without a VDS-system.

3.3. VDA System acceptance, perceived usefulness and satisfying ratings

To measure the overall acceptance and the two sub-measures usefulness and satisfaction, the mean values for all participants were calculated. All subjects rated rather homogeneously with acceptance scores ranging from 0.45 to 0.95. Considering that the scale starts at -2 rather than 0, the ratings are high.

There was no significant difference between the ‘warning algorithm’ nor the ‘warning reliability’. That means that no matter of false positive warnings or the frequency of the warnings (‘warning algorithm’) driver ratings of the system acceptance are considered equal.

Focusing on the two sub-measures of the acceptance questionnaire, we can conclude that the systems were rated more useful than satisfying. A paired samples t-test revealed significant differences between the two sub-scales (t= 14,840; df= 55; p>0.001).

Although there is no significant difference between the warning systems, all systems were rated as very useful, indicated by the high usefulness scores (between 0.59 for GHSG/not reliable and 1.4 for SG/not reliable). All systems, even if false positive warnings were provided, are rated as being useful.

All ratings regarding the satisfying score are lower than the ratings for usefulness (between -.16 for GHSG/not reliable and 0.33 for SG/not reliable). Except for the GHSG/not reliable systems all other systems are rated as satisfying. Figure 6 shows an overview of all tested four system conditions and their usefulness scores and satisfying scores.

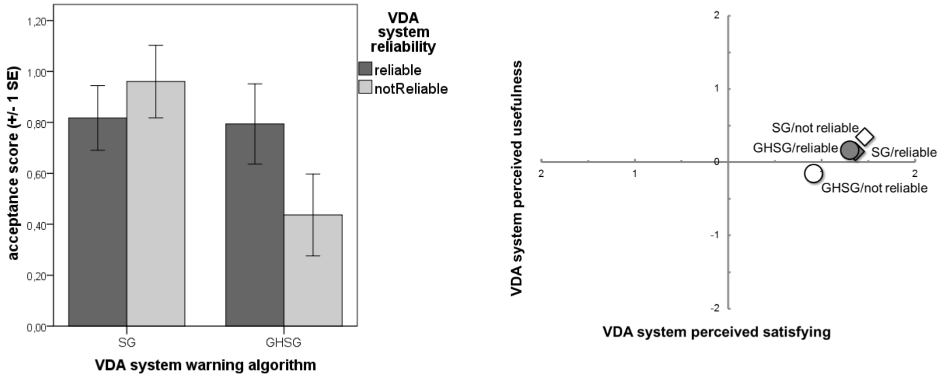

Figure 6: System acceptance (left) as well as system usefulness and satisfying (right) ratings using the Van der Laan Scale for acceptance

Table 3. Effects for the ratings of acceptance, usefulness and satisfying

	Effect	***F*(1,52)**	***p***	***partial η^2***
acceptance	warning algorithm	3.446	.069	.062
	reliability	.528	.471	.010
	warning algorithm*reliability	2.872	.096	.052
usefulness	warning algorithm	3.826	.056	.069
	reliability	.868	.356	.016
	warning algorithm*algorithm	2.507	.119	.046
satisfying	warning algorithm	1.749	.192	.033
	reliability	.118	.733	.002
	warning algorithm*reliability	2.018	.161	.037

3.4.Drivers perception of the VDA System

System perception which reflected the driver's attitude towards the system and the warning tones were evaluated using a 7-point Likert-scale (1 – strongly disagree to 7 – strongly agree).

VDA Systems reduce distraction and lane departures

A drivers opinion about the reduction of distraction is very high (M = 5,36, SD = 1,381) independent of false positive warnings or the warning algorithm. Likewise independent of false positive warnings or the warning algorithm, a VDA System has a significant effect on the reduction of lane departures (M = 5,38, SD = 1,383).

Warning tones are helpful, easy to understand, predictable and consistent, attention catching but slightly annoying

In general drivers stated that the alert tones were easy to understand (M = 5,86, SD = 1,086), were ranked high for annoyances (M = 4,87, SD = 1,810), also were considered very helpful (M = 5,34, SD = 0.880), were regarded as predictable and consistent (meaning that the driver always knew what to do when a warning was issued) and truly got the drivers attention on a high level (M = 6,21, SD = 0,889). Concerning the characteristic of the warning tone, there is no difference between any of the four experimental conditions for the mentioned measures.

Reliable VDA Systems improve safer driving

For the general question on whether the system improves driving, the opinion is very positive (M = 5,30, SD = 1,094). It is perceived that a reliable VDA System improves driving more than an unreliable VDA System (F(1,52) = 6.151, p = 0.016, *partial* η^2 = .106).

Independent of the warning algorithm, in general drivers believe that they drive safer when using a VDA System (M = 5,50, SD = 1,06) compared when they are not using the system. However drivers only regard themselves as a safe driver when the system is reliable (F(1,52) = 4.160, p < 0.046, *partial* η^2 = .074).

Overall, the VDA System is perceived to make driving easier (M = 4,39, SD = 1,485). A reliable system (F(1,52) = 6.866, p < 0.011, *partial* η^2 = .117) makes driving significantly easier than an unreliable system. And a reliable system with a transparent SG-warning algorithm (F(1,52) = 6.866, p < 0.011, *partial* η^2 = .117) makes driving easier compared to a reliable system with an non-transparent GHSG-warning algorithm.

Drivers stated with M = 5, 27 out of seven (SD = 1,314), that driving with a VDA System increases their awareness of the traffic situation (awareness of other vehicles and lane position). False positive warnings reduces drivers situational awareness significantly compared to no false positive warnings (F(1,52) = 6.998, p < 0.011, *partial* η^2 = .119).

The same effects are found for drivers' perception of the reduction of speeding events when assisted with a VDA System. Drivers perceive that they significantly reduce speeding events when the VDA System is activated compared to when it is deactivated (M = 4,16, SD = 1,671). Drivers agree that a reliable system would reduce speeding events which is not the case for a not reliable system (F(1,52) = 8.842, p = 0.004, *partial* η^2 = .145).

Impression of false alerts and warning frequency

Consistently all drivers stated that only when they have received false warnings, the warnings tones occurred when they did not need them. When they did not receive any false warnings, they did not have the impression that they received unneeded warnings (F(1,52) = 15.028, p = 0.000, *partial* η^2 = .224). This shows that our experimental manipulation (false warnings are unneeded) is valid.

Regarding the frequency of the warnings there is a significant interaction of the two factors warning algorithm and reliability (F(1,52) = 4.784, p = 0.033, *partial* η^2 = .084). Drivers found that there were too frequent warnings in the GHSG-warning algorithm/not reliable condition compared to the SG/not reliable condition in which too frequent warnings are no issue.

In Table 4 a summary of the effects of both controlled factors ´warning algorithm´ and ´system reliability´ on drivers perception of the VDA System is shown.

Table 4. Effects for drivers perception of the VDA System

	Ratings M (SD)	Main effect warning algorithm	Main effect system reliability	Interaction effect warning algorithm*system reliability
“The VDA System				
…reduces distraction.”	5,4 (1,4)	-	-	-
…reduces lane departure.”	5,4 (1,4)	-	-	-
… makes me a safer driver.”	5,5 (1,1)	-	yes	-
…improves driving.”	5,3 (1,1)	-	yes	-
…reduces speeding events”	4,2 (1,7)	-	yes	-
…makes it easier to drive.”	4,4 (1,5)	-	yes	-
…makes me more aware of the traffic around me (e.g. other vehicles).”	5,3 (1,3)	-	yes	-
“The VDA Systems warning tones				
…got my attention.”	6,2 (0,9)	-	-	-
…are easy to understand.”	5,8 (1,1)	-	-	-
…are helpful.”	5,3 (0,9)	-	-	-
…are predictable and consistent.”	4,6 (1,8)	-	-	-
…are annoying.”	4,9 (1,8)	-	-	-
…occurred when I didn`t need them.”	4,3 (1,9)	-	yes	-
…are too frequent.”	4,5 (1,7)	-	-	yes

4. Discussion

The results are discussed in relation to the seven research hypotheses.

Perceived performance over time (driver adaptation)

It was hypothesized (H2) that a VDA System enhances driver estimation of performance (perceived behavioral control). The results indicate that this hypothesis can be confirmed - drivers change their subjective ratings of performance over time. In particular there is an increased perceived ability to keep the lane, a decrease in the number of lane departures, an increase in the ability to keep the posted speed and an increase in the ability to keep the eyes on the road. This driver adaption effect is independent of the warning algorithm (H4 not confirmed) as well as independent of false positive warnings (H6 not confirmed).

Drivers believe they are more attentive to the road and have better vehicle control when they receive warnings. This driver adaptation effect to the VDA System can be interpreted as a '*cognitive adaptation effect'*. The finding that drivers rated performance enhancement equally for both the SG- and the GHSG-warning algorithm, leads to the conclusion that drivers are not able to differentiate the details of the warning algorithm. Future studies should investigate if this effect persists when activating the VDA System for a longer period of time and/or when deactivating the system in future trips (such as a driver changing from a vehicle equipped with the VDA System to a vehicle not equipped with the system). One limitation of the current study could be that we cannot completely dismiss a learning effect. It might be possible that drivers believe they improved in various behaviors due to an increase in the amount of exposure to the primary task (driving) and/or the secondary distracting task. This issue was addressed in the experimental design by providing a relatively long learning period of the individual tasks as well as the tasks together. The learning period was almost as long as the actual experimental period, and each participant was asked if they believe they are trained well in performing the task. Because we were especially interested in drivers perceived performance over time, we used a within-subjects experimental design. In future studies it could be advisable to conduct a between-subjects study to compare the effects. Due to the scarcity of professional truck drivers to participate in a driving simulator study, this was not possible. Nevertheless, the fact that professional truck drivers were tested is a strength of the study. This driver population does seem to have the ability to identify perceived performance enhancement enabled through the VDA System. In the future, this 'driver cognitive adaptation effect' should be tested with other driver populations (e.g. car drivers, teen drivers).

Perceived vs actual performance over time (driver calibration)

VDA-equipped vehicles result in more attentive drivers (thereby confirming H1). This finding is in line with previous studies reporting similar effects (Lee et al., 2013; 2012; Croke, & Cerneaz; Donmez, Boyle, Lee, & McGehee, 2006). As these studies have not correlated the perceived with the actual performance (driver calibration) over time, one focus of this study was to compare perceived with actual enhancement of attention allocation on road over time.

Previously, Horrey and Lesch (2008) showed that distracted drivers are not well calibrated (mismatch of actual and perceived performance) to the effects distracted driving has. The current results, however indicate that distracted drivers are sensitive to low eyes-on-road time when the VDA System does not provide warnings. Likewise, drivers are sensitive to increased eyes-on-road time when the VDA System provides warnings. That means that, consistently throughout the experimental drive (VDA System disabled followed by VDA System enabled), the degree of correspondence (as in level of distance) of perceived and actual attention allocation on-road was remarkably constant. This was shown by the correlation of both measures. This sensitivity to detect the change in performance can be interpreted as drivers being calibrated to the performance benefits of a VDA System. Unreliable warnings have no significant effect on a driver's ability to estimate performance.

For the actual eyes-on-road time (PRC), what was believed to be a non-transparent warning algorithm (GHSG-warning algorithm), leads to more attention allocation on-road that a simpler, transparent warning algorithm (SG-warning algorithm). This finding rejects hypothesis 3 (H3)and is particular interesting with regard to the result showing that, independently of the warning algorithm transparency, drivers *perceive* the increase in attention equally well. In other words, drivers *react* to a GHSG-warning algorithm by attending to the road more, however drivers *do not perceive* this behavior as significantly different than from the SG-warning algorithm. As a speculation, the GHSG-warning algorithm could be more close to a drivers own "feeling" of unsafe glance behavior, drivers may believe that getting a warning for a series of glances is justified in addition to a single long glance warning. As such, two research needs for future studies are identified. First, the factor 'warning algorithm' could be assessed in more detail in a counterbalanced within-subjects experimental design rather than in a between-subjects experimental design as in the current study. Second, the factor 'warning algorithm' could have three factor levels (SG, GH, and GHSG) compared to the two factor levels (SG, and GHSG) used in the current study. Implementing a glance history (GH) based warning algorithm in the absence of single long glance (SG) warnings, would potentially identify clearer estimates of the relevance of a series of glances compared to a series of glances coupled to single long glances (GHSG). However, the "*Eyes off forward roadway algorithm"* (Klauer, Dingus, Neale, & Sudweeks, 2006) tested by Lee et al. (2013) is a glance history algorithm (total glance time) and it was shown to be less effective (AUC=.75) than the Multi Distraction Detection Algorithm (which was essentially identical to the present GHSG algorithm at AUC=.87). Thus, our present results serve to complete this picture in combination with the work by Lee et al (2013) because the SG algorithm was not present in their comparison.

Drivers acceptance and perception of the VDA System

For the system acceptance it was found that *regardless of* false positive warnings or the warning algorithm, driver ratings of the system acceptance was high, and the system was rated as very useful and satisfying. In general the system is rated more useful than satisfying. Once exception is unreliable systems with a GHSG-warning algorithm – they are rated as less satisfying. A potential explanation for this could be the higher frequency of warnings in the GHSG/unreliable-warning condition. This explanation is also supported by the finding that drivers rated the warnings in the same condition as "too frequent warnings" compared the other conditions of the experiment. It could be a problem for drivers to feel annoyed or disturbed by the VDA System warnings with too many false alarms. If the VDA System provides too frequent warnings, the system is perceived as annoying. If a system is perceived as annoying it can undermine trust and traffic safety, as shown in previous research (Lees, 2010; Lee, & See, 2004). This may lead to confusion and neglect of the system such as the driver is unwilling to respond to warnings (Dixon, & Wickens, 2007). However, the drivers in this study stated, that the warnings were not confusing but instead are predictable and comprehendible – however only when reliable. Future studies should investigate the threshold for “too frequent”, annoying warnings and test over a longer period (e.g. in naturalistic driving studies) to address this issue.

Drivers significantly perceive an unreliable VDA System as inferior to a reliable system. However when measuring specifically system acceptance using the van der Laan Scale for acceptance (1997), results show that drivers even accept an imperfect VDA System, thus rejecting H7. The system acceptance finding is in line with other research on (slightly different) distraction mitigation technology (e.g. Donmez, Boyle, Lee, & McGehee, 2006) indicating that unreliable warnings are a less relevant issue. However, these results should be replicated over a longer time period in naturalistic driving studies, where false positive warnings might influence acceptance, and in turn usage, of a VDA System. Future research should also evaluate if a higher frequency of false positive warnings does have a significant negative effect on system acceptance. This would indicate that the frequency of false positive warnings in the current study was not sufficient to detect a possible effect.

It was expected that acceptance of a warning system providing transparent warnings (SG-warning algorithm) would be higher than the acceptance of a warning system providing non-transparent warnings (GHSG-warning algorithm). This hypothesis (H5) was not confirmed. Thus, the notion of observability (Rogers, 1995) meaning that the driver will rate a system more favorably if its actions are comprehensible and the decision rationale is transparent, could not be confirmed. This could mean that we were incorrect in labeling the GHSG algorithm a priori as less transparent (i.e. a GHSG- warning algorithm may not actually be less transparent than a SG-warning algorithm). The findings indicate that both warning algorithms are equally comprehendible. This assertionis supported by taking into account the drivers ratings of easiness to understand the warnings, helpfulness of warnings, predictability of warnings, and consistency of warnings being equally distributed across all experimental conditions. Furthermore, questionnaire analyses reveal that even though drivers ranked the VDA System fairly high on annoyance, drivers always knew what to do when a warning was issued. For the general question on whether the system improves driving and attention, their opinion is very positive. In general drivers stated that they drive safer and more attentive when using a VDA System compared when they are not using the system.

However drivers only regard themselves as a safe driver when the system is reliable. Only a reliable VDA System increases perceived awareness of other vehicles and lane position and reduces speeding events. A reliable system makes driving significantly easier. And a system with a transparent SG-warning algorithm makes driving easier compared to a system with a non-transparent GHSG-warning algorithm.

In conclusion, drivers believe that a VDA System reduces distraction and that a reliable VDA System improves safer driving. Furthermore, drivers *react* to a GHSG-warning algorithm by attending to the road more, however drivers *do not perceive* this behavior as significantly different than from the SG-warning algorithm. *Regardless of* false positive warnings or the warning algorithm, drivers’ ratings of the system acceptance were high, and the system was rated as very useful and satisfying. In general, drivers are calibrated to the benefit a VDA System has on attention allocation on-road.

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6. List of key Points

- A VDA System was found to be an effective countermeasure.
- A behavioural adaptation effect over time was found, as well as a driver calibration effect which was stable over time.
- It was found that a warning algorithm that provides warnings for both single long glances and glance history (a series of glances) warning algorithm (GHSG-warning algorithm) significantly improves attention on-road.
- The ability to detect the effects of false warnings on driver actual and subjective performance was demonstrated. Drivers showed a receptive attitude towards a reliable VDA System, demonstrating that such a type of support is well accepted and well perceived.

7. Précis

It was shown that VDA Systems can prevent visual distraction and inattention in situations they are designed for, both by inducing appropriate reactions to warnings, and by provoking a subjective attention benefit.

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CHAPTER 5 PAPER IV

Paper IV

Safer Distraction – Assisting Distracted Drivers with a Visual Distraction Alert System.

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Safer Distraction – Assisting distracted drivers with a Visual Distraction Alert System

Claudia A. Wege, Trent W. Victor

Volvo Group Trucks Technology (GTT), Götaverksgatan 10, M1.6, 405 08 Göteborg, Sweden

Key words: attention improvement, advanced safety systems, concurrent driver feedback

Abstract

Objective: The focus of this study was to compare two distraction warning algorithms in a Visual Distraction Alert (VDA-) System (with or without false warnings) regarding their effects on attention on-road and vehicle control.

Background: Visual Distraction Alert (VDA-) Systems have the potential to mitigate distraction once it occurs. Despite developments on such systems being on the forefront, it is yet unclear which distraction warning algorithm is most effective in improving attention allocation on-road, improving driving performance, and decreasing engagement in distracting tasks.

Methods: 56 professional truck drivers were compared regarding their eye-glance behavior, engagement in a distracting task and driving performance behavior when driving on a simulated highway. After experiencing distracted driving (entering text messages), the VDA- system assisted each distracted driver by providing distraction warnings.

Results: Statistical analysis of the results showed that (1) visually distracted drivers who received a warning became more attentive to the roadway. This was found to be both (2) an immediate adaptation effect after the system was used and (3) it persisted over time. However, in contrast to our hypothesis, (4) a warning algorithm which provides a warning for both a single glance and glance history was more effective than an algorithm warning for single glances only, an effect that was also (5) stable over time. One explanation is that a combined single long glance and glance history warning algorithm is more congruent to a drivers own “feeling” of unsafe distracted driving. (6) Additionally it was found that an unreliable VDA System compared to a reliable VDA System is equally effective at increasing attention to the forward roadway and increasing vehicle control.

Conclusion: As the VDA System was found be a successful real-time distraction countermeasure technology, it is concluded that in the future distraction can be made safer.

1. Introduction

Distracted driving is, with regard to crash prevalence, one of the most important safety concerns of our age. Today, “distraction is part of everyday driving” (Aitkin, Chairman NRMA-ACT Road Safety Trust, 2009) and it is expected that the problem of distracted drivers will intensify in the future as new technologies are marketed increasingly more. It is unlikely that distraction will ever be eradicated as a road safety problem, at best it can be effectively managed (Regan, 2010). The management of driver distraction using vehicle-based technology motivated this paper.

Vehicle-based technology has the potential to combat driver distraction once it occurs. Review papers from Engström and Victor (2008), Hickman and Hanowski (2012), Horrey, Lesch, Dainoff, Robertson and Noy (2012), Victor (2012) and Kircher and Ahlström (2013) provide overviews on a variety of on-board driver monitoring systems. Long-term field tests with a *Driver State Sensor (DSS)* System showed a significant elimination of crashes attributed to distraction or fatigue (Croke, & Cerneaz, 2009).

Visual driver distraction is occurs when drivers take their eyes off the road for an extended period of time compromising safety and resulting in increasingly more people being killed each year (NHTSA, 2013). Attention-related failures were identified to be the contributing factor in 78 percent of all crashes and 65 percent of all near-crashes (Neale, Dingus, Klauer, Sudweeks, & Goodman, 2005). However, exactly what glance behavior should the real-time distraction monitoring systems be detecting?

It has been found, that often, one short glance is not sufficient when completing a non-driving related task, so the driver most often quickly look back and forth to the road, a glance pattern defined as ‘visual time sharing’ (Victor, Harbluk, & Engström, 2005; Zwahlen, Adams, & de Bald, 1988; Merat, & Jamson, 2007). That means that the task is temporally “chunked” (i.e. occur in bursts of glances). It has been determined that drivers choose a series of repeated glances rather than extending one single glance, if the secondary task demands attention for a longer period of time. Drivers tend to “chunk” large tasks into smaller interactions of between 1 and 2 seconds glance duration (Zwahlen, Adams, & de Bald, 1988; Wierwille , 1993; Dingus, McGehee, Manakkal, Jahns, Carney, & Hankey, 1997) . The mean glance duration to an in-vehicle display does typically not exceed 2 s (Rockwell, 1988; Wierwille, 1993). This is in line with findings of 1.6 seconds being regarded as safe (Pradhan, Divekar, Masserang, Romoser, Zafian, Blomberg, & Thomas, 2011) and that over 80% of the crashes were attributable to drivers glancing inside the vehicle for longer than 1.6 s (Horrey, & Wickens, 2007).

Klauer, Dingus, Neale and Sudweeks (2006) and Olson, Hanowski, Hickman and Bocanegra (2009) show that critical events are associated with high eyes-off-road times during a six second period preceding an event onset. In a re-analysis of the 100-car data, Klauer, Dingus, Neale, Sudweeks and Ramsey (2009) showed total Time Eyes Off the Forward Roadway (total TEOR) within a time period is associated with increased crash/near-crash risk. The shortest significant amounts were 20% (3 seconds) total TEOR for a 15 second task duration, or 30% (2 seconds) total TEOR for a 6 second task duration. It is important to mention that these results refer to a total off road glamce time of two seconds or more in a six second period, and do not refer to a single glance duration. In other words, critical events were associated with an extended eyes-off-road time during the six second period preceding an precipitating event onset (e.g. a lead vehicle initiating braking). Overall, these studies indicate that accumulated eyes-off-road time (glance history) is associated with higher crash probability, but they did not test independently the effect of single glance duration or asses how single glance duration combines with glance history to influence crash risk.

Liang, Lee, and Yekhshatyan (2012) used the 100-Car study data to compare different approaches in estimating distraction and established which characteristics of driver eye glance behavior indicate crash risk. Twenty-four algorithms – that varied according to how they considered glance duration, glance history, and glance location – were compared on how well they predicted crash risk. They found that algorithms estimating risk as a linear function of instantaneous changes of off-road glance duration produce the most sensitive estimation to crash/near-crash risk. That is, instantaneous single off-road glance duration and not glance history was the best crash predictor. Although algorithms considering both glance history and glance location did not improve estimation above glance duration algorithms alone, they were still predictive of crash/near-crash risk. For example, algorithms that summarized glance measures using a small window led to better performance than those that used a large window.

Various warning algorithms detecting potentially distracting glances have been developed. In a recent study Lee, Moeckli, Brown, Roberts, Victor. Marshall, Schwarz, and Nadler (2012) and Lee, Moeckli, Brown, Roberts, Schwarz, Yekhshatyan, Nadler, Liang, Victor, Marshall, and Davis (2013) compared four distraction detection algorithms on their ability to detect distraction during a simulated highway drive while participants performed a secondary task. It was found that the Multi Distraction Detection algorithm identified visual driver distraction better than the three other algorithms. The description of each algorithm along with the AUC values reported by Lee et al. (2012) can be found below (the AUC - area under the curve - values indicate algorithm performance with 1.0 for a perfect algorithm).

- The "*Eyes off forward roadway algorithm"* (Klauer, Dingus, Neale, & Sudweeks, (2006) defines visual distraction as a cumulative glance away from the road of 2 seconds within a 6-second running window) (AUC = 0.75).
- The "*Risky visual scanning patterns algorithm"* (Donmez, Boyle, & Lee, 2007; 2008) considers the history of glances and considers both the duration of the current glance and the cumulative glances away from the road to define risky visual scanning patterns (AUC = 0.67).
- The *"AttenD algorithm"* (Kircher, & Ahlström, 2013) considers long glances away from the road as hazardous, and uses a buffer (begins at 2 seconds and is decremented over time when looking away) to represent the amount of road information the driver possesses (AUC = 0.71).
- The "*Multi Distraction Detection algorithm"* (Victor, 2010; Victor, & Larsson, 2010) identifies visual and cognitive distraction using the percent of glances to the road center (PRC) and long glances away from the road (AUC = 0.87).

Although it was found that the multi distraction detection algorithm *detects* visual distraction best, it is still unclear whether drivers *attend the road more* when they are assisted with either a warning algorithm that detects long single glances (a Single Glance warning algorithm (SG) warning algorithm) *or* a series of off-road glances in combination with long single glances (a Glance History and Single Glance warning algorithm (GHSG) warning algorithm). It is unknown if SG warnings or GHSG warnings have a significant impact on attention on-road and driving behavior. The present study focused on comparing the effects of SG warnings and GHSG warnings on visual- and driving performance.

The SG algorithm is interpreted to be more transparent than the GHGH algorithm. Transparency refers to how easily the driver understands what glance behavior is causing the warning. It was expected that the SG warning algorithm would be easier to understand and therefore more transparent to the driver, thus making it "easier" to avoid warnings. In contrast, the GHSG warning algorithm was expected to be less easy to understand and therefore less transparent to the driver, thus making it "more difficult" to avoid warnings.

We hypothesize that a transparent warning algorithm has a better potential to reengage the driver to pay more attention to the driving task and thus to have better vehicle control than a less transparent warning. We hypothesize furthermore that this transparent warning algorithm is most effective for behavioral change.

Warning reliability

Unreliable warnings are a relevant issue when designing warning systems. The general principle when designing ADAS is that false warning rate should be low (ECE, 2001). Unreliable warnings can be false positive warnings which are warnings provided when the driver is looking on road. False positive warnings are defined by Lees and Lee (2007) as a warning or alarm associated with a context where the operator is unable to identify the source (e.g. system malfunction) and are also called nuisance warnings. In contrast, false negative warnings are warnings that should be have been provided, but were missed. Research has shown that false positive warnings can be more detrimental to driver`s performance than false negative warnings (Lee, & See, 2004). Previous research confirms that unreliable feedback can undermine driver acceptance and trust (Lees, 2010; Lee & See, 2004) which may lead to confusion and neglect of the system such as the driver is unwilling to respond to warnings (Wickens, & Dixon, 2007). Studies have found that trust can be recovered if the system only experiences a small number of errors (Goa & Lee, 2006). The initial response to false positive warnings is usually driver frustration which can also undermine traffic safety (Donmez, Boyle, Lee, & McGehee, 2006). However, some studies show that not all false positive warnings are harmful. False positive warnings may also lead to more cautious driving and thereby result in reduced warnings (Parasuraman, Hancock, & Olofinboba,1997; , Lees, & Lee, 2007) In sum, the effect of false warnings on driving performance has largely been studied on ADAS such as forward collision warning systems (Bueno, Fabrigoule, Deleurence, Ndiaye, & Fort, 2012), however it has not been studied in regards to VDA-systems. Based on the above findings we also hypothesize that unreliable warnings reduce the effectiveness (less performance benefit) of a VDA-system.

2. Method

A driving simulator study was set up to monitor driver eye movement behavior, driving performance and engagement in secondary tasks at all times. A VDA system detected visual driver distraction. During the deactivated system period the warnings were logged to file, but not issued to the driver. During the activated system period all warnings were logged and issued to the driver.

Participants

56 male participants (14 in each of four experimental groups) were tested. Participants were professional truck drivers, on average 37 years old (SD = 10 years), holding a valid, unrestricted driver's license, are licensed for an average of 19 years (SD = 10 years) driving a car and licensed for an average of 15 years (SD = 10 years) driving a truck and drive on average 128.000 km/year. None of them had participated in a driving simulator study before. They were all in good general health, have had normal hearing and were right handed. Each participant was given a 200 SEK gift card as an incentive for participation.

Driving Simulator

The truck simulator is a non-moving base simulator from Volvo Group Trucks Technology in Sweden. The simulator consists of a static Volvo Truck, and a cylindrical display system. The chassis is a real Volvo FH12 fully equipped truck compartment with a force-feedback steering wheel and sensors for pedals and steering wheel measures. The cylindrical display system has a 3.5 m radius and a horizontal field-of-view of 180° at which participants did not see any static objects, such as the floor, ceiling or walls. Three Projection Design projectors render three images (1920x1200 @ 60Hz) which are blended to form one seamless panorama of simulated road and traffic environment. The rear-views to be integrated using LCDs. Traffic and warning systems sounds are generated by a sound server and a RME Hammerfall multichannel soundcard. All log data was recorded in 60Hz. Eye-tracker data was logged on a separate machine and merged by synchronization between the driving simulator and the eye-tracker system during each test run.

Driving scenario

The simulated traffic scenario showed a two-lane motorway with a W-beam-guardrail to the left and a gravel lane to the right (Fig. 1). There was a medium traffic density with approximately 23 meeting cars and two passing vehicles per minute when the ego vehicle was travelling at 90 km/h. The driver was asked to keep a speed limit of 90 km/h at all times.

Visual Distraction Alert System

Non-intrusive eye-tracker systems made it possible to monitor the level of driver distraction. The eye-tracker system was a Facelab 4.2.2 eye tracking system (Seeing Machine) with two analog cameras and two separate infrared lights installed in the top center of the instrument cluster (see Fig. 1). The eye tracker data was processed in real-time in 60Hz. Fig 1 shows the eye-tracker cameras capturing eye glance data (Fig 1 shows eye-tracking cameras capturing eye glance direction indicated by two yellow lines).

As the drivers' glances were continuously tracked, immediate feedback (an audio alert "short beep") was provided to the driver when the system detected an inappropriate glance behavior. The warning depended on a pre-set warning threshold set by a driver distraction warning algorithm. Attending the road at all times, avoid a warning. The warning algorithm was implemented in Simulink software including data preprocessing and calibration parameters available in a patent (Victor, 2005).

Description of the real-time feedback with two driver distraction warning algorithms

The implementation of the distraction warning was based on the Multi Distraction Detection algorithm (Victor, 2010; Victor, & Larsson, 2010). Two different warning algorithms, both focusing on different aspects of visual behavior, were tested. The audio alert was the same alert sound for the SG and GHSG warnings. Both algorithms used the Percent Road Center (PRC) measure as its basis for issuing a warning. PRC is defined as the percentage of gaze- or head angle data points that fall within a road center area. The algorithms rely on the notion that drivers should spend a certain amount of time glancing towards the road center area. The road center area is defined as a circle of 10 degrees radius centered on the road center. The road center is defined as the most frequent gaze angle during normal driving. Each data-point is classified as being either ‘eyes within road center area’ or ‘eyes off road’ on the basis of whether it falls within the road center area. A calibration period of 2500 samples at 60Hz (41.7s) was used, after which the on-off road classification started. First there was a “pre-processing” stage where the data quality is checked and noise is filtered. Then the algorithms trigger an off road center calculation.

The warning algorithms were similar to the Multi Distraction Detection algorithm used in the study by Lee et al. (2013) however with refinements (see below). Contrary to the study by Lee et al. (2013), the algorithm did not use vehicle state inputs (i.e., speed) to adjust thresholds for algorithm variables and did not use a seat sensor. This made the algorithm robust and reliable. Drivers were driving above a speed of 80 km/h at all times, and thus algorithm was always engaged after the road center cone was identified. This means that the no mechanism were used to “freeze” the algorithm (e.g. when the speed would have dropped below the minimum threshold). The size of the road center cone was adjusted to the sensor signal, increasing from 10 to 20 degrees when sensor input shifts from eye glance to head pose signals. When eye glance data was unavailable, the algorithm used head pose data to calculate PRC.

The distraction warning algorithms:

> *Single Glance warning algorithm (SG warning algorithm):* identifies visual distraction from a single long (2.4 second) glance away from the road center area
>
> *Glance History and Single Glance warning algorithm (GHSG warning algorithm):* identifies visual distraction from a single long (2.4 second) glance away from the road center area and *additionally* identifies visual distraction from a history of glances away from the road center area. Glance history warnings are provided when drivers’ glances fall below a percent road center (PRC) of 60 percent within a 17.3-second running window. In addition to the PRC window, a second PRC window is also calculated to improve reliability and consistency; it is called the visual time sharing (VTS) PRC window. This separate PRC calculation relies on a 4-second running window. When a sink is detected (a PRC value below 65%) followed by a rise (a PRC value above 75%), then the visual distraction PRC windows is reset to 80 percent. Resets are used as a mechanism to saturate the maximum value of the medium length window (17.3 s) to 80 percent, and the minimum value of the long window (60 s) to 60 percent. Whenever a VTS event is detected, all the PRC windows are reset. (Victor, 2010).

Warning reliability manipulation

Within the “reliable warning” condition we gave zero false positive warnings. Within the “unreliable warning condition” we gave initiated, controlled false warnings. This was controlled by an extra algorithm running in parallel to the VDA-algorithms. Every other distracting period and every other non-distracting (normal driving without doing a secondary task) one false positive warning was issued. As the length and frequency of the distracting periods varied for each participant, the number of false positive warnings varied among participants between one and seven.

Distracting task and portable device

Participants were asked to engage in a distracting task which caused them to glance between a secondary task and the forward roadway, thus causing visual time sharing. Thereby the VDA system had the opportunity to detect distraction.

This is sentence number 1. Keep your eyes on the road and try to rewrite this in the text field below.

Figure 1: Positioning of the iPad tablet and eye-tracking cameras (capturing eye glance direction indicated by two yellow lines) in experimental set-up, driving scenario and drivers eye glance direction pointing off-road to the iPad tablet (white arrow)

The distracting secondary task required an interaction with an iPad tablet equipped with a text entry software that was developed specifically for this experiment. The drivers were presented a series of different truck driving work related sentences on the tablet. The driver was asked to read a sentence and to copy it by typing it into a text field (Fig 1). This typing copying task was done at a drivers own pace (without any time pressure). This resulted in the length and frequency of the distracting periods varying for each participant. Pressing the "send message" button indicated the end of the task. 30 seconds after task completion, a voice message indicated the start of the next text-copying task. During the 30 second pause the text field "Keep your eyes on the road" was presented on the tablet screen. After the voice message indicating start, the driver chose whenever it was safe to start writing the message by pressing a “write message” button. If the driver did not press the start button within 10 seconds, another voice message reminded the driver to start the task and so on (Figure 2). All text was in the drivers’ native language. The task demand of writing the text message was controlled by an equal text length of 83-87 characters including spaces. Text messaging was regarded as a natural source of distraction as it is currently common in a truck driver’s interaction with fleet management systems. The sentence to be copied was visible during the task. It needs to be made clear that the purpose of the secondary task was not to encourage drivers how to conduct text messaging while driving, but rather to provide a representative secondary task. The display used for the visual/manual task was positioned spherically 45° clockwise horizontally and 45° clockwise vertically from the center of the steering wheel, re-creating a common position for vehicle-fixated devices in real traffic. Figure 1 shows the Positioning of the iPad tablet and eye-tracking cameras in the experimental set-up. The figure also shows the driving scenario, and a drivers eye glance direction pointing off-road to the iPad tablet (white arrow in Fig. 1).

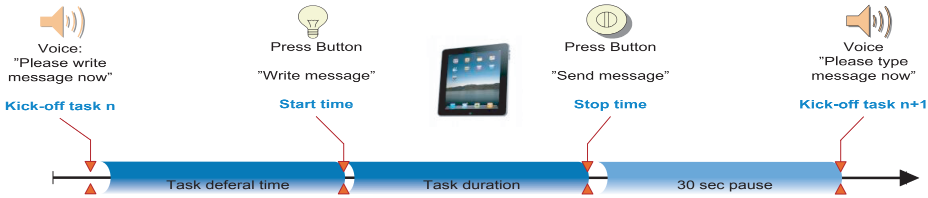

Figure 2: Timeline secondary task

Experimental design

The experimental design was a 2x2x2x4 (“system activation”, “warning algorithm transparency”, “system reliability” and “behavioral adaptation”) between- and within-subjects design. “System deactivated “ vs “system activated” was compared as a within-subject factor. Half of the participants were assisted with the SG-warning algorithm, half with the GHSG-warning algorithm. Additionally the groups were divided into the two conditions ‘reliable warnings’ and ‘unreliable warnings’. Thus, we compared two transparency levels (high “SG-warning algorithm” vs. low “GHSG-warning algorithm”) and two different system reliabilities (high reliable system vs low reliable system) as between-subjects factors. As all participants drove the deactivated warning condition first, followed by the activated warning condition, the behavioral change was assessed within the activated warning condition. As a consequence of this, the factor ‘behavioral adaptation effect‘ (comparing four points in time within the experiment with each other) is a within-subject factor with four factor levels. All experimental factors were never analyzed in one ANOVA together, however only in groups of factors, depending on the relevant research question.

Experimental Procedure

Drivers had a 5 minute practice drive in the simulator to get used to steering, accelerating and braking. After providing informed consent and giving basic instructions for the simulator as well as study instructions, participants were shown how the text copying task was to be performed on the iPad tablet and a walk-through of the secondary task. Participants completed a demographic and driving experience questionnaire. The eye tracking system was calibrated and the experimenter evaluated the quality of the eye and head tracking systems prior to beginning of the drive. Each participant was trained in a practice-drive which consisted of one sequence during which the participant was only driving and one sequence during which the participant was asked to use the portable device while driving. In the practice-drive no visual-distraction alert warning was given. Next, participants completed a series of drives: a ten minute practice drive (in order to rule out any practice effects and to flatten the learning curve) followed by a 12-minute drive with a deactivated system (warnings were logged but not given to the driver) and an 18-minutes-drive with an activated VDA-System according to the group they have been assigned to (SG-reliable warnings, SG-unreliable warnings, GHSG-reliable warnings and GHSG-unreliable warnings group). During the drives, after the first 5 meters of driving, a prompt voice saying "please write message" indicated that the driver should begin engaging in the secondary task. After driving, the drivers filled in a post-drive questionnaire about how realistic the simulator was and how they felt after the completion of the study.

In order to rule out any practice effects, the practice time of the driving task itself (15 minutes) and the secondary task (15 minutes) was sufficiently long as indicated by Strayer, Watson and Drews (2011) and Rouzikhah, King and Rakotonirainy (2013).

Data Analysis

Univariate ANOVAs were used to test the statistical significance at a 5% level in the dependent variables. There were time periods when the driver was distracted (during secondary task engagement) and periods when the driver was just driving (30-sec "normal driving" sequences). In the current paper only the distracting periods of the drive are analyzed.

A. Engagement in distracting task

In order to investigate drivers' engagement in the distracting task we used two measures: the number of started text messages per minute and the percentage of time that each driver spent with completing each text messaging-task.

B. Driving performance

The driving performance is indicated by measurements of the longitudinal position of the vehicle (deviation of speed) and the lateral position of the vehicle. For the lateral position of the vehicle two measures were used, one was the steering wheel reversal rate, SWRR (Markkula & Engström, 2006) and the other one was the standard deviation (SD) of lane position.

C. Visual behavior

For glance measures, glances below 0.2 seconds and above 5 seconds were filtered out in order to secure valid glance data according to physical constraints. The different dependent variables of glance behavior were used according to standard practice (ISO 15007-1, 2002). In order to measure the off-road glance behavior, the number of warnings (SG, GHSG and total) per minute, , the number of glance transitions off/on-road per minute, PRC off-road and on-road, the single long glance duration on-road and off-road was calculated and statistically analyzed. Graphical analysis was performed for the number of glances per minute for all single glance duration thresholds as well as their cumulative percent distribution.

3. Results

The results are reported in three parts according to the analysis depending on the specific research question. First, (1) the effect of the VDA-system on all dependent variables is analyzed, thereafter (2) the difference of the two investigated warning algorithms is evaluated. Thereafter, (3) the analysis of the effect of false positive warnings is provided, followed by (4) an analysis of the adaptation effect over time when the system was deactivated and activated.

Table 1 provides the mean (and standard deviation) values for all performance indicators for the experimental groups. The darker boxes indicate a significant different value from each other. The number of started texting as well as the number of warnings is analyzed per minute in order to make the deactivated and activated driving periods comparable. The driving periods differed in length however they were equally long among experimental groups.

Fig 3 shows the number of glances per minute for all single glance duration thresholds as well as their cumulative percent distribution and the standard deviation lane position (SD LP) and steering wheel reversal rate (SWRR). Measures for glances off road (left) and glances on road (right) for the reliable warning condition (above) and the unreliable warning condition (below)The number of total glances and their percent are depicted in 0.1s bins. A quality filter threshold was used whereby only glances between 0.2s and 5.0s long were included.

Table1: Average performance (SD) for all dependent variables for all experimental groups

	VDA System deactivated	VDA System activated	VDA System activated					
			SG-warning			GHSG-warnings		
			All	Reliable	Not reliable	All	reliable	Not reliable
Engagement in distracting task								
% time spending texing	80.0 (6.0)	87.7 (6.0)	85.1 (5.6)	84.1 (6.0)	86.1 (5.1)	90.4 (5.4)	90.2 (6.2)	90.5 (4.9)
Mean started texts per minute	0.36 (0.11)	0.25 (0.11)	0.30 (0.11)	0.32 (0.11)	0.29 (0.11)	0.20 (0.09)	0.21 (0.12)	0.19 (0.06)
Visual behavior on road Visual behavior off road								
Mean number of total 2.4s SG warnings per minute	1.8 (1.7)	0.39 (0.55)	0.73 (0.90)	1.01 (1.08)	0.42 (0.52)	0.20 (0.31)	0.29 (0.39)	0.11 (0.17)
Mean number of total GH warnings per minute	3.85 (1.54)	1.36 (1.01)	N/A	N/A	N/A	1.36 (1.01)	1.32 (1.06)	1.39 (1.01)
Mean number of total SG and GH warnings per minute	3.85 (1.54)	1.36 (1.01)	0.73 (1.08)	0.42 (0.53)	0.73 (0.90)	1.71 (1.50)	1.80 (1.71)	1.63 (1.30)
Mean SG duration (s)	1.05 (0.38) 1.63 (0.83)	1.57 (0.76) 1.13 (0.27)	1.13 (0.30) 1.23 (0.31)	0.98 (0.27) 1.38 (0.37)	1.26 (0.27) 1.12 (0.21)	1.96 (0.85) 1.03 (0.15)	1.98 (0.89) 1.07 (0.17)	1.94 (0.84) 0.99 (0.12)
PRC	41.0 (12.5) 59.0 (12.5)	56.2 (12.6) 43.7 (12.6)	48.75 (10.33) 51.25 (10.33)	44.39 (10.43) 55.61 (10.43)	53.12 (8.5) 46.88 (8.48)	63.71 (10.04) 63.29 (10.05)	63.3 (10.6) 36.97 (10.60)	64.4 (9.8) 35.62 (10.04)
Glance transitions per minute	45.71 (10.68)	46.75 (9.70)	47.80 (9.08)	48.21 (9.29)	47.37 (9.19)	45.86 (10.33)	43.95 (10.40)	47.60 (10.35)
%-SG duration above 2.0s	8.7 (6.2) 19.0 (5.3)	17.3 (12.7) 5.3 (5.7)	13.28 (11.7) i) 7.2 (8.7)	6.9 (5.3) 11.2 (10.5)	19.2 (13.1) 2.7 (1.8)	21.1 (13.0) 3.5 (2.8)	23.5 (14.0) i) 5.0 (3.2)	18.9 (11.7) 2.0 (1.1)

Note: i) = Interaction between factors “algorithm type” and “reliability” is significant,

Note: the shaded boxes show significantly differences between the factors on a 0.005 significance-level

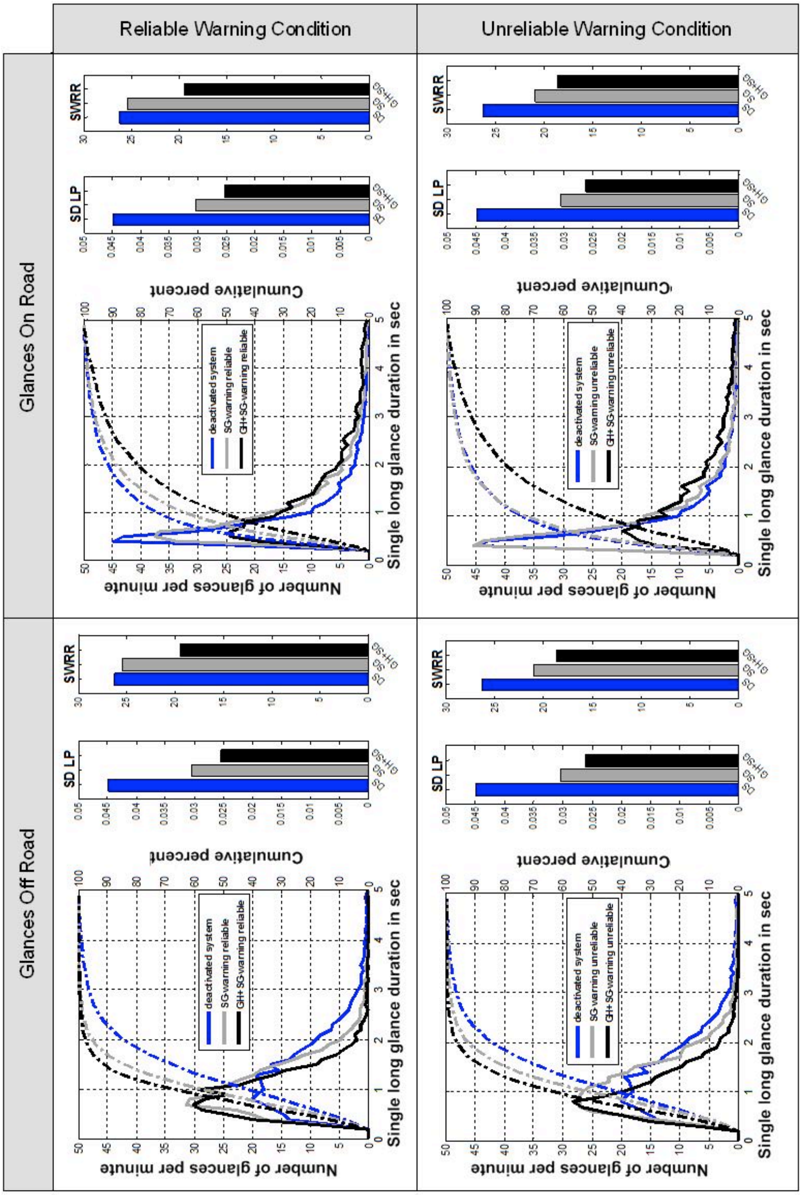

Figure 3: The number of glances per minute for all single glance duration thresholds as well as their cumulative percent distribution and the standard deviation lane position (SD LP) and steering wheel reversal rate (SWRR). Measures for glances off road (left) and glances on road (right) for the reliable warning condition (above) and the unreliable warning condition (below)

1) Analysis 1: Significant effects of the VDA-system

In order to assess the effect of the VDA-system, a repeated measure ANOVA (Huynh-Feldt test) with "system activation" as a within-subject variable was conducted on various dependent measures. The overall effect is equal across *all measures* with the statistical details of the significant effects presented below.

Engagement in distracting task

There were fewer started text messages per minute when the VDA-system was activated (M=0.25, SD = 0.10), than when the system was deactivated (M = 0.36, SD = 0.12), showing that drivers engaged less in distracting tasks; *Wilks*-λ= .501, F (1, 55) = 54.827, $p < 0.001$, *partial* η^2 = .499. Drivers spent more time texting when the system was activated (M= 87.0%, SD = 6.0 %), compared to when it was deactivated (M = 80.0 %, SD = 6.0%); *Wilks*-λ= .386, F (1, 54) = 85.921, $p < 0.001$, *partial* η^2 = .614.

Glance behavior

Drivers attended to the road more when the system was activated (M=56.2%, SD = 12.6%) compared to when the system was deactivated (M=41%, SD = 12.5%), *Wilks*-λ= .418, F (1, 55) = 76.453, $p < 0.001$, *partial* η^2 = .582. The values are vice versa for the *PRC off-road* (see Table 1).

Every single glance on road was on average longer in duration when the system was activated (M=1.57, SD = 0.76), compared to when it was deactivated (M = 1.05, SD = 0.38) ; *Wilks*-λ= .733, F (1, 55) = 19.998, $p < 0.001$, *partial* η^2 = .267. The effects are similar for every single glance off road (Table 1).

The percent of glances off-road that where longer than 2 seconds in duration was higher (M=19.0 %, SD =14.2%) when the system was deactivated compared to when the system was activated (M=5.3%, SD = 5.7 %); *Wilks*-λ= .539, F (1, 53) = 45.343, $p < 0.001$, *partial* η^2 = .461. The effects are similar for the percent of glances on-road that where longer than 2 seconds (Table 1).

There were more glance transitions per minute between on-road and off-road when the system was activated (M=46.75, SD = 9.70), compared to when the system was deactivated (M = 42.71, SD = 10.68); *Wilks*-λ= .908, F (1, 53) = 5.341, p = 0.025, *partial* η^2 = .092.

The VDA-system had a direct effect on the number of warnings provided. In total, there were fewer total warnings per minute when the system was activated (M=1.26, SD = 1.32) compared to when it was deactivated (M = 4.42, SD = 3.26); *Wilks*-λ= .384, F (1, 55) = 84.677, $p < 0.001$, *partial* η^2 = .606. This was further differentiated in an analysis of SG-warnings per minute (for both algorithms) and in a separate analysis of GHSG-warnings per minute (only for the GHSG-warning algorithm). For the SG-warnings per minute analysis, there were fewer 2.4s-SG-warnings per minute when the system was activated (M=0.39, SD = 0.56), compared to when it was deactivated (M = 1.80, SD = 1.70); *Wilks*-λ= .508, F (1, 50) = 48.438, $p < 0.001$, *partial* η^2 = .492. For the GHSG-warnings per minute analysis, there were fewer glance history warnings per minute when the system was activated (M=1.36, SD = 1.01), compared to when it was deactivated (M = 3.85, SD = 1.54); *Wilks*-λ= .324, F (1, 27) = 56.280, $p < 0.001$, *partial* η^2 = .676.

Driving performance indicators

There was less deviation in speed when the system was activated (M=0.63, SD = 0.21) compared to when it was deactivated (M = 0.86, SD =0.27). The lateral position of the vehicle also improved when the system was activated, which was indicated by two measures. The SWRR was significantly less when the system was activated (M=18.80, SD = 7.58) compared to when it was deactivated (M = 23.55, SD = 7.46); *Wilks*-λ= .511, F (1, 55) = 52.631, $p < 0.001$, *partial* η^2 = .489. Also, when the system was activated there was less deviation in the lane position (M=0.27, SD = 0.07), compared to when the system was deactivated (M = 0.37, SD = 0.10); *Wilks*-λ= .293, F (1, 54) = 130.436, $p < 0.001$, *partial* η^2 = .707.

2) Analysis 2: Main effects warning algorithm and system reliability

In order to investigate the effects of the warning algorithm and system reliability, a UNIANOVA with two between subject variables "warning algorithm" and "system reliability" was applied on various dependent variables. For all measures, except the measure percent of glances off-road above a 2.0s threshold, there was no significant main effect for 'Reliability', nor a significant interaction effect. All the significant effects for ´warning algorithm´ are reported below.

Engagement in distracting task

In the GHSG-warning algorithm condition, drivers started significantly less texts (M=0.20, SD = 0.09) than in the SG-warning condition (M = 0.30, SD = 0.11); F (3, 52) = 9.975, p = 0.001, *partial* η^2 = .206. Consequently, drivers spent more time texting in the GHSG-warning algorithm condition (M=90.4%, SD = 5.4) than in the SG-warning algorithm condition (M = 85.10 %, SD = 5.6); F (3, 51) = 11.977, p = 0.001, *partial* η^2 = .190.

Glance behavior

Drivers in the GHSG-warning condition looked on the road more (M=63.71%, SD = 10.04%) than drivers in the SG-warning condition (M = 48.75%, SD = 10.3 %); F (3, 52) = 32.166, $p < 0.001$, *partial* η^2 = .382. The effects for the *PRC off-road* are similarly opposite (see table 1).

Each on-road glance was on average longer in the GHSG-warning condition (M=1.96, SD = 0.85), compared to the SG-warning condition (M = 1.13, SD = 0.30); F (3, 51) = 22.83, $p < 0.001$, *partial* η^2 = .309. Similar effects were found for the *SG-duration off-road* (see table 1).

In the GHSG-warning condition there were less *percent of glances off-road above a 2.0s threshold* (M=3.5%, SD = 2.8%) compared to the SG-warning condition (M = 7.2%, SD = 8.7%); F (3, 48) = 4.746, p = 0.034, *partial* η^2 = .090. There was a main effect for 'reliability' with the reliable condition having more off-road glances (M = 8.2, SD = 8.4) than the unreliable condition (M= 2.4%, SD = 1.6); F (3, 48) = 12.544, p = 0.001, *partial* η^2 = .207. There is no significant interaction effect.

There fewer *glance transitions per minute* in the GHSG-warning condition (M=22.10, SD = 4.69) compared to the SG-warning condition (M = 24.95, SD = 4.99); F (3, 52) = 4.873, p < 0.032, *partial* η^2 = .086.

The effect the warning algorithm had on glance behavior also had a direct effect on the number of warnings provided. There were fewer total warnings in the SG condition (M = 0.73, SD = 1.08) than the GHSG condition (M=1.71, SD = 1.50); F (3, 51) = 8.820, p = 0.005, *partial* η^2 = .147. This is not surprising, because the latter group received more warnings by the nature of the algorithm itself (i.e. both SG and GH warnings).

In the SG-warning algorithm condition there were significantly more 2.4s SG warnings per minute (M = 0.73, SD = 0.90) compared to the GHSG-warning condition (M=0.20, SD = 0.31); F (3, 49) = 8.329, p = 0.006, *partial* η^2 = .145.

In the group of drivers who received GHSG-warnings there is no main effect for reliability F (1, 26) = .034, p = 0.856 for the *number of GHSG-warnings per minute.*

Driving performance indicators

For the *SD speed* the UNIANOVA showed no significant main effect for ‘Algorithm type’ nor ‘Reliability’ in SD speed. There was no significant interaction effect.

There were more SWRR in the SG-warning condition (M = 20.60, SD = 7.87) compared to the GHSG-warning condition (M=16.35, SD = 6.22); F (3, 51) = 4.873, p < 0.032, *partial* η^2 = .087. Similar effects were found for the *SD lane position.* There was significantly less deviation in lane position in the GH+SG-warning condition (M=0.25, SD = 0.07) compared to the SG-warning condition (M = 0.29, SD = 0.06); F (3, 51) = 6.046, p < 0.017, *partial* η^2 = .106.

3) Analysis 3: Behavioral adaptation

To assess the behavioral adaption effect during the deactivated system period and the activated system period, we compared the first minute of the first message with the last minute of the last message in the deactivated system and activated system period with one another. The factor “behavioral adaption over time” was used in order to test the effect on the factors “system activation” and “system reliability” over time. A repeated measures ANOVA with one within-subject factor ‘adaptation (time)’ and two between subject factors (‘warning algorithm’ and ‘Reliability’) was calculated. The most interesting effects lay within the significant interaction effects of the measure *PRC on road* for the “adaptation” factor with the “warning algorithm” factor, *Wilks-*λ= .818, F (3, 153) = 3.636, p = 0.019, *partial* η^2 = .182. The values for the specific PRC (SD) for this effect can be found in Table 2. Additional ANOVAS have also been conducted for the deviation of speed, lane position, number of SG and GHSG-warnings, and duration of number of SG and GHSG-warnings with similar results. Figure 4 shows the adaptation effect over time for PRC for the deactivated system and an activated system time period for both warning algorithms (the factor reliability is not included in this plot because it was found not to have an adaptation effect).

Table 2. PRC (SD) for the significant interaction effect Adaptation * Warning algorithms

Interaction effects Adaptation*Warning algorithms	Beginning of VDA system deactivated period		End of VDA system deactivated period		Beginning of VDA system activated period		End of VDA system activated period	
Warning algorithm	SG	GHSG	SG	GHSG	SG	GHSG	SG	GHSG
PRC in % M (SD)	39.8 (15.0)	43.8 (15.5)	39.6 (15.7)	42.7 (15.6)	54.1 (12.0)	61.2 (15.6)	46.8 (1325)	63.2 (12.7)

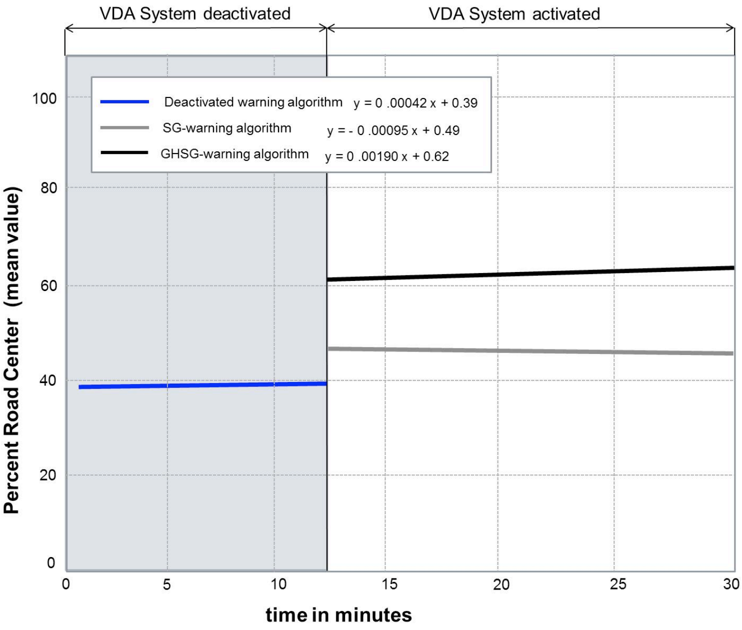

Fig 4. PRC Behavioral adaptation over time for the deactivated system and an activated system time period for both warning algorithms (the factor reliability is not included in this plot because it was found not to have an adaptation effect).

4. Discussion

The aim of the study was to better understand the characteristics of glances that constitute an effective distraction warning algorithm in terms of attention enhancement on road, improved vehicle control and a reduction of secondary task engagement. Although the research on real-time driver monitoring systems that identify risky glance behaviors away from the road and warn drivers is active, it was still unclear whether drivers respond best to single long glance (SG) warnings or to glance history warnings combined with single glance warnings (GHSG). As such, little was known about which warning algorithm increases safer glance and driving behaviors and whether unreliable warnings have an effect. Thus, the present study focused on comparing the effects of SG warnings and GHSG warnings on visual- and driving performance benefits.

The visual behavior data, driving performance data and data about engagement in the secondary task was analyzed in three steps. First the effects of a VDA-system was analyzed, thereafter the influence of two warning algorithms along with unreliable warnings, followed by an assessment of the behaviorbehavioral adaptation effect on the percent eyes on road was analyzed.

Attention and performance improvement when assisted with a VDA-system

When the VDA-system was activated, drivers engaged less in the distracting tasks which was shown by fewer started text messages, compared to when it was deactivated. Drivers took longer time to type a text message (87.0%) when the system was activated, compared to when it was deactivated (80.0 %). Due to less distraction, drivers received less warnings (total SG-warnings and GHSG warnings) when the system was activated compared to the number of warnings they would have received in the period when the system was deactivated (warnings not issued but logged).

Glance behavior assessment showed that drivers attended to the road more (56.2% on road time) when the system was activated, resulting from longer single long glance on road, and more glance transitions between on-road and off-road, compared to when the system was deactivated (41% on road time). As such, the percent of glances off-road that where longer than 2 seconds in duration dropped from 19.0 % when the system was deactivated to 5.3% when the system was activated.

The performance benefit of attention on-road had a corresponding improvement on vehicle control. When the system was activated, there was less steering wheel reversals and better lane keeping, and less deviation in speed.

The performance benefit effect of a VDA-system confirms previous research by Lee et al. (2013) and Donmez, Boyle and Lee (2008) who found that concurrent feedback has a greater performance increase than no feedback at all. Donmez et al. tested this “feedback-benefit” effect with a between-group design. The current study showed that the “feedback benefit” effect is also valid in a within-group design. That means that distracted drivers who were previously not assisted with the system, benefit from being assisted with a VDA-system improving attention on-road and driving performance. It can be assumed that more attentive drivers who also have better vehicle control when assisted with a VDA-system would cause less crashes (Olson, Hanowski, Hickman, & Bocanegra, 2009).

Our results are in line with other studies showing a strong correlation between visual time sharing and driving performance. Visual time sharing normally induces abrupt steering wheel corrections, large and frequent lane deviations, and reduction in reaction times to lead vehicle braking (Angell, Auflick, Austria, Kochhar, Tijerina, Biever, & Diptiman, Hogsett, & Kiger, 2006; Carsten, & Brookhuis, 2005;

Markkula, & Engström, 2006). Correlations between eye movement and lane keeping measures in experiments are usually in the r=.60 to .80 range (Ito, & Miki, 1997; Wierwille, 1993; Zhang, & Smith, 2004). Olson, Hanowski, Hickman and Bocanegra (2009) showed that distraction was a contributing factor in 78% of unintentional lane deviations found in naturalistic studies.

The GHSG-warning algorithm outperforms the SG-warning algorithm

A VDA-system, either reliable or unreliable, is effective in improving attention on-road, driving performance and decreasing engagement in secondary tasks. However both warning algorithms were not equally effective. Consistently throughout *all* performance measures the GHSG-warning algorithm condition outperformed the SG-warning condition. When drivers were assisted with a VDA system using the GHSG-warning algorithm they started significantly less texts than in the SG-warning condition. Interestingly, in the GHSG-warning condition there were significantly less SG warnings than in the SG-warning algorithm condition. The GHSG-warning algorithm resulted in more attention on-road (63.71%), compared with the SG-warning condition (48.75%). Glances on-road were on average longer and glances off-road were shorter in the GHSG-warning condition and there were fewer glance transitions per minute._The GHSG-warning condition generated a lower percentage of glances off-road above a 2.0s threshold. The only significant effect for reliable warning systems is that they showed a higher percentage of off-road glances above a 2.0s threshold than the unreliable systems. This is the only anomaly and is contrary to our hypothesis that reliable systems should generally improve attentive behavior. However, because this measure was the only measure that had a significant effect of unreliable warnings compared to reliable warnings, it might be an artifact. The GHSG-warning algorithm improved longitudinal vehicle position (less steering wheel reversals, better lane keeping) better than the SG-warning algorithm.

Although both warning algorithms improved attention on road over time, with the GHSG-warning algorithm drivers maintain a higher percent eyes on road throughout system usage time. The attention benefit of both systems can be interpreted as two separate adaptation effects. The first adaptation effect is the immediate improvement in attention on-road once the system is activated (immediate adaptation effect) and the second adaption effect is the persistence of attention on-road throughout usage time. The total usage time of the system was 18 minutes, which was due to time constraints on the experiment. Further studies need to investigate if the second adaptation effect persists (a) for longer usage times (e.g. several hours, days, weeks of continuous usage), (b) when the user drives with a deactivated VDA-system after experiencing its benefits (e.g. ABA experimental), and (c) when the user is activating the system again (ABAB-experimental design). The concept of a persistent behavioral adaption effect after system removal is called *behavioral change transfer*. The mechanisms behind the sustainance of an ADAS effect are further discussed in Manser, Crease, and Boyle (2013) and Wege, Pereira, Victor, and Krems (2014).

The behaviorbehavioral adaption effect with continuous use is in line with results from a field validated test study of the DDS system providing SG-warnings (Croke, & Cerneaz, 2009). For 9 weeks 18 truck drivers drove with a deactivated DSS-system followed by 33 weeks with an activated system. As soon as the DSS distraction system got activated the daily average of distraction event duration went from approximately 4.5 seconds to approx. 2.5 seconds. After enabling the alerts, within all 33 weeks, the durations remained about the same. The important drop was right after enabling the system. This lends support to the assumption that there would not be much behavioral change over time, and that the major adaption effect occurs when turning on the system. Further research with the VDA-system over a longer period of time is needed in order to find parallel long-term results to Croke and Cerneaz (2009). We can only speculate that using the VDA-system over a longer period of time can result in less usage of portable devices and less engagement in distracting tasks due to the fact that the driver is made aware of the dangerous potential of his or her actions.

Even though the GHSG warning algorithm provides less transparent warnings, drivers utilize those warnings better than expected. The information that the “glance history characteristic dimension” adds to the “single long glance characteristic dimension”, seems to be very important for the driver to time off-road glances. This can be interpreted as the “glance history”-dimension being closer to a drivers own feeling/own experience of what is “unsafe”.

Our hypothesis that a transparent warning algorithm is most efficient was falsified by the current results. In contradiction to what we expected, what was hypothesized as a less transparent warning algorithm (GHSG) is more effective. The main purpose of the VDA is to help the driver to realize that he/she is being ´tricked´ into glancing away from the road for too long and/or too often. It seems like the driver is responding to the characteristics of the particular algorithm, thereby “tricking the system” not to warn by glancing away within the algorithms limits. The question that is needs to be examined more in future research is “Do drivers recognize a limit of inattentive glance behavior and thus adapt their behavior to be close to the limits of a warning threshold?”

It was hypothesized that the SG algorithm would be easier to understand and respond to than the GHSG algorithm, thereby improving performance over the GHSG algorithm. Recall that this GHSG algorithm was also implemented by Lee et al (2013) in their Multi Distraction Detection algorithm (showing the best results) and that Croke and Cerneaz (2009) showed that a SG algorithm was highly effective in the field. The current results seem to bring into question whether what was assumed to be a simpler, transparent algorithm – the SG algorithm – really is the more important psychological characteristic that influences behavioral change. In our study, adding a glance history warning to a long single glance warning was clearly more effective. In the current study, the warning parameters were explained well to the driver before using the system and this may have helped drivers to comprehend the warning characteristics.

It doesn’t seem like we should draw the conclusion that the more non-transparent or complex a warning algorithm the better. Other, more sophisticated or complex algorithms exist, for example those reviewed by Engström and Victor (2009) and Lee et al. (2013), for example the AttenD algorithm. These algorithms typically include intelligent solutions to better approximate “true” distraction detection. For example using a penalty function based on visual eccentricity whereby glances further away from the road center are penalized more heavily or count glances to mirrors as less distracting. These algorithms have not been shown to perform better than the GHSG or Multi Distraction Detection algorithm. Instead, it seems more plausible that we should conclude that both single glance length and glance history are important dimensions for distraction warning algorithms. More research is needed.

It needs to be noted that with the GHSG-warning algorithm, the drivers received generally more warnings. This was due to the inherent characteristics of the algorithm. However, it seems premature to conclude that the more warnings the driver receives, the better the attention allocation on-road”. If that would be true, we would have found a main effect of ‘warning reliability’, e.g. there were much more warnings in the unreliable warning condition. But this factor showed no influence in glance-, driving- and task engagement measures.

Unreliable warnings are less relevant than expected

In the current study, when analyzing the effects of unreliable warnings, it was found that for *all* performance measures, unreliable warnings do not have a significant effect. This is surprising because it was hypothesized that false positive warnings would result in less performance increase. One explanation that needs to be investigated is that the rate of false positive warnings was not high enough to have had an effect on driver behaviorbehavior. Our results confirm results by Dixon and Wickens (2006) and Xu, Wickens, and Rantanen (2007) who found that an automated attention guidance system will generally assist human performance, even if it is less than fully reliable, so long as that reliability is above about 0.80.

Even though drivers experience false positive warnings, they do not become less attentive nor do they start to ignore valid alerts intentionally. It could not be demonstrated that false warnings decrease drivers' compliance, nor was there an increase of lane deviation. This is not in line with other studies. One explanation for our results could be that drivers (in the reliable and unreliable condition) anticipated some false warnings because they knew that it is a newly developed system. The main conclusion should not be that false warnings in the real-word do not have a negative influence. Thus, we agree with Donmez, Boyle, and Lee (2008) who argues that "For a warning system to be effective, an acceptable false alarm rate should be established." Apparently our false alarm rate was an acceptable false warning rate. This can be supported by the fact that the factor 'warning reliability' did not have an effect in usefulness, satisfaction nor acceptance ratings (Wege, & Victor, in review).

Future research

Future studies should evaluate the transferability of the effects to an on-road setting with actual system usage over time. It is advisable to test the function that the driver has the control on engaging and disengaging the system when needed. However, it can be argued that drivers might not be aware of the fact that they would need its assistance. Previous research showed that distracted drivers are unaware of their own distraction decrements, which usually leads them to believe their driving performance is better than it really is (Horrey, 2009).

One limitation of the study is that we did not test a stand-alone glance history warning. The glance history warning was never provided in the absence of single long glance warnings, only in combination in the GHSG algorithm. Recall that an algorithm based on glance history –the "*Eyes off forward roadway algorithm"* (Klauer, Dingus, Neale, & Sudweeks, 2006) – was shown to be less effective than the Multi Distraction Detection Algorithm (which was essentially identical to the present GHSG algorithm) in the Lee et al (2013) algorithm comparison. This would indicate that the stand-alone glance history algorithm part of the GHSG would be less effective, although it remains to be tested.

It would also be advisable to provide separate alert tones when the system is warning for a single long glance or a series of glances. Although this work clearly indicates that the SG-warning algorithm is less effective than the GHSG-warning algorithm, it would be convenient to confirm this result in further studies (e.g. by setting a new threshold such as 3.0 seconds) before dismissing this idea completely.

In sum, the VDA-system significantly improves attention and driving performance. Hence, it can be considered a useful advanced driver assistance system that prevents driver distraction and makes distraction safer.

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6. List of key Points

- A VDA System was found to be an effective countermeasure, however not all warning algorithms were equally effective.
- It was found that a warning algorithm that provides warnings for both single long glances and glance history (a series of glances) warning algorithm (GHSG-warning algorithm) significantly improves attention on-road and driving performance and alters engagement in distracting tasks.
- In connection to this, it was found that false positive warnings do not influence behaviours.

7. Précis

It was shown that reliable VDA Systems can prevent visual distraction and inattention in situations they are designed for, both by inducing appropriate reactions to warnings, improving driving performance.

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CHAPTER 6 PAPER V

Paper V

Distraction and Inattention Prevention by Combining Behaviour-Based Safety with Advanced Driver Assistance Systems.

Wege, C., & Victor, T. (2013). Distraction and Inattention Prevention by Combining Behaviour-Based Safety with Advanced Driver Assistance Systems. In A. Stevens, C. Brusque, & J. Krems (Eds). *Driver adaptation to information and assistance systems*. IET published book. ISBN: 978-1-84919-639-0; E-ISBN: 978-1-84919-640-6.

Chapter 11

Distraction and inattention prevention by combining Behaviour-Based Safety with Advanced Driver Assistance Systems

Claudia A. Wege[1] and Trent W. Victor[1]

Abstract

Development of Behaviour-Based Safety (BBS) and Advanced Driver Assistance Systems (ADAS) has been carried out largely independently of each other. Although both approaches have the same goal of improving traffic safety, they operate at different timescales to achieve accident prevention. This chapter examines how both ADAS and BBS approaches can be combined into a more holistic framework and applied to preventing distraction and inattention.

The combination of ADAS (immediate feedback) with BBS (long-term feedback) is illustrated by using the analogy of ‘team play’. Both ADAS and BBS are players of the same team on the ‘accident prevention playing field’ and united, they become a better team. With the BBS-ADAS team, traffic safety has the opportunity to advance into an entirely new league.

11.1 Time for kickoff

In this chapter, two accident prevention approaches are summarised: the Advanced Driver Assistance Systems (ADAS) approach and the Behaviour-Based Safety (BSS) approach. The scope of the chapter is (a) to summarise the literature on ADAS and BBS, (b) to identify ADAS and BBS principles, (c) to examine their impact on traffic safety, (d) to identify barriers to implement ADAS and BBS techniques and (e) to discuss how to apply these approaches when providing inattention prevention feedback.

Development of ADAS and BBS has been carried out largely independently of each other. To our knowledge, an effort to combine the benefits of both has not yet been developed; there is an apparent scarcity of research on how to prevent inattention whilst it is occurring, *and* in the long-term through aggregated behavioural feedback.

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[1] Volvo Group Trucks Technology (GTT), Sweden

There is a need to further enhance the current ADAS and BBS approaches, both independently and in an integrated fashion. A novel integrated approach, based on modern technological innovations, combines ADAS and BBS, into *one* Behaviour-Based-Safety-Advanced-Driver-Assistance-System (BBS-ADAS) approach. As an exemplification of the combined BBS-ADAS feedback approach, this chapter focuses on attention feedback through the combination of immediate attention feedback with long-term attention feedback. BBS driver behaviour management is effective, but can be more effective when drivers are also immediately made aware of their behaviour and when the immediate ADAS feedback is delivered in a coordinated way along with the long-term BBS feedback. The independent and combined approaches are presented in Figure 11.1 together with their respective driver feedback properties.

Research on human–machine interaction and automated ADAS has suggested the theory of 'team play' [2]. In this chapter, the theory of 'team play' is adapted to the field of accident prevention and the novel BBS-ADAS approach. The analogy of team play is visualised in Figure 11.2. As shown in the figure, the playing field is accident prevention with a focus on attention enhancement. Team ADAS and BBS have the same goal but different playing strategies. Both teams are already successful independently of each other, but integrating the best players of each team into one united team could provide the opportunity to increase success, a key reason being that players from both teams complement each other's shortcomings.

11.2 The playing field: Accident prevention

The estimated number of road traffic fatalities worldwide is about 1.24 million [3] and 39,300 in the EU each year [4]. Road traffic injuries were the eighth leading cause of death worldwide in 2012 [5]. Trends by the World Health Organization suggest that by 2030 road traffic injuries will become the fifth leading cause of death worldwide, if nothing is changed to prevent traffic accidents. Most of the accidents, however, are preventable. Accident causation research has greatly progressed from the time when Bortkiewicz [6] stated that accidents occurred at random and were thus inexplicable. Scholars now believe that accidents are primarily (90%) due to human failure [7–9]. It is therefore only logical to put the 'human factor' at the forefront of accident research and to examine underlying risky behaviours that lead to accidents. Once the risky behaviours have been examined, it becomes necessary to advance initiatives about *how to change* them. This chapter focuses on one risky behaviour, that of visual attention away from the forward roadway; [10–12]. When drivers' visual attention is not allocated to the source of a conflict in the forward roadway, this can lead to incidents, near-crashes and crashes. Distracted driving is one of the major causes of accidents with 10 people being killed, 960 people being injured and 2,040 properties being damaged each day in the United States alone [13]. Damage of $43 billion per year has been estimated due to driver distraction related crashes in the United States [14].

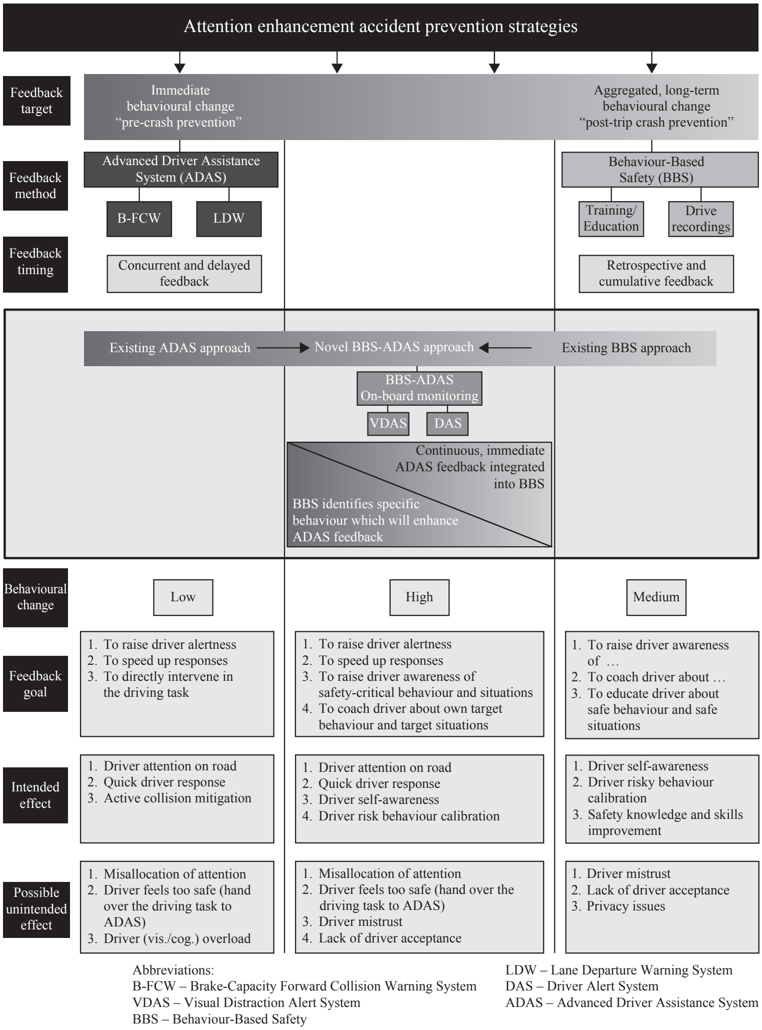

Figure 11.1 Attention enhancement accident prevention strategies: ADAS, BBS and BBS-ADAS

A naturalistic driving study found that 78% of crashes and 65% of near-crashes included distraction as a contributing factor [15]. Recently, algorithms which are claimed to be able to predict crash risk from risky glance patterns in naturalistic driving have been developed [16–18]. Research on distraction and inattention detection is very active [e.g. 19, 20]; however, in order to make studies comparable,

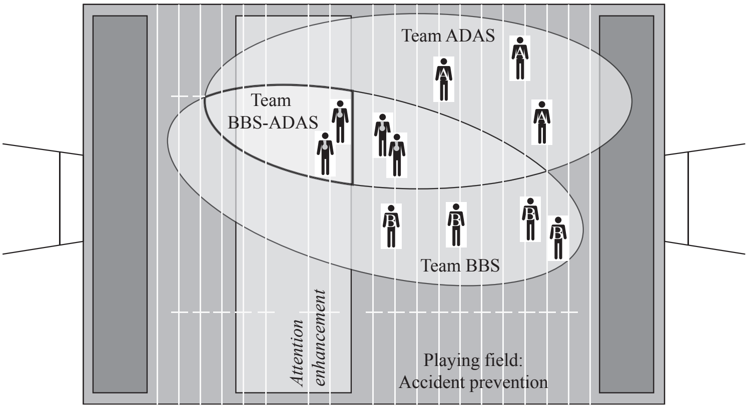

Figure 11.2 Uniting a winning team: BBS and ADAS applied to attention enhancement on the accident prevention playing field

a common terminology for driver distraction and inattention is important. A number of key experts have met since 2009 as the United States and European Union Bilateral Intelligent Transportation Systems Technical Force with the objective of establishing a conceptual framework and taxonomy for understanding and categorising driver inattention [21]. The key assumption is that there are two general forms of inattention: insufficient attention (e.g. sleep related attentional impairment and insufficient attentional effort) and misdirected attention. Misdirected attention can be categorised into more specific processes, such as *driver distraction* and *incomplete selection of safety-critical activities.*

Driver distraction can be defined to occur when the driver diverts attention away from activities critical for safe driving to one or more activities that are not critical for safe driving [22]. This can occur due to various contributing factors. Typically, these factors can be clustered into visual distraction (e.g. looking away from the roadway), auditory distraction (e.g. responding to a ringing cell phone), biomechanical distraction (e.g. manually adjusting the radio volume) and cognitive distraction (e.g. being lost in thought) [23] or some combination of these. Visual distraction occurs when, instead of focusing visual attention on the road, distracted drivers look at other targets for a certain period of time. The most common driver initiated contributing factor to visual distraction is interaction with mobile devices brought into the vehicle, which usually involves drivers taking their eyes off the road [8]. Several studies show that drivers are willing to interact with mobile devices while driving (e.g. using a cell phone) [24] and are often unaware of the extent to which distracted driving is dangerous [25]. A common glance pattern associated with distracted driving is, so called, ‘visual time sharing’ when visual attention is allocated back and forth between the forward roadway and a secondary task such as dialling a phone number. Elvik [26] identified statistical regularities of risk factors that are referred to as ‘laws of accident causation’ that are associated with road accident occurrence. One of the attempts to explain visual overload when driving and texting simultaneously is the ‘law of complexity’. It states that the more units of information per unit of time to which a road user must attend, the higher the probability of an error. This ‘law’ implies the accident rate will increase as more elements of information a driver must process also increase (e.g. visual time-sharing when text messaging).

Incomplete selection of safety-critical activities refers to ‘situations where the driver allocates sufficient resources to one or more activities critical for safe driving, or believed by the driver to be critical for safe driving, while the resources allocated to other activities critical for safe driving do not match the demands of these activities’ [21, p. 35]. As an example, consider the situation where a driver is following another vehicle and approaches too close resulting in a forward collision warning (FCW) that alerts the driver to the impending collision. If the FCW is designed correctly it will direct and enhance attention to the appropriate information needed for forward collision avoidance; for example, it will cause the driver to direct attention towards a lead vehicle. However, if this warning is inappropriately designed, it may cause the driver to look towards the vehicle interior displays seeking explanatory information. This type of inattention may become more important in the future as safety systems are increasingly designed to alert drivers to upcoming potential dangers [e.g. 27, 28]. Thorough evaluations of ADAS Human–Machine Interface (HMI) design with suitable methods [e.g. 29], along with the formulation of ADAS design guidelines and principles based on human capabilities are needed.

11.3 Team player line-up

11.3.1 Team Advanced Driver Assistance Systems (ADAS)

As defined in Chapter 2, ADAS have emerged in modern vehicles to support the driver in the driving task. The key point for the present chapter is that ADAS focus on providing *immediate* feedback to influence *current* driving behaviours. Such ADAS are designed to change behaviour immediately and part of the behaviour change includes direction of attention towards relevant parts of roadway traffic. Thus, for the purpose of this chapter, ADAS are limited to pre-crash *driver warning systems* that alert the driver by providing immediate risk-relevant feedback targeting a near-crash or crash event. A near-crash is defined as an event whereby a vehicle comes ‘dangerously close’ to another vehicle, object, person or animal [31]. For example, a brake-capacity forward collision warning (B-FCW) system can provide a warning in order to requiring some kind of decision making and/or action to prevent a crash [29].

In general, according to drivers’ needs and requirements, ADAS enhance safety, comfort, entertainment and awareness with the overall objective of avoiding drivers’ errors and accidents. It is speculated that the implementation of ADAS may lead to a fatality decrease of 40% [32]. Today, a number of ADAS are on the market, varying in function, design and manufacturer [33, 34]. A large body of literature on ADAS functionality was categorised [35], including longitudinal support systems, lateral support systems, driver awareness support systems, visibility support systems and off-board information systems. Categories of ADAS systems can be further distinguished by the *type of intervention* they provide to the driver [36]:

(a) *Driver information systems* (which aim to increase the driver's situation awareness; examples being night vision systems, navigation systems and e-horizon systems)
(b) *Driver warning systems* (which warn in case of lapses, such as unintended lane changes, or provide information concerning blind spots and forward collisions)
(c) *Intervening systems* (which provide active support to the driver; for example, an adaptive cruise control system or a queue assistance system or emergency braking system)
(d) *Integrated active safety systems* (which encompass all systems including some of the above that work towards vehicle safety in a cooperative manner)

The timing of ADAS feedback is either 'concurrent feedback' within milliseconds (e.g. FCW system) or 'delayed feedback' within seconds (e.g. Driver Alert System) [37].

The feedback goals of ADAS are to:

1. raise driver alertness to a safety-critical situation
2. speed up responses in safety-critical situations
3. sometimes (not always) directly intervene in the driving task

The intended ADAS feedback effects are to:

1. achieve driver attention to a relevant part of the driving scene
2. facilitate quick driver responses
3. avoid or mitigate accidents

Primarily, ADAS do not intend to provoke long-term driver behavioural change but rather focus on changing current behaviours.

There are potential shortcomings in techniques used to develop and evaluate ADAS; they are usually evaluated over a short time period and/or in a simulated driving environment, not allowing drivers to use the systems as they would if they were permanently installed in their vehicles. The overall expectation is that drivers will learn to interact with ADAS and will adapt to new systems in the ways that were intended by the developers; however, ADAS can have effects that are not intended by the designers. Unintended ADAS effects can include the driver feeling too safe (overreliance) or too stressed about interacting with the ADAS (cognitive overload). Although engineering research for technical improvement of ADAS is ongoing, a recent study [29] has demonstrated the challenges in designing HMI for ADAS. The results of this study indicate that drivers might experience two problems: a 'need for comprehension' when a B-FCW warning is discontinued, and a 'confirmation from the system' that a collision warning is over. Overall, the safety impact of ADAS depends to a great extent on their interaction with the driver. For example, in order to provide efficient support for the driver to avoid crashing into an obstacle ahead, it is crucial that the system warning intuitively generates the appropriate response, e.g. eyes towards the obstacle and initiation of an avoidance manoeuvre [38]. For a natural, effective and intuitive user interaction with ADAS, human factor specialists need to study drivers' natural reactions to these systems operating in real world naturalistic conditions to ensure that they do not adversely affect attention [29]. Different ADAS HMI designs may cause different behavioural effects over time, including unexpected behavioural adaptations. An overview of the above mentioned properties of ADAS feedback is provided in Figure 11.1.

There are a variety of major telematics guidelines, practices and standards for ADAS design. UMTRI [39] provides a general overview of in-vehicle telematics principles literature and legislation. However, guidelines for visual presentations in ADAS HMI design are not well developed. Some user interface requirements exist for ADAS for voluntary use by manufacturers [30, 40–44]. Additionally, technical reports on ergonomic aspects of in-vehicle presentation for transport information and control systems [45] exist. However, specific ADAS HMI ISO standards are still lacking although work on guidelines are ongoing [e.g. 46].

In general, HMI principles build upon principles from psychology and cognitive science. Likewise, the principles of psychology (the cause and effect of human behaviour) and cognitive science (the working mechanisms of the human mind) are strongly connected to BBS principles (see the following section). However, human factors and BBS principles are not yet strongly connected to ADAS design. In this chapter, we argue that there is a need to integrate BBS principles into the ADAS design process. Natural, intuitive and long-term effective ADAS–user interaction is achievable if known human factors and BBS principles are applied. The development of the existing ADAS approach towards a more integrated BBS-ADAS approach is visualised in Figure 11.1 by the arrow pointing from the existing ADAS approach to the novel BBS-ADAS approach.

11.3.2 Team Behaviour-Based Safety (BBS)

In this section, an overview on the main principles of behaviour-based safety (BBS) programmes is given and barriers for their application in the automotive domain are identified. BBS program is used as a synonym for behavioural management technique. The general BBS principle, adapted from Skinner's [47] operant conditioning learning theory, is that behaviours followed by desirable consequences are more likely to be repeated in the future and those followed by undesirable consequences are less likely to be repeated in the future [1]. BBS strategies are based on the original four-step BBS process developed by Geller [1] called DO-IT. DO-IT is an acronym for **D**efine, **O**bserve, **I**ntervene, and **T**est trageted at-risk and/or safe behaviours. It was originally conceptualized to target immediate behaviour. Safety managers in industrial work settings can usually systematically observe safe versus at-risk behaviour of employees and provide feedback later. Geller [1] was among the first who introduced the BBS concept into industrial work safety and occupational behaviour research. Safety program techniques following the BBS principle have proven to be relatively easy to implement, cost-effective and highly efficient for reducing occupational injuries and fatalities in a variety of industrial domains. Examples include introduction in a pizza delivery company [48], a paper mill [49], the mining industry [50], a gas pipeline company [51], a food manufacturing plant [52], an oil and natural gas company and a glass manufacturing company [53] as well as in the rail industry such as Amtrak's ticket handling system [54]. Meta-analyses of health and safety BBS studies have found a significant reduction in injuries ranging from 96.6% [55], to 59.6% [56], to 69% [53]. Krause, Seymour and Sloat [57] conducted an analysis comparing the injury reduction due to BBS strategy implementation at 43 different sites over time. In Figure 11.3, results are shown with a continuously increased reduction of work related injuries over a five-year period.

Research on BBS programmes applied to traffic safety is limited. And, no BBS-study has specifically focused on attention enhancement yet. Only a few studies have examined the effects of BBS principles applied in the automotive domain. Thus, the literature review on BBS programmes best practices in this chapter is largely based on reviews by Hickman *et al.* [58], Hickman and Hanowski [31], and Victor *et al.* [59]. It is hypothesised that adapting BBS principles techniques and processes to the automotive industry, and ultimately to ADAS design, can yield lasting changes in improving road safety, in general, and driver attention support management, in particular. BBS programmes, which aim to coach or

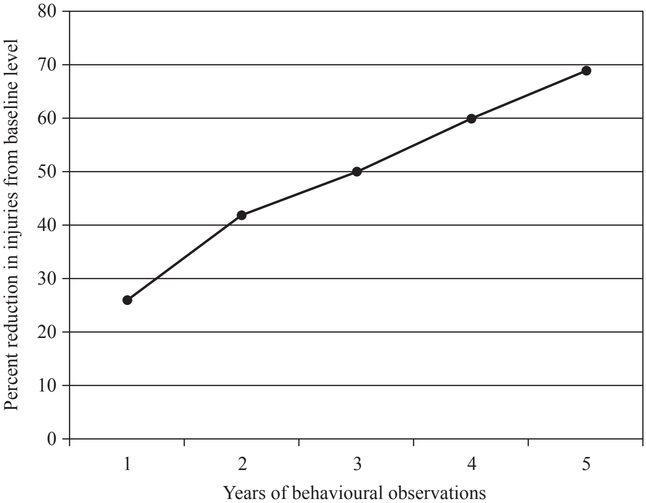

Figure 11.3 The average percent injury reduction across 73 sites using a BBS program (reported by Krause, Seymour and Sloat [57, table 3])

educate drivers, have the opportunity to operate as attention enhancing accident prevention strategies. However, until recently, the primary problem with implementation was the difficulty in obtaining good quality, continuous measures of behavioural data. Studies evaluating the benefit of BBS in the motor transport domain are rare because implementation of BBS programmes in fleets is a relatively new field [50, 60, 61]. The study reported by Hickman *et al.* [58] as well as a knowledge-review paper [62] provide a comprehensive overview of existing BBS approaches in commercial vehicle operations. Hickman and Hanowski [63] investigated the safety benefits of on-board safety monitoring devices over a 17-week period. Results showed a significant reduction of recorded safety-related events by 52.2%. In another report on the same dataset, Hickman and Hanowski [31] showed that the same device affects the prevalence of distracting activities while driving, for example through a significant effect for cell phone usage compared with baseline. Toledo and Lotan [64] investigated the effects of an on-board driver monitoring device over a five-month period. In this study driver feedback was presented on a personal webpage giving drivers access to information about previous trips. It was found that drivers only reduced their at-risk behaviour for the first month after performance feedback was provided. After the first month, at-risk behaviour remained stable. Initially, feedback improved safety, but this effect diminished over time as drivers accessed their webpages less frequently. This pattern of behaviour was not further explored by the authors. An interpretation of the results is that drivers may have developed an awareness of safety-critical events which caused the initial decrease in at-risk behaviours.

In order to closer compare BBS with the previously characterised ADAS approach, the same properties that were used to describe ADAS are used here to describe BBS (see Figure 11.1).

In general, the BBS approach is defined as 'post-trip accident prevention'. The primary aim of BBS is to coach a driver by providing risk-relevant feedback targeting a safety-critical behaviour event, near-crash event or crash event.

The feedback goals of BBS are to:

1. raise driver awareness of safety-critical behaviour and situations
2. coach drivers about their own target behaviour and target situations
3. educate drivers about safe behaviour and safe situations

The intended BBS feedback effects are:

1. driver self-awareness [25]
2. driver calibration [65]
3. improvement in driver safety knowledge and skills [1]

The BBS approach intends to provoke a long-term driver behavioural change. The unintended effects of BBS feedback can include driver mistrust, scepticism, privacy issues and disciplining of drivers without a driver policy in place. If the BBS program is improperly managed, it may give rise to negative attitudes within the workforce. The feedback about risky behaviour is usually delivered to the driver after a trip; the timing of the feedback of BBS is either 'retrospective feedback' within minutes or hours after the trip or 'cumulative feedback' within days, weeks or months [37] after a behavioural event, a near-crash event or a crash event occurred. The general target users of BBS are safety managers of commercial fleets (truck, bus, taxi, and distribution or delivery fleets). The proposed move of the traditional BBS perspective towards a more BBS-ADAS approach is visualised by the arrow pointing from an existing BBS approach to the novel BBS-ADAS approach in Figure 11.1.

Hickman and Hanowski [63] have identified four main BBS techniques that can be applied to the automotive domain:

1. training and education
2. behaviour-based incentives and goal-setting
3. behavioural observation
4. feedback and coaching

These BBS techniques are interpreted for application to attention enhancement techniques and are explained in more detail below.

11.3.2.1 Training and education

Driver attention training includes driver education for novice drivers [e.g. 66]. Safety-related training is generally applied using driving simulators [67, 68] or computer-based training to improve attention selection in driving [e.g. 69]. Distraction, as an issue, has been largely neglected in the design of driver education and training programmes. This fact is surprising because, as stated in [19, p. 560], research shows that 'the driving public has little understanding of what activities are distracting, of the relative risk associated with different sources of distraction, of the impact of distraction and the need to self-regulate in response to distraction'. In general, attention training and education is a necessary, but not sufficient, safety management technique. Drivers need the knowledge on how to drive safely and to identify unsafe behaviours; however, the existence of knowledge does not necessarily result in safe driving. If a driver has no knowledge on how to drive safely, he/she has a knowledge gap. However, if he/she has the knowledge but still engages in unsafe behaviour, then it becomes a motivation gap (i.e. 'I know how to drive safe, but I choose not to do it.'); behavioural feedback and coaching address this latter issue.

11.3.2.2 Behaviour-based incentives and goal-setting

The importance of goal setting and incentive strategies is discussed in literature from many different research domains. Barton, Tardif, Wilde, and Bergeron [70] provide a general framework for the implementation of incentive schemes in the automotive domain. Bandura [71] examined why feedback motivates behavioural change. According to Bandura, individuals who are dissatisfied with their performance will be motivated to increase their effort in the future if given proper feedback. In order for feedback to have an effect on individual performance, the individual must have a performance goal. A performance goal provides the individual with a standard and expected level of performance. Furthermore, goals allow individuals to compare their performance with their standard performance level.

11.3.2.3 Behavioural observation

Behavioural observation can be carried out in different ways. It can range from observation by a safety manager, usually referred to as ‘human watchdog observation’, to peer observation and covert observation. When observations are performed, a behavioural checklist can help to systematically record and track behaviours. Without behavioural observation, no performance feedback can be provided. Behavioural observation in an in-vehicle setting can be carried out using vehicle sensors and cameras. One example of this observation type is on-board distraction monitoring devices (see [72] for a review). Technological constraints have prevented observation of high quality behavioural data derived from driving behaviours thus far. Most on-board safety monitoring devices are kinematic-trigger-based (e.g. acceleration triggers, excessive speed triggers, unplanned lane departures, frequent hard braking, close following distances, failure to yield at intersections) and are not based on driver visual behaviour (e.g. off-road glances, or eye-closures). Furthermore, current technology can generally not distinguish between safe and at-risk behaviour during a safety-related event as it occurs. Hickman and Hanowski [31] analysed data from DriveCam, a vendor of on-board safety monitoring systems for professional fleets aimed at reducing risky driving behaviours using in-vehicle video technology. With the DriveCam system, it is possible to ‘flag’ those triggered driving events, to save 12 s of video (e.g. 8 s prior to the event trigger and 4 s after) and to automatically send them to trained data analysts. Analysis of distraction-related behaviours is thus performed by human review and classification of behaviours from the video material and associated telematics data. This procedure also allows drivers and fleet safety managers to review data and video at a later date; thus, the feedback is delayed. Driver safety performance scores and feedback are maintained in a database so that a manager can rank drivers to determine who most needs coaching. A key difference between the DriveCam system and other types of driver recorders is that a long-term coaching service is provided, instead of only providing in-vehicle feedback or capture of video recordings.

11.3.2.4 Feedback/coaching on behavioural events

The role of feedback in changing behaviour has been studied in various domains. In general, BBS approaches are based on human learning theories and their underlying cognitive, motivational and energetic processes. One particular theory is that of operant conditioning by Skinner [47]. Skinner influenced the ‘behavioural approach’, which means that once behaviour can be operationally defined, and reliably tracked, it can be influenced. In Chapter 2, several learning theories are reviewed that explain factors underlying behavioural change. With drive-recording systems that also provide a coaching service (e.g. DriveCam or SmartDrive), events can be reviewed and feedback on safe and at-risk driving behaviours provided.

In a coaching session, video events examples of risky behaviours (e.g. near-crashes or close following behaviours) and feedback on aggregated driving performance data (e.g. last three months) can be provided. The primary benefit of coaching is that users are collaboratively engaged in the behaviour improvement process.

11.4 Advancing into a new league: Uniting ADAS and BBS team players

In the following section, an integrated approach of ADAS and BBS is described. Both of the approaches have shortcomings that may lead to an overestimation of the safety effects that individual ADAS or BBS approaches have. Although both approaches have been proven to be effective, they lack important aspects for more stable effects and maximum traffic safety potential.

The main shortcoming of the ADAS approach as an attention enhancement measure is that, although the behavioural feedback warnings provide immediate accident prevention, they do not target long-term effects on behavioural change. For example, drivers might forget about the warning that previously identified a behavioural event. Studies have found that an estimated 80% of near-accidents are forgotten after two weeks [73]. This suggests that a driver's memory of his/her glance behaviour and driving performance needs to be reviewed retrospectively. Current ADAS have the potential to signal drivers to direct their attention towards a hazard once a safety-critical event occurs. However, traffic changes can occur very rapidly in the driving environment and, although ADAS are technologically capable of tracking these changes, the driver may fail to react accordingly.

The main shortcoming of the traditional BBS approach is that feedback is provided a relatively long time after the behavioural event occurs. Until now, almost all BBS techniques that are based on driver monitoring systems focus on pre- or post-trip feedback. For these purposes on-board monitoring devices to observe driver behaviours are often used in fleets. In one study, 35.4% of the companies involved used on-board monitoring devices but they did not provide immediate feedback on visual distraction to the driver [58]. According to previous studies, feedback is most effective when given immediately, or as soon as possible, after the occurrence of the behaviour [1]. Research shows that when drivers only receive pre- or post-trip feedback at the office, at-risk behaviour does not continuously decrease. As stated above, Toledo and Lotan [64] showed that drivers only reduced their at-risk behaviour for the first month after cumulative performance feedback (on a personal webpage) was provided. Over a longer time period, this effect diminished and performance remained low because drivers accessed their webpages less frequently. Attention enhancement efforts need to be maintained over a longer period of time.

It has been found that if drivers only receive post-trip feedback they may not be aware of at-risk behaviour once it occurs. Poor immediate feedback about how distraction affects safe driving leads drivers to believe that their driving performance is better than it really is [25]. That people in general are poor judges of their own behaviour was discussed by Bandura [71] who stated, ‘Since people’s attentiveness to their on-going behaviour fluctuates widely, they are not always all that self-observant’ (p. 337). Furthermore, almost all prior BBS research has been applied in work settings where employees can systematically observe safe versus at-risk behaviours of themselves and/or of their co-workers. As Hickman *et al.* [58] argue, truck and bus drivers work alone in relative isolation and thus may require alternative BBS processes.

Previous research suggests that the combination of on-board driver monitoring systems with other safety-management techniques like BBS management is likely to be one of the most powerful approaches in reducing crashes [74]. In a study evaluating the safety benefits of the DriveCam system with driver feedback and offline coaching, results show a 52.2% reduction in safety-related events and a 59.1% reduction in severe safety-related events [63]. Therefore, driver monitoring approaches with *combined feedback* about risky behaviours *at different timescales* are needed. A new approach is to combine ADAS and BBS accident prevention strategies by providing both immediate/delayed feedback and aggregated feedback to achieve a long-term effective BBS-ADAS.

In this chapter, the BBS-ADAS approach as applied to attention enhancement is defined as ‘on-board driver monitoring for both immediate and aggregated inattention feedback’. With BBS-ADAS methods, the driver receives feedback about a behavioural event targeting a safety-critical behaviour both immediately and after driving. With the introduction of new technologies, objective real-time measures and feedback systems for driver visual behaviour, with the possibility to save the recorded events, will become available. The type of feedback is informative by notifying the driver about risky behaviour both during a trip and after it. The feedback timing of BBS-ADAS is *a combination* of ‘concurrent feedback’ within milliseconds, ‘delayed feedback’ within seconds after the occurrence of the behavioural event [37] and long-term aggregated feedback. The aim of the combination of different feedback timings allows the driver to train for preventing events in future trips.

The feedback goals of BSS-ADAS are to:

1. raise driver alertness to safety-critical situations (as with ADAS)
2. speed up driver responses in a safety-critical situation (as with ADAS)
3. raise driver awareness of safety-critical behaviour (as with BBS)
4. coach the driver about own target behaviour (as with BBS)

The intended BBS-ADAS feedback effects are:

1. driver attention on-road (as with ADAS)
2. quick driver responses (as with ADAS)
3. driver self-awareness (as with BBS)
4. driver calibration (as with BBS)

The BBS-ADAS approach intends to provoke driver behavioural change over different timescales. The unintended BBS-ADAS feedback effects range from the driver feels too safe (as with ADAS) to driver mistrust and scepticism (as with BBS).

The general target user of BBS-ADAS with regard to road safety is, unlike BBS approaches, the individual driver both immediately when a behaviour occurs, and retrospectively over a longer period of time exhibiting multiple instances of this at-risk behaviour. The advantage of the BBS-ADAS approach is that warnings can be recorded and logged to file for a post-trip summary report. This report can be either assessed individually or can be forwarded to the fleet safety manager for further coaching discussions. In summary, inherent in the BBS-ADAS approach is multiple feedback timescales, continuous check-ups, self-awareness enhancement at multiple levels and with various involved personnel. Figure 11.1 gives an overview of the properties of BBS-ADAS feedback and puts them into perspective with existing approaches.

It is important to mention that whilst the BBS-ADAS approach may be an improved approach, if the driver does not appreciate the persistent intervention, or has privacy concerns, he/she may choose to deactivate the ADAS.

11.4.1 Game tactics

In order to achieve sustained change regarding safe glance performance, a combination of immediate feedback *and* post-trip feedback is suggested. A combination of both visual behaviour feedback on a continuum in the pre- and post-trip dimension is the *DO-IT BEST Feedback Model* [75]. In the DO-IT BEST Feedback Model the BBS techniques are coupled to different feedback timescales, adapted from [37], and feedback sources, including the vehicle, aggregated performance analysis, the manufacturer (automotive and telematics devices industry) and the society. The DO-IT BEST Feedback approach is a further development of the four-step DO-IT process on continuous behavioural improvement first introduced by Geller [1]. As described above, DO IT is an acronym for **D**efine, **O**bserve, **I**ntervene and **T**est targeted at-risk and/or safe behaviours. It was originally conceptualised to target immediate behaviour but in an offline setting. Wege and Victor [75] interpret Geller's original four-step process for an example of an immediate/delayed *and* cumulative/aggregated attention enhancement strategy for preventing traffic accidents. The original DO-IT process is not only translated into an online, immediate visual behaviour feedback approach, but also developed further into the DO-IT BEST Feedback approach. BEST is an acronym for **B**ehavioural check-ups, **E**ducation, **S**afety benefit analysis and **T**raining for targeted at-risk and/or safe behaviours. For the DO-IT BEST Feedback approach to be effective, it is necessary to provide immediate feedback to drivers during a safety-critical event (for example looking off the road for an extended period of time) *combined with* post-trip feedback regarding previously recorded safety-critical events.

11.4.1.1 Team ADAS perspective

For the immediate feedback to be effective, vehicles need to be equipped with reliable real-time distraction monitoring technology. Technology can track behaviour and provide an immediate warning when specific behaviours occur. The ADAS warning can be recorded and later used in a BBS-offline setting for further discussion. Recently, research on real-time driver feedback technologies has overcome the problem of capturing and documenting key safety-critical behaviours. Eye-tracking systems [76] and distraction detection algorithms make continuous observation and detection of drivers' glances possible. The main challenge for implementing BBS-ADAS for attention enhancement is accurate, low-cost, mass-market, unobtrusive eye-tracker systems with sufficient tracking uptime. ADAS of these kinds are being developed and real-time distraction detection algorithms have been tested in controlled settings [16, 17, 77, 78]. A review of existing functions can be found in [37, 72, 77]. One example is a Visual-Distraction-Alert System (VDAS), a real-time distraction prevention system based on head/eye movement recordings. It provides informative feedback (a warning) regarding a distracting event (looking away from the road for too long or too frequently) immediately when it occurs [16, 59, 78]. The main purpose of the visual distraction alert is to help distracted drivers realise that they are being 'tricked' into glancing away from the road for too long and/or too often. The alerts should train them to recognise a limit of inattentive glance behaviour. As such, it is a preventative warning system without direct coupling to near-crash situations, but coupled to risky glance behaviours.

In recent years, the focus for technological solutions to the visual distraction prevention problem has intensified. Some first-generation products are already available, but there is little consensus regarding which real-time distraction countermeasure functions are the most effective and useful. Wege and Victor [78] recently found that a reliable warning strategy, taking into account a driver's glance history along with single long glances off the road, increases the percentage of time the eyes are on the road centre as well as driving performance. The findings are in line with Lee *et al.* [16], who evaluated four vision-based algorithms for detecting driver distraction, with the warning algorithm used in Wege and Victor [78] being the most effective. Unlike other ADAS, which target a dangerous situation (e.g. FCW, LDW), the VDAS aims to target dangerous behaviour (e.g. writing a text message while driving). By using technological features that only ADAS are capable of providing (e.g. detection and warning of off-road glances), drivers have the possibility to detect and learn immediately about their risky behaviour. The drivers self-observation component makes it an ideal 'team player' to enhance attention in a BBS-ADAS-style.

Victor *et al.* [59] asked participants about their subjective beliefs as to how efficient a VDAS is compared with other systems. It was found that 63% of the participants stated that a VDAS could reduce crashes. Current scientific research with a similar concurrent driver feedback system, the Driver State Sensor System (DSS), showed a 78% reduction in the distraction event frequency [79]. Another example of an ADAS for enhancing attention is Volvo's Driver Alert Support System (DAS). The DAS alerts the driver when path control deteriorates. It is based on detecting changes in attentional state (due to both drowsiness/fatigue and distraction) from lateral control performance and provides immediate feedback to the driver.

Not only organisations and fleet companies can benefit from the data and feedback gathered from BBS-ADAS devices. Although the BBS-ADAS approach may be most applicable for occupational drivers as retrospective feedback can be provided in a controlled manner by workplaces, the approach can also be applied in non-occupational vehicles. The BBS-ADAS principles may also augment private cars, for example through self-learning tools (post-trip awareness scores and/or web-based self-learning tools). Takeda *et al.* [80] introduced a self-coaching system to improve driving behaviour by allowing drivers to review a record of their own driving performance data (not of their visual behaviour activity).

11.4.1.2 Team BBS perspective

The warnings generated by the ADAS and recorded while driving can be used in a BBS setting for further discussion. During the BBS discussion (e.g. face-to-face meeting among fleet drivers and fleet safety managers) specific behaviours can be identified that will enhance the feedback strategy of ADAS. The ADAS can provide specific warnings according to a set goal (e.g. target behaviour) previously agreed upon. That way, the ADAS feedback can become richer and more tailored to an individual. The warning settings could be adjusted and/or specific warnings could be emphasised according to the BBS goals. This type of *BBS-generated ADAS* is a completely new approach. It is expected that these kind of BBS-ADAS will provide drivers with an individualised performance score (e.g. attention score), which will in turn translate to an *individual safety status* e.g. attention status. The personalised warnings can create a more meaningful and coherent training effect than standardised ADAS warnings would provide. One example of personalised warnings is that the top prioritised risky behaviours identified by BBS (e.g. following too close or drowsy driving) can be given as input to ADAS. ADAS could then emphasise providing more feedback on the prioritised problematic behaviours while driving, for example by providing headway coaching or more drowsiness related feedback. Personalised warnings can create an even more meaningful training effect for an individual driver and can be tied to the current goals and incentives in the BBS program.

11.5 Players debriefing

In conclusion, it is unlikely that distraction will ever be eradicated as a road safety problem – it therefore needs to be effectively managed. Reducing the effects of distracted driving is possible if the right approaches are applied to the problem. Today, there are two separate approaches for improving traffic safety, ADAS and BBS, where development has been carried on largely independently from one another. There is a need to further develop current ADAS and BBS approaches independently, and also in an integrated fashion. Both approaches apply feedback at different timescales to achieve *the same goal:* accident prevention.

Research on HMI and automated ADAS has suggested the theory of ‘team play’ [2]. Adapting the theory of ‘team play’ to the field of accident prevention it can be argued that both teams (team ADAS and team BBS) have the same goal, but because of applying different strategies they have yet not been united into one winning team. As stated above, although ADAS and BBS programmes have been proven to be effective, both lack important aspects for more stable effects.

Rudin-Brown [81] addressed one important question: ‘Are our “intelligent” transport systems really that intelligent?’ Without *adaptive* design, ‘intelligent’ in-vehicle transport systems have limitations as stated above. Feedback timescales do not have to be mutually exclusive. For a joint BBS-ADAS concept to operate successfully, immediate *and* aggregated feedback should be conceived and designed as ‘team players’. Therefore, research focus should not be on either making one or the other ‘more intelligent’, but rather on how they can *cooperate* as members of the same team on the accident prevention playing field. Adapting the theory of ‘team play’ to the field of accident prevention, the question that arises is not ‘which accident prevention approach has more influence?’ The question that should arise is ‘How do both team players get along together to play in the same team – united together?’

In the future, ADAS designers and developers, as well as safety management developers, need guidance on how to support the coordination between ADAS and BBS; the mechanisms and ‘game rules’ need to be defined in order for both team players to cooperate. According to ‘team play’ theory, good and effective team players make their activities observable for fellow team players, communicate together and are easy to direct.

The combination of BBS and ADAS, a holistic BBS-ADAS approach, can improve safety over and above each approach on its own. On-board driver monitoring devices that provide only immediate feedback may not result in sustained behaviour improvement when implemented in the absence of a BBS program. The combination of an ADAS with a BBS program (including rewards) is expected to result in sustained behavioural improvement when correctly implemented [82]. Hickman *et al.* [58] suggested that weekly feedback in combination with other BBS techniques can result in a very powerful safety improvement. Vice versa, previously discussed BBS techniques can enhance ADAS feedback by providing training sessions or personalised warnings. The BBS-ADAS approach focuses on how to harmonise the ADAS and BBS feedback into one holistic feedback process. The DO-IT BEST feedback approach was presented as one example of such a harmonised process [75].

The mechanisms of cooperation and the effects of different BBS techniques combined in one program need to be further evaluated. Adaptation effects over a longer time period (e.g. several months) have only been tested in two studies; by Krause, Seymour and Sloat [57] and Toledo and Lotan [64]. Further assessment of the effects on safety of BBS-ADAS over a longer period of time is therefore necessary. Further work is also needed to validate that accident prevention strategies work as intended, are wanted by customers and are effective (e.g. in terms of return on investment). As Victor *et al.* [59] stated, recent safety impact results are showing great potential, and no doubt the future driver will be assisted by attention technology.

In this chapter, we presented a reason why the future driver will be assisted by attention technology: when both players are united (BBS-ADAS) they form a team that wins more easily. Due to the use of more precise safety metrics directly representing distraction, the safety benefits of BBS-ADAS are expected to exceed the benefits of ADAS and BBS alone. This can be translated as BBS-ADAS being more than the sum of its parts. ADAS and BBS, united into a BBS-ADAS team with connected strength, may have the best possible impact on accidents rates. With the BBS-ADAS team, traffic safety has the opportunity to advance into an entirely new league.

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CHAPTER 7 PAPER VI

Paper VI

The DO-IT BEST Feedback Model - Distracted Driver Behaviour Management and Prevention Before, While And After Driving

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The DO-IT BEST Feedback Model - Distracted Driver Behaviour Management and Prevention Before, While And After Driving

Claudia A. Wege and Trent W. Victor
Volvo Group Trucks Technology (GTT), Sweden

Abstract

Applied to driver distraction and inattention prevention/mitigation, this paper expresses how to enhance attention allocation using the DO-IT BEST Feedback Model – a model on ‘behavioural change’. Today, there are two main approaches to improve traffic safety through feedback to drivers. One approach is Advanced Driver Assistance Systems (ADAS), which are concurrent feedback systems that warn the driver in a dangerous situation (e.g. taking the eyes off the road). The other approach, behaviour-based safety management programs (BBS), use deferred feedback (i.e. pre- or post-trip) and target, for example, a habit of sending text messages while driving. If both approaches are used, feedback to drivers is provided during different timescales before, while and after driving. Each approach on its own is an effective crash prevention strategy, however they tend to be used independently and would benefit from being integrated into *one* holistic crash prevention strategy. The DO-IT BEST Feedback Model is such a holistic and integrated crash prevention strategy. DO-IT BEST is an acronym for **D**efine, **O**bserve, **I**ntervene, and **T**est targeted at-risk and/or safe behaviour as well as to assimilate **B**ehavioural check-ups, **E**ducation, **S**afety benefit analysis and **T**raining on targeted at-risk and/or safe behaviour. The model consists of a closed circuit set of feedback strategies, based on the driver’s own behaviour, and ranging from concurrent on-board driver feedback to deferred post-trip feedback. The various feedback sources (e.g. technology- or human-based feedback) are included in the model.

> *"The whole is something over and above its parts, and not just the sum of them all..."*
> Aristotle

Introduction

Driver distraction and inattention may be caused by a range of factors including drivers willingness to engage in distracting tasks (Klauer, Dingus, Neal Sudweeks & Ramsey 2006, Victor, Harbluck & Engström 2005, Dingus et al 2011), sleepiness (Bunn, Slavova, Strttmann & Browning 2005), day dreaming (Forster 2013) or reaching for an object or person inside the vehicle (Roney, Violano, Klaus, Lofthouse & Dziura 2013). In some traffic situations distraction and inattention can have fatal consequences. Driver distraction has been identified as a major contributor for crashes (Klauer et al. 2006, Hanowski, Olson & Bocanegra 2009, Hanowski, Perez & Dingus 2005). As "distraction […] is part of everyday driving" (Aitkin, Chairman NRMA-ACT Road Safety Trust 2009), we need to develop strategies on how best to manage and/or prevent distraction and inattention. Two strategies, Advanced Driver Assistance Systems (ADAS) and behaviour-based safety management programs (BBS), already exist. However they have never been synthesized into *one* holistic model. It is expected that when these approaches are used together, it will improve crash prevention. This paper describes such a holistic model for how to manage safety by providing behavioural feedback about a specific, pre-defined behaviour before it occurs, while it occurs in the vehicle and after it has occurred. Thereby, the focus of the 'behavioural change' is on how to enhance attention allocation to the driving scene.

Present countermeasures for (visual) driver distraction

Today, there are two main approaches to improve traffic safety through feedback to drivers. Although having the same goal, the two approaches take into account different time-scale perspectives for crash prevention. One approach is *Advanced Driver Assistance Systems (ADAS)* which are technology-based safety countermeasures. ADAS are concurrent feedback systems (i.e. immediate feedback) that warn the driver in a dangerous situation (e.g. taking the eyes off the road). ADAS are defined as pre-crash *driver warning systems* that alert the driver by providing immediate risk-relevant feedback prior to a near-crash or crash event. It has been speculated that the implementation of ADAS may lead to a fatality decrease of 40% (Thalen 2006). Today's distraction countermeasures in the automotive industry are almost exclusively ADAS of the type of 'reactive pre-crash mitigation' systems ((e.g. FCW, LDW), for a review see Engström and Victor (2008)). A conceptual framework to cluster various ADAS is presented by Victor (2011). This framework is time-based by classifying ADAS to the time prior to a (possible) crash.

The other approach, *behaviour-based safety management programs (BBS)* are safety countermeasures that use deferred feedback (i.e. "offline", pre- or post-trip feedback) to target a 'behavioural change' (e.g. a habit of sending text messages while driving). Geller (2001) was among the first who introduced the BBS-concept in the area of industrial work safety and occupational behaviour research. *Safety program techniques* following the BBS-principles have proven to be relatively easy to implement, cost-effective and highly efficient for reducing occupational injuries and fatalities in a variety of industrial domains. Meta-analysis of health and safety BBS studies found a significant reduction in injuries in 96.6% cases (Sulzer-Azaroff & Austin 2000), 59.6% cases (Guastello 1993) or 69% cases (Krause 1998). Research on BBS programs applied to traffic safety is however limited. Only a few studies have examined the effects of BBS principles applied to the automotive domain (Hickman et al 2007, Hickman & Hanowski 2010, 2012, Victor et al 2011). Hickman et al (2007) and Horrey, Lesch, Dainoff, Robertson and Noy (2012) provide comprehensive overviews of existing BBS approaches in commercial vehicle operations. In this context, Hickman and Hanowski (2010) have identified four main BBS techniques: 1) training and education, 2) behaviour-based incentives and goal-setting, 3) behavioural observation, and 4) feedback. See Wege and Victor (in press) for a further discussion of these BBS techniques.

Motivation for the development of the DO-IT BEST Feedback Model

Both the ADAS and BBS approaches, although proven to be effective, have shortcomings which may lead to an overestimation of the safety effects that they actually have (Wege & Victor, in press). The magnitude of shortcomings of present countermeasures motivated the development of a more comprehensive, holistic crash prevention strategy: the DO-IT BEST Feedback Model (Figure 1). ADAS as countermeasures may not lead to sustainable, long-term behavioural adjustment (long-term effect on behavioural change), such as taking decisions to stop engaging in distracting activities. The reasons why may be a) the “failure of memory”, a phenomenon whereby an estimated 80 % of near-crashes are forgotten after two weeks (Chapman & Underwood 2000), b) the “failure of association” whereby the driver cannot associate an overall increase in lane departure warning with lane deviations caused by a distracting activity and/or c) that the driver might not have access to potential feedback (Toledo & Lotan 2006). The main shortcoming of BBS as a countermeasure is that feedback is provided a fairly long time after a certain behaviour occurred. According to previous research, feedback is most effective when given immediately or as soon as possible after the occurrence of the behaviour (e.g. Geller 2001, Skinner 1953). Research shows that when drivers only receive deferred feedback, at-risk behaviour does not continuously decrease.

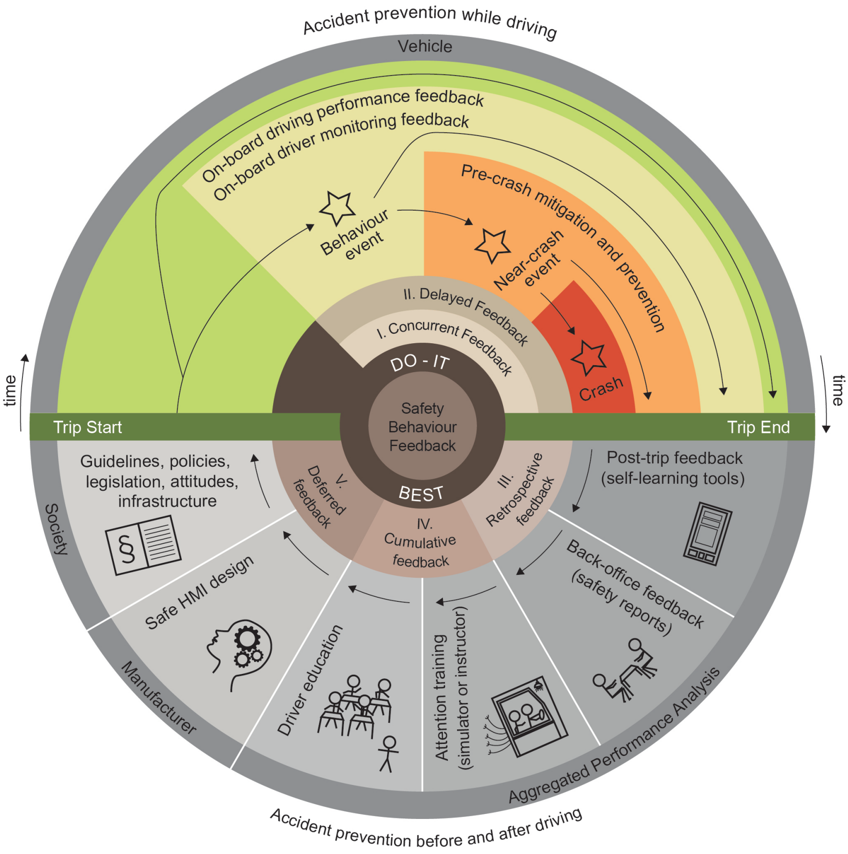

Figure 1. DO-IT BEST Feedback Model

Previous work as a basis for the model

The DO-IT BEST Feedback Model was developed based on previous research and developments within the automotive domain, the educational domain, and the behavioural psychology domain.

BBS-programms in industrial work settings (Geller 2001)

The original BBS process is a four-step process called DO-IT process which was developed by Geller (2001). DO-IT is an acronym for the following terms: (1) **D**efine the critical target behaviour(s) to increase or decrease, (2) **O**bserve the target behaviour(s) during a pre-invention baseline period to set behaviour-change goals and, perhaps, to understand natural environments or social factors influencing the target behaviour(s), (3) **I**ntervene to change the target behaviour(s) in desired directions, and (4) **T**est the impact of the intervention procedure by continuing to observe and record the target behaviour(s) during the intervention program. According to Geller safety feedback is most effective when given immediately or as soon as possible after the occurrence of the behaviour. Ludwig and Geller (1997, 2001) recommend involving participants as much as possible in the implementation of the DO-IT approach at their work site. The self-involvement has positive effects on participants self-regulatory capacities which allow them to motivate and regulate behaviour through internal standards and self-evaluation of their behaviour. If it is possible for individuals to monitor and record their own behaviour, behavioural and cognitive change is possible through self-management. The DO-IT process has been successfully applied in a variety of industrial domains such as secure prison management (Geller et al 1977), community recycling (Geller 1980), effectiveness of child dental care (Kramer & Geller 1987) and safety for pizza deliverers (Ludwig & Geller 1991). For an extensive review on a number of BBS studies involving a total of 25,852 people see Cooper (2009).

As Geller and colleagues conceptualized the DO-IT process it targeted at-risk and/or safe behaviour which was usually systematically observed by trained safety managers (“human watch guards”) in industrial work settings during so called intervention programs. Feedback on safe versus at-risk behaviour of employees was provided later. The DO-IT process has (to our knowledge) never before been applied in the automotive context focusing on distracted drivers, especially not in an online automotive context (i.e. giving feedback while driving). Thus, we have taken the classic DO-IT process out of its original context (industrial work settings) into the context of online crash prevention. More specifically, the human performance analyst (“the human watch guard”) is transferred to the automotive setting by replacing it with technologies (on-board monitoring devices). Online technologies are able to observe the situation and either to intervene appropriately online and/or to log events for a later occasion. Thus, Geller’s original process is interpreted here as an online crash prevention strategy in the DO-IT BEST Feedback Model.

‘Behavioural change and behaviour adaptation’ (Wege, Pereira, Victor & Krems, in press)

Adaption processes become important each time a driving situation embodies one or several unfamiliar components. These processes involve a behavioural change emerging into previously established behavioural patterns. A variety of concepts, theoretical models as well as empirical research regarding the concept of ’behavioural changes’ exist. For a review of the literature see Wege, Pereira, Victor and Krems (in press). In general, it is the role of feedback in changing behaviour that is of importance because ‘behavioural change’ is largely based on human learning theories and their underlying cognitive, motivational and energetic processes. One particular learning theory is the theory of operant condition by Skinner (1953). Skinner influenced the “behavioural approach” which assumes that once behaviour can be operationally defined, and reliably tracked, it can be influenced.

Research on on-board safety monitoring devices (OBSMD) (Hickman et al 2007, 2010a)

In recent years, driver monitoring systems have been developed and tested during on-road field studies (Hickman et al 2007). In these studies, the goal of driver monitoring is to record safety critical behavioural events for post-trip analysis and *post-trip behavioural feedback* which is provided either hours, days or even weeks later. On-board safety monitoring devices (OBSMD) enables safety managers at fleet companies to collect safety-specific information (e.g. instances of seatbelt non-compliance, distraction, or fatigue) related to driver on-road behaviour and performance. Employers with drivers who operate a motor vehicle as part of their job usually do not have the opportunity to directly observe workers and interact with them in an effort to improve safety to the same extent as employers with a fixed worksite have. Technologies such as OBSMD and real-time distraction feedback systems have several benefits. These systems have the potential benefit 1) to detect and identify behavioural events while driving; 2) to give the opportunity for proactive, corrective, immediate feedback (thus, bringing the event to the awareness of the driver and requiring an immediate, appropriate response); 3) to automatically store data surrounding a behavioural event for later download, for subsequent review, for generation of individual trip awareness scores and/or recordings for driver training and coaching (thus, preventing events from reoccurring in future trips). Knipling and Hyten (2009) noted additional benefits of using such systems in commercial fleet operations: 4) the feedback and related evaluations are objective, timely, and frequent; 5) drivers can receive positive feedback and rewards for good behaviours (these rewards can also be structured to reinforce group or fleet-level achievements); 6) benchmarks for driving behaviours can be set in order to establish carrier or group norms and expectations; and finally 7) the systems may replace time consuming ride-along observations conducted by a human. According to Horrey, Lesch, Dainoff, Robertson and Noy (2012) OBSMD can offer valuable information to drivers concerning undesired behaviours, driving errors and lapses, including those that the drivers themselves might not be aware of. Thus, drivers benefit most from actually experiencing their own errors.

Several OBSMD that log dangerous behaviour but do not give immediate feedback exist, for example Tripmaster®, DriveCam®, Driver Alert Support System® and Transsecurity System®. Horrey, Lesch, Dainoff, Robertson and Noy provide a comprehensive state-of-the-art review of studies concerning OBSMD. The primary safety behaviours measured by these systems are extreme braking events, speeding, sudden acceleration and lateral control performance. The consequences of distracting behaviour are logged and send via a wired or wireless connection to a fleet safety management software. Toledo, Musicant and Lotan (2008) investigated the effects of an on-board driving performance monitoring device over a 5-month period. It was found that drivers only reduced their at-risk behaviour for the first month after performance feedback was provided, after that the effect remained stable. Although the mentioned products have been shown to reduce fleet-wide crashes up to 52.2% (Hickman & Hanowski 2010), no OBSMD measuring off-road glances is yet on the market. Research in this field is active and systems such as a Visual-Distraction-Alert System have been studied in simulator experiments (e.g. Lee et al 2013, Ahlström, Kircher & Kircher 2011, Wege & Victor, in press). One example of a device measuring visual behaviour (based on head movement, but again, no off-road glances) is the Driver State

The conceptual framework for distraction and inattention countermeasures (Victor 2011)

Within the DO-IT BEST Feedback Model, the conceptual framework on technology-based safety countermeasures found in Victor (2011) is further developed by extending the time-based nature of the framework into a circular time scale from a linear time scale progressing from normal driving to a (potential) crash. In the original conceptual framework 16 emerging technology-based safety countermeasures are clustered according to descriptive characteristics and functions. The division of pre-drive, normal driving, pre-crash, crash, crash and post-drive countermeasures is adapted based on this framework.

The"information-processing model with temporal feedback" (Donmez, Boyle & Lee 2008).

Four of the five driver feedback timescales in the DO-IT BEST Feedback Model (i.e. concurrent, delayed, retrospective and cumulative feedback in Figure 1) are based on the "information-processing model with temporal feedback" by Donmez, Boyle and Lee (2008). An additional fifth timescale ('deferred cumulative') was added in order to address long-term societal impacts like to laws that restrict distracting behaviours while driving as a form of deferred feedback.

Research on driver training, education and formal driver retrospective feedback

The beneficial effects of driver training and education have been studied especially for young and novice drivers (e.g. Roelofs, Vissers, van Onna, Kern 2012, Washington, Cole & Herbel 2011, Weiss, Petzoldt, Bannert & Krems 2013). A recent study involving professional drivers showed that professional driver training is associated with enhanced safety attitudes and less frequent self-reported risk behaviour. Concerning driver distraction and inattention, Regan (Regan, Lee & Young 2008, p. 559) stated that driver distraction, as an issue, has been largely neglected in the design of driver education and training programs. The same holds true for programs providing retrospective driver feedback targeting visual distraction and inattention. Although retrospective feedback has shown successful effects with bus drivers (Olsen & Austin 2001), short haul truck drivers (Hickman & Geller 2003) and truck drivers (Hickman & Hanowski 2010, Victor et al 2011), it has mainly targeted driving performance measures instead of visual behaviour measures.

In particular, retrospective driver feedback about *their own* errors has the potential to allow drivers to experience the consequences of unsafe behaviours. This was shown to lead to greater improvements compared to conditions in which drivers are only informed of possible driving errors or when no individual driving error were identified (Horrey, Lesch, Dainoff, Robertson & Noy 2012). McGehee, Raby, Carney, Lee and Reyes (2007) conducted a naturalistic driving study over 6 months and showed an 89 % decrease in the number of incidents for the more at-risk drivers when retrospective feedback was provided. Furthermore, a combination of concurrent and retrospective feedback resulted in 57 % reduction of crash (Hickman & Hanowski 2010). Toledo and Lotan (2008) investigated driving performance over a 5-month period as influenced by cumulative feedback presented on a personal webpage. Using this webpage, drivers could access the information on all their previous trips and also received information about performance of other drivers. Initially, feedback improved safety, but this effect diminished over time as drivers accessed their webpages less frequently. Wang, Lesch and Horrey (2009) examined whether feedback delivered at one timescale persisted through different follow-up intervals. In their study drivers received video-based feedback regarding their own simulated driving performance, with an emphasis on the contribution of dual-tasking to degraded performance. Perception and attitude toward cellular phone use while driving was investigated using a questionnaire before, immediately after, and one month following the testing. The feedback treatment group showed significant attitude change toward cellular phone use while driving (toward being less favorable), whereas the control group had no attitude change. At the one-month follow-up, the benefit of feedback was sustained. Self-coaching systems can improve safe driving behaviour by allowing drivers to review a record of their own driving activity. On-road risky driving behaviour was detected from driving performance signals (e.g. acceleration and brake pedal pressure, steering-wheel angle, velocity, and following distance) and was reduced by 50 % for non-expert drivers after receiving feedback about their own driving (Takeda et al 2012). A two-year follow-up study investigating customized training coupled with active learning in a driving simulator effectively improved driver scanning behaviour (Romoser 2013). Other examples of self-coaching systems as well as web-based training and their potential to counteract driver distraction can be found in Prahdan et al (2009), Robin et al (2005) and Gordetsky (2000).

In sum, safety training and education is a necessary, but not sufficient safety management technique. Drivers need the knowledge on how to drive safely and identify unsafe behaviors, but this does not imply that they drive safely. If a driver has no knowledge, he/she has a knowledge gap; however, if he/she has the knowledge but still engages in unsafe behavior, then it’s a motivation gap (i.e., “I know what to do, but I choose not to.”).

Model description

The DO-IT BEST Feedback Model is a model on ‘behavioural change’ which focuses on *providing the driver with both concurrent and deferred feedback about their own behaviour* by integrating ADAS and BBS approaches and their associated technologies. The intended goal is to encourage positive behavioural change over a plurality of timeframes, for instance: (1) immediate (e.g. short-term compensatory behaviours like changing braking behaviour, or aborting a complicated task), (2) trip (e.g. turning off mobile phone), (3) day to day (e.g. removing distracting devices from front seat), and (4) long-term (adoption of a different distraction attitude).

The main assumption of the DO-IT BEST Feedback Model is that once behaviour can be operationally defined, and reliably tracked, it can be influenced based on classic learning theories as mentioned above (e.g. Skinner 1953). Further, more specific assumptions were embedded in the development of the model. First, was assumed that drivers are willing to change behaviour, consent that their behaviour is monitored, recorded and reviewed. A second assumption was that technical equipment is sophisticated enough to reliably track, identify, warn and record certain behaviour as well as technical solutions exist that are capable to store, process, aggregate, analyze, visualize and display behavioural data. Third, it was assumed that after-market devices or in-vehicle information displays are sufficiently mature, safety analysts are well trained, safety managers well educated and safety educators sufficiently competent in order to provide feedback to drivers. A fourth assumption was that vehicle manufacturers will develop safe products and carry out research on products and services. Fifth, that traffic authorities will collaborate with research and industries and communicate guidelines and policies. The sixth and final assumption was that society is willing to create, to value and to maintain a safety attitude in the traffic environment.

The DO-IT BEST Feedback Model is divided into different areas (Figure 1) which are crash prevention strategies or safety behaviour feedback strategies. They are illustrated in a closed circuit as a “flow” (continuously ongoing). The source of the feedback is illustrated as part of the outer circle around these areas. Once a trip starts and no driver feedback on degraded driving or visual behaviour is detected, the driver is traveling safe (green in Figure 1). If the driver is distracted a ‘behavioural event’ is detected either by an ‘on-board driver monitoring system’ or ‘on-board driving performance monitoring system’. Behaviour events are for example a long off-road glance or lane departures. The driver is warned for the behavioural event and/or the event is logged to file and recorded for future analysis. Depending on the driver’s reaction, a behaviour event can either lead to a safe continuation of the trip (arrow in yellow area from behaviour event to trip end, Figure 1) or to a ‘near crash event’. Near crash events are behaviour events associated with an external event or consequence and are usually defined as an event whereby a vehicle comes “dangerously close” to another vehicle, object, person(s), or animal(s) (Hickman & Hanowski 2012). ‘Pre-crash mitigation and prevention systems’ such as Forward-collision-warning systems (FCW-systems) or Lane-departure-warning systems (LDW-systems) warn the driver immediately and/or the event is logged to file and recorded for future analysis and feedback. Again, depending on the drivers reaction, a near-crash event can either lead to a safe continuation of the trip (arrow in orange area from near-crash event to trip end, Figure 1) or to a ‘crash event’. A crash is usually defined as any occurrence involving a motor vehicle coming in contact with another vehicle, property, person(s), or animal(s) that resulted in human death, bodily injury, and/or any property damage (Hickman & Hanowski 2012).

The feedback in behaviour events and near crash events is defined as concurrent (ms) and/or delayed feedback (s). For both feedback types the source of the feedback is an intelligent monitoring device installed in the vehicle. As described above, the original DO-IT process is applied in an on-line driving setting wherein the safety behaviour feedback strategies *while* driving are:

D **Define target behaviour**

Target behaviour is for example defined as “poor timing of long off-road glance(s) due to distracting activities while driving”

O **Observe target behaviour**

Behaviour is observed by means of ‘on-board driver monitoring systems’ or ‘onboard driving performance monitoring systems’

I **Intervene to influence target behaviour**

Intervention is made by providing a concurrent (ms), or delayed (s) feedback such as a warning immediate or as soon after the target behaviour occurs

T **Test the measured effectiveness of the intervention**

Effectiveness is measured by measuring the consequences of the intervention such as total increased on-road glance time and/or reduction of lane deviation within a defined time after the warning occurred

The logged events are then aggregated and analyzed as a source for retrospective post-trip driver feedback (min, hours, days) or cumulative (weeks, months). This feedback can be carried out by a safety manager (Hickman & Hanowski 2010), a parent (McGehee, Raby, Carney, Lee & Reyes 2007) or an automated data algorithm software (Takeda et al 2012). The retrospective or cumulative feedback could include an analysis of the magnitude or frequency of distracting behaviour events which is displayed on an in-vehicle or portable device (e.g. in the instrument cluster or on a mobile phone application). Further, in a one-on-one feedback session, a driver receives direct feedback about his/her own behaviour events from a safety analyst and/or fleet manger. In one-on-one meetings behavioural events are examined and performance (attention) scores are reviewed. In this coaching session video events examples of risky behaviours (e.g. near-crashes or close following behaviours) and feedback on aggregated driving performance data (e.g. of last three months) is provided. The primary benefit of coaching sessions is that individual drivers are collaboratively engaged in the behaviour improvement process. In a personal plan, agreed upon goals and objectives for future trips can be negotiated. Alternatively, retrospective feedback could be provided by parents or through self-coaching software. As a further step, attention training in a driving simulator or on a test-track with or without a physical instructor providing guided feedback could be given. The role of driver education has been well established (see above). Safety education courses should target specific driver issues (e.g. driver overconfidence while using cell phones while driving) rather than driving skills in general which is the focus of traditional driver education.

The safety behaviour feedback strategies *before* and *after* driving described above usually fall in one of these four categories:

B **Behavioural check-ups**

Behavioural check-ups and feedback on target behaviours over an extended period of time (e.g. per trip, per day, per week or per month) with the option of comparing them to previous periods (e.g. "Today´s trip was x improved compared to yesterday´s trip")

E **Education**

Goal-directed safety education can include case studies or cognitive learning activities and knowledge on risk-perception, laws, policies and regulations

S **Safety benefit analysis**

Aggregated safety benefit analysis on a fleet, community and/or society level including the benefits on reduction of injuries, repair costs and/or insurance costs

T **Training**

Professional and/or informal attention training in a driving simulator and/or with a (web-based) self-training tool

Part of the crash prevention before and after driving can be seen as deferred feedback, such as safe human-machine interface design of ADAS and mobile communication devices. The source of the feedback is the manufacturer (vehicle or mobile device manufacturer) which design human-centered products. Real-life data records of a driver's reaction during behaviour events could lead to new conclusions regarding guidelines, hours of service regulation or cell-phone policies at a product development level. Deferred feedback also includes impacts on societal guidelines, policies, legislation, attitudes and infrastructure that restrict distracting behaviours while driving. In this case the source of the feedback is the society. The society has the potential to direct, for example attitudes towards cell phone use while driving which then in turn influences a driver's day-to-day habits.

The expected effects of the DO-IT BEST Feedback Model

The expected effects of the DO-IT BEST Feedback Model are similar to the safety effects of ADAS (real-time feedback) and BBS (aggregated feedback) but go beyond, because of the combination of ADAS and BBS. For a further description on how to combine ADAS and BBS as team players see Wege and Victor (in press). Possible safety effects could be based on enhanced self-awareness (Bandura) and self-reflection about distracting habits, driver calibration (Roberts, Horrey & Liang 2008) and different safety attitudes and responsibilities. The safety effects could be reflected in a reduction of injuries and fatalities as well as less repair costs for property damages along with less insurance costs.

Conclusion

The DO-IT BEST Feedback model is a model on how to *'encourage positive behavioural change'* over a plurality of timeframes on various impact levels. In this paper the focus is on strategies for preventing/mitigating adverse effects of (visual) distraction and inattention before, while and after driving. The target of the behavioural change is the *individual driver* and his/her behaviour (e.g. a habit of sending text messages while driving), cognition and attitudes (e.g. driver overconfidence while using cell phones while driving). It is assumed that, in order to achieve sustained change regarding safe glance performance, *a combination* of immediate driver feedback (ADAS) *and* deferred driver feedback (BBS) is most effective. In the model different *feedback timescales* (adapted from Donmez, Boyle & Lee 2008) and different *feedback sources* on the vehicle level, the aggregated performance level, the manufacturer level (automotive and telematics devices industry) and the society level are illustrated (Figure 1). In future research, the model clearly needs to be further validated. In particular, there are a number of open issues regarding empirical testing and analysis. Research is also needed to define further potential application areas both within the automotive domain (e.g. fuel efficiency management) and within other domains (e.g. global energy saving or healthier lifestyle).

The novelty of the model is that it further develops and integrates existing theories and research into *one holistic view.* Thereby the essence of effective ´behavioural change´ is to be found along lines of Aristotle's famous words *"The whole is something over and above its parts, and not just the sum of them all..."*

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CHAPTER 8 CONCLUSIONS AND DISCUSSION

8.1. Contributions

This chapter integrates the findings from the conducted research and discusses their implications for the development and implementation of ADAS and BBS in general and how they contribute to prevent distraction and inattention in particular. The chapter closes by indicating the limitations of the work as well as identifying future research needs.

Connected to the general aim of this thesis on how to improve safe driver behaviours by understanding their underlying psychological mechanisms, empirical assessments of two ADAS was conducted. Two empirical studies, one field operational test study and one driving simulator study, were carried out. The research included data collection and analysis from multiple sources such as extensive literature reviews, and statistical analysis of driving performance data, visual behaviour data, video footage, and subjective data. The analysis focused on the assessments of drivers responses (actual such as driving performance and visual as well as subjective). Safety relevant conclusions were derived from the results to guide future research and technology. Building upon the findings, a novel, holistic model on accident prevention was developed.

The main findings of the thesis include:

- A literature review on the diversity of theories, concepts and empirical research on driver behavioural adaptation to ADAS. This review included up-to-date conceptualization and terminology generation such as *behavioural change transfer (paper I)*.

- The evaluation of an on-market B-FCW on brake reactions and visual behaviour embedded in an assessment of driver distraction and warning predictability showed that drivers respond to a B-FCW as intended, however change their initial response. Based on the results the need for a guideline on safe interface design was formulated (*paper II)*.

- It was shown that VDA Systems can prevent visual distraction and inattention in situations they are designed for, both by inducing appropriate reactions to warnings, improving driving performance, and by provoking a subjective attention benefit. A VDA System was found to be an effective countermeasure, however not all warning algorithms were equally effective. It was found that a warning algorithm that provides warnings for both single long glances and glance history (a series of glances) warning algorithm (GHSG-warning algorithm) significantly improves attention on-road and driving performance and alters engagement in distracting tasks. In connection to this, it was found that false positive warnings do not influence behaviours (*paper IV*). The ability to detect the effects of false warnings on driver actual and subjective performance was demonstrated. Drivers showed a receptive attitude towards a reliable VDA System, demonstrating that such a type of support is well accepted and well perceived (*paper III*).

- A synthesis of research on ADAS and BBS resulted in the development of a novel BBS-ADAS approach which is expected to support long-lasting behavioural changes while providing both immediate behavioural feedback (ADAS) and cumulative feedback (BBS). The characteristics of the novel approach are presented in *paper V*.

- The DO-IT BEST Feedback Model, a holistic user-centered driver behaviour feedback model that expands on previous literature was developed. The model organizes the diversity of key developments and trends in accident prevention strategies before, while and after driving. It is a model that is equally relevant to researchers in academia, and human factors professionals in the industry (*paper IV)*.

Given these results, it is argued that the targeted intention of the thesis to analyze safe driver behaviours in the context of attention allocation and behavioural adaptation to ADAS was met. Before presenting the implications of these results on ADAS (interface) design, and the contributions to advance research in the field of traffic psychology, the results of the individual publications are discussed.

One issue is the proposition of an up-to-date definition of behavioural adaptation to ADAS (*paper I*). This definition should include that the behavioural change can be intended and wanted by the initiator of the change. This is in contrast to the OECD definition (1990) and also in contrast to for example Dragutinovic, Brookhuis, and Marchau (2004) or Rudin-Brown (2010) who focused exclusively on unwanted changes involved with ADAS usage. However, the consequences of ADAS use should not only be pre-defined as "negative consequences on safety", as they are now in the OECD definition. It is correct that ADAS can have negative consequences on adaptive behaviour. This is partially confirmed in the B-FCW study with regard to drivers taking their eyes off the road to look at visually presented warnings (*paper II*). However, "positive consequences on safety" also exist such as an increase in attention to the forward roadway right after a collision warning (*paper II*) or after visual distraction warnings (*paper IV*).

Contrary to the OECD definition being criticized about its applicability to recent research (discussed in *paper I*), the three main prerequisites to behavioural adaptation that the OECD definition presents, have proven to be essential in this thesis. The three main prerequisites are 1) the *presence of feedback* of a driver's behaviour, (2) a driver's *motivation to change behaviour* and (3) a driver's *capability* to change behaviour. All three are relevant for counteracting driver distraction and inattention.

The relevance of the *presence of feedback* was considered the backbone for effective distraction and inattention prevention. The particularities of safety behaviour feedback being an essential mediator in behavioural change was considered when developing the DO-IT BEST Feedback Model (*paper VI*). Due to its relevance, safety behaviour feedback was placed in the center of the model. In fact, as explained in *paper VI*, safety behaviour feedback should be provided at different time scales before, while and after driving.

The second prerequisite, *motivation to change behaviour*, can be enhanced by the society encouraging changing attitudes and norms which then feeds back to a drivers individual behaviour. It is expected that when a driver receives positive feedback on safe behaviours, he/she will, in turn, be motivated to continue to improve safe behaviours. The importance of the social norms should not be underestimated and thus, it was necessary to include them into the DO-IT BEST Feedback Model. Social norms, attitudes, guidelines and policies were classified as "deferred feedback" to the driver. Deferred feedback is the fifth type of feedback in the model. The model consists of a total of five types of driver feedback, whereas feedback types I to IV were based on (further adapted) the "information-processing model with temporal feedback" by Donmez, Boyle and Lee (2008). More detailed discussions on the relevance of a drivers motivation to change behaviour can be found in Haupt and Risser (in press).

The third prerequisite, the *human capability to change*, can be utilized and can be supported by *technology* that encourages safe behaviours and/or *post-trip safety information feedback* (e.g. delayed feedback in the DO-IT BEST Feedback Model) and/or *safe human-machine-interface design* (e.g. deferred feedback in the DO-IT BEST Feedback Model).

Overall, the prerequisites mentioned in the OECD definition were essential for developing the DO-IT BEST Feedback Model. Because the model plays a central role in this thesis it is presented in Fig. 6. As demonstrated in more detail in *paper IV*, the model expands on previous literature. Its main structure is based on the "conceptual framework on countermeasure technologies" by Victor (2012) in Figure 3. The main structure of the model arises from five main feedback time scales. The fifth feedback time scale, deferred feedback, was added in order to include feedback sources such as manufacturers and the society into the model. Other elements such as changes related to education, training, and enforcement of new in-vehicle technologies (e.g. publicity campaigns, or legislation) have not been addressed in behavioural adaption research before. By including these elements in the model, their importance in counteracting distraction and inattention is emphasized. It is speculated that modifications in guidelines, policies and legislations will have an impact on driver's interaction with ADAS over time, and therefore they were included in the model. And, vice versa driver's interaction with ADAS will have an impact on decision making among authorities – a speculation that needs to be investigated in further research.

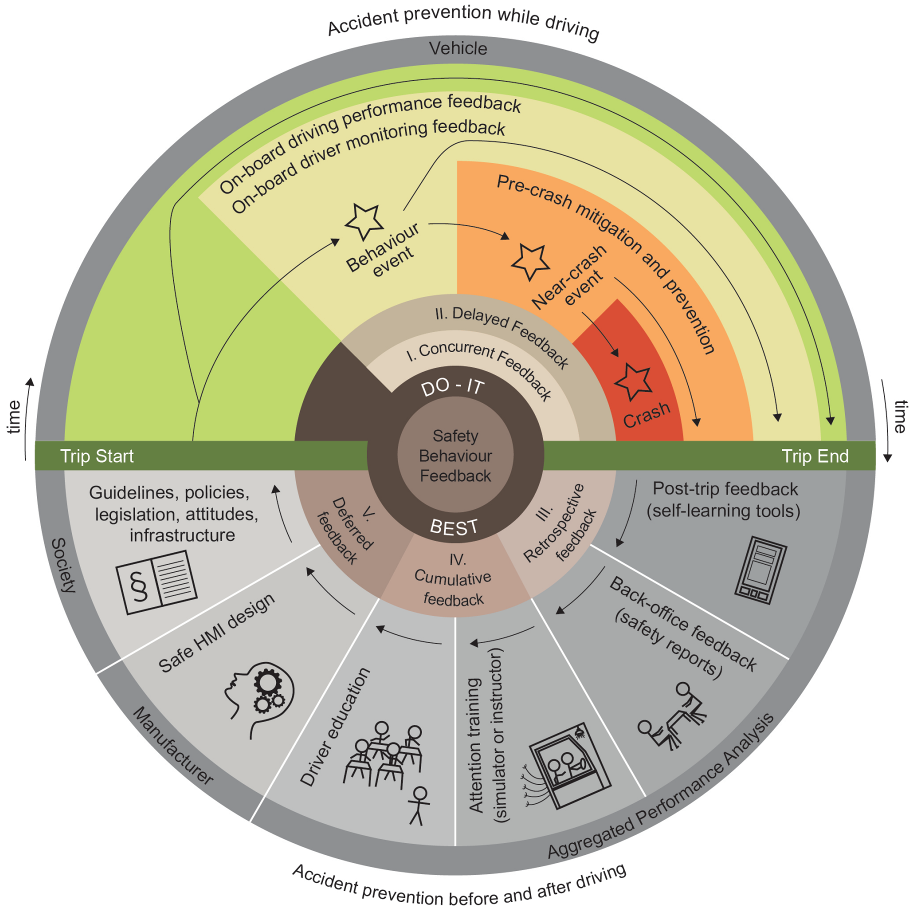

Fig. 6 The DO-IT BEST Feedback Model (*paper VI*)

In the behavioural adaptation literature review (*paper I*) it became evident that the concept of behavioural adaptation is a vague and slippery concept. The details and the relationships among contributing variables are complex and not well defined. It needs actual research on actual findings, perhaps like in this thesis, to define the concept of behavioural adaptation. If the concept of adaptation is not well defined, it might be overlooked by researchers when analysing datasets.

One example of a lack of a definition is the concept of *time* during which behavioural adaptation occurs. After what amount of time is an examined behavioural change considered behavioural adaptation? As it was discussed in *paper I*, the OECD definition does not identify a temporal or spatial range of behavioural adaptation. Because this is still unclear, for the purpose of this thesis the concept of *time in behavioural modification* was applied to the actual research in *three ways*: a) a behavioural modification following the initial behavioural response, b) an immediate behavioural modification once a system is activated and c) a behavioural modification that persisted when the system remained activated. In order to investigate these concepts, two evaluation studies were developed. They provided empirical assessments of drivers' responses (actual such as driving performance and visual performance as well as subjective performance). In what follows the three concepts are discussed in relation to the results of the thesis:

First, behavioural adaptation was considered as "*a behavioural modification following the initial response*", which means, as explained in *paper II*, drivers initially brake and look forward after receiving a B-FCW. However, drivers adapt their behaviour by looking away from the road to the location of the warning. The onset of the warning was defined as "threat-period" and the following behavioural adaptation occurred in the "post-threat recovery period". As the results indicate, the increased amount of eyes-off-road time during the post-threat-recovery-period might be the effect of two causes: (1) comprehension problems and/or (2) confirmation seeking. It can be argued that drivers feel the need for comprehension due to the loss of information after the collision warning was displayed. It can also be argued that drivers seek confirmation from the system that the threat is over. In order not to overlook a drivers behavioural change after an initial response, it is important to examine the "post-threat-recovery period" in more detail in future studies that investigate a warning systems effect.

Second, behavioural adaptation was considered as "*an immediate behavioural modification once a warning system is activated*". That means that a driver shows a change in driving performance, visual behaviour and engagement in secondary tasks when assisted with a warning system compared to when not being assisted with a warning system. That was the case in the VDA System study reported in *paper III* and *paper IV*. Drivers immediately attended the road, had fewer lane deviations and engaged less in distracting tasks when the VDA System was activated compared to when it was deactivated. These results give support to Evans work (see *paper I*) from 1985 who argued that for behavioural adaptation to occur, feedback from the road system change has to be perceived by the road user and that changes that are perceived quickly might result in faster behavioural changes. Because the distraction warnings provided by the VDA System were immediate warnings that were consistently provided in a relatively short time period (18 minutes) driver apparently were able to change the behaviour fast. A future study should investigate if the adaptation-effect persists even if fewer warnings are presented and if these warnings are spread out over a longer time period, such as several trips. An indication of the possible answer to this question can be drawn when looking at the results of *paper IV*. There, not only was it possible to observe a behavioural change immediate when the system was actiavted, this effect also *persisted when the system remained activated* for 18 minutes. This behavioural phenomenon was the third behavioural adaptation consideration (*paper IV*) of this thesis.

Equally important as the the concept of time in behavioural modification is if the *behavioural adapation is persistent after system removal*. Behavioural change can be observed when a previously assisted driver, continues to drive without being assisted. Thus far, the amount of research on ADAS that is based on an ABA-experimental design (control-treatment-control design) is small. This is surprising because as more vehicles will be equipped with ADAS, drivers might experience difficulties when using non-ADAS vehicles, for example as part of their job-routine (fleet vehicles, rental cars etc.). Recent ABA-design studies include the ones by Carney, McGehee, Lee, Reyes and Raby (2010), Dotzauer, Caljouw and Brouwer (in press) and Gouy (2013) reported in *paper I*.

The research presented in this work is evidence that behavioural adaption has a varied, vaguely defined scope. This thesis has attempted to find a common ground as is presented in *paper I*. Also, effort was made to identify the range of relevant internal and external factors associated with behavioural adaptation and to integrate them into one framework. Based on previous work by Popken (2006) it was proposed to include cognitive, motivational and energetic psychological processes into the framework. This conceptual framework represents the current status of a common view on behavioural adaptation within the ADAPTATION project (Wege et al., 2010). The framework also rounds up the literature review on theories and empirical research. Among the proposed psychological processes are specific phenomena, identified in the thesis. Understanding the influence of these psychological processes is important and needs to be considered in the ADAS design process. One such phenomenon is the ´need for comprehension´ after a visual warning diminishes, described in *paper II*). The ´need for comprehension´ was also expected to have an influence on driver’s adaptation processes when assisted with a VDA System. It was hypothesized that an intentionally simple warning algorithm (single glance warning algorithm) enables the algorithm to be more transparent and thus influences visual and driving performance more than a non-transparent warning algorithm (warning also for a history of glances). It was expected that, in order to achieve behavioural change it is important that the driver can figure out why a warning was issued at a particular moment. Additionally the driver must comprehend the warning algorithm to be able to modify the glance behaviour to avoid the warning. The driver needs to understand if a warning is issued because of a single long glance or as a result of a series of glances. Contrary to the expectations, a less transparent warning algorithm resulted in more percent on road time as well as better driving performance (*papers III and IV*). The information that the “glance history characteristic” adds to the “single long glance characteristic”, seems to be very important for the driver to time off-road glances. This can be interpreted as the “glance history” being closer to a drivers own feeling/own experience of what is “unsafe”. Subjective ratings confirm that the GHSG-warnings were easy to understand, as well as predictable and consistent. Clearly this points out that more research is needed to explain this finding. Nevertheless, phenomena such as ‘the need for comprehension’ should be taken into account when establishing future theoretical frameworks.

A clear effect of the VDA System on attention improvement, driving performance improvement and reduction in distracting tasks was observed in the driving simulator study. It is reasonable that an ADAS can better reduce the crash risk if the driver self-experiences their potential. The results of a large body of research investigating the relationship between visual distraction and driving control was replicated, such as the loss of forward attention corresponds to a deterioration of driving control (e.g. Regan, Lee, & Young, 2008; Regan, Lee, & Victor, 2013, Peng, Boyle, & Hallmark, 2013; Olson et al., 2009, Angell et al., 2006; Angell, & Lee, 2010; Carsten, 2005; Markkula, & Engström, 2006; Zhang, & Smith, 2004; Castro, 2012; Birrell, & Young, 2011, Engström et al, 2013). Glance history warnings coupled with single long glance warnings was identified as a successful warning algorithm. The present results support research by Kircher and Ahlström (2013) and Lee et al. (in press) that real-time distraction mitigation functions increase eyes on road time by alerting the driver of inappropriate visual behaviour as it occurs. Overall, this research area has an important contribution for identifying behavioural events to drivers, warning for an immediate response of attention allocation to the forward roadway and for selecting behavioural events to be recorded for later feedback. Despite unreliable warnings having a significant negative effect on system perception, they do not seem to have a noteworthy detrimental effect on objective data. These findings are in line with the results from a study on four progressively complex warning algorithms by Lee et al. (2013), where the Multi Distraction Detection algorithm showed the most promising effects. Comparing the subjective ratings with the objective indicators of the driving performance when the driver is distracted, the drivers seem to feel safer when they are assisted with the VDA System (resulting in more attention on road and better vehicle control), whereas false positive warnings are less preferred. These findings suggest that special attention should be paid to the drivers' subjective view on the effectiveness of a system in addition to the driving performance and visual behaviour effects. The subjective ratings point towards a considerable influence of the reliability of warnings, whereas the objective performance data point towards an influence of the warning algorithm. Both visual behaviour data as well as driving performance data confirm the relevance of the warning algorithm, an effect that was previously not found in the subjective ratings. As a consequence consideration should be given to multiple data sources (visual data, driving data and subjective data)

The results of the VDA-study showed that concurrent driver feedback increases eye-on-road time. However, the mechanisms explaining *why* real-time distraction mitigation functions are effective have not been examined in previous literature, as was attempted here by examining transparency and reliability. It can be expected that the *mechanisms* that play a role in the effectiveness of human feedback guides behavioural change. Hence, it was important to better understand humans underlying psychological mechanisms when provided with feedback. Two possible approaches could serve as partial explanation for the current results:

One explanation is related to research that advanced from operational conditioning (Skinner, 1953), social cognitive psychology (Bandura (1986, 1997) and the psychology of safety (Geller, 2001). Among others, Skinner, Bandura and Geller found that feedback is most effective when provided while the target behaviour occurs. In this thesis, it was shown that immediate feedback is important, and it was speculated that additional delayed cumulative feedback would have a larger effect. This needs to be confirmed by actual BBS related research in the context of VDA

Systems and/or B-FCW systems. However, how “immediate” should the “immediate feedback” on target behaviour be? Considering visual warnings that take into account a drivers’ glance *history* (within a length window of 17.3 s) as not immediate feedback, one might need to re-think the relevance of immediate feedback. Perhaps it is of more importance to “correct” for the right behavior at the right time. This argument should be further investigated in a study which includes a “glance history warning algorithm in absence of a single long glance warning algorithm. That means that instead of combining glance history warnings with single long glance warnings (GHSG-warnings) as in this thesis, one should have three warning algorithms: SG-, GH- and GHSG-warnings.

The other approach that could help in understanding the mechanisms of behavioural change is research in the field of Cognitive Behavioural Therapy (CBT). CBT is a psychological therapy approach with the most solid and widest evidence base for efficacy and effectiveness in modifying behaviour. It is proven to induce behavioural change since many decades. Beck (1963, 1964) was among the first addressing behaviour modification linked to cognitive processes. Connected to this is an initial *cognitive adaptation* process prior to behavioural change. Because the main working principles of CBT could partially explain the effects found in *papers III and IV*, a future publication (Wege, & Victor, in prep) will focus on comparing the principles of real-time driver feedback technology to the principles of CBT. The seven basic principles of CBT are: the problem-oriented principle, the cognitive principle, the behavioral principle, the ‘here and now’ principle, the ‘putting into practice’ principle, the ‘measurable’ principle and the ‘therapeutic relationship’ principle (Westerbrook, Kennerley, & Kirk, 2007). Putting CBT in the context of behavioural adaptation to ADAS means that a cognitive change (cognitive adaptation) prior to a behavioural change (behavioural adaptation) is necessary in order to ensure long-term effects on safe behaviours. As such, it could be argued that effective driver distraction prevention might involve a paradigm shift from “safer driving” to “*safer thinking*”. Awareness of a behavioural event (e.g. taking the eyes off the road) is an important initial step for a behavioural change during which a drivers perception of own at-risk behaviour can change. The goal of attention feedback is thus to encourage positive behaviour change by increasing driver awareness, driver perception and driver judgment about off-road glances by thus enabling behavioural change. To validate this assumption, the perceived performance and the actual driving performance of distracted drivers driving with and without a VDA System should be more thoroughly compared. And it should be investigated if a concept like cognitive adaptation exists, and if so, if it plays a role in self-monitoring or self-management processes. It could be possible that processes like cognitive adaptation results in sustained behaviour improvements.

The importance of *sustained behaviour improvements* was discussed in *paper V*. Driver distraction and inattention countermeasures such as a VDA System may or may not result in sustained behaviour improvement. It was therefore investigated why ADAS may not result in sustained behaviour improvements when implemented in the absence of a BBS program. To explore the possibilities of ADAS *beyond* their current functionalities, a novel approach to provide behavioural feedback was described in *papers V and VI.* This novel approach is the BBS-ADAS approach. The BBS concept, a successful concept to improve safety behaviour in industrial work setting since many decades, was transferred into the automotive domain. By this, the original BBS principles by Geller (2001) have been adopted to be applied to driver feedback to enhance attention on road. The BBS-ADAS approach is expected to complement shortcomings that both individual ADAS and BBS approaches have. With the BBS-ADAS approach, the analogy of team-play was used to illustrate how both approaches can be members of the same winning team on the attention enhancement playing field (*paper V*). For a joint BBS-ADAS concept to operate successfully, immediate and aggregated feedback should be conceived and designed as ‘team players’. In the future, ADAS designers and developers, as well as safety management developers, need guidance on how to support the coordination between ADAS and BBS. Furthermore, the mechanisms and ‘game rules’ need to be defined in order for both team players to cooperate. According to ‘team play’ theory, good and effective team players make their activities observable for fellow team players, communicate together, and are easy to direct. One example of how to coordinate ADAS and BBS is the implemented in the DO-IT BEST Feedback Model (*paper VI*).

8.2. Implications

The present research contributes on a theoretical and applied level. From the assessment of the actual field data (*paper II)* and driving simulator data (*papers III and IV*) implications on how to improve safe driver behaviours followed. The first set of implications is on (A) safe ADAS interface design, the second set of implications is on (B) the development of safe ADAS warnings, the third set of implications is on (C) general safety management, and the fourth set of implications is on (D) advances in traffic psychology research. They give valuable guidance on which issues should receive particular consideration in future research.

A. *Safe ADAS interface design implications:*

- By reference to the results obtained during the post-threat-recovery period (PTRP) (*paper II*) which showed a significant influence of the warning presentation on drivers behavioural response, this work shows that special care should be given to the interface design when providing drivers with collision warnings. A visual warning presented in the instrument cluster might be problematic due to various reasons presented in *paper II.*
- Due to the fact that during unpredictable events and during events when the driver is distracted, glances to the instrument cluster increase, there is reason to consider how current HMIs of on-market B-FCW systems could be redesigned. The results seem to support recommendations to place B-FCWs close to the source of the hazard and not in the instrument-cluster
- Human Factors Specialists should anticipate potential conflicts arising after the threat-period (e.g. ‘need for comprehension’)
- Identification of research needs such as to investigate if similar responses as found to B-FCWs are to be found with other ADAS

B. *Safe ADAS warning development implications:*

- A key finding was that a VDA System successfully assists drivers in redirecting attention to the relevant aspects of the driving task and by that driving performance is significantly improved.
- In particular, the results on attention improvement indicate that glance history warnings coupled with single long glance warnings is a successful warning algorithm for a VDA System.
- Despite unreliable warnings having a significantly negative effect on system perception, they do not seem to have a noteworthy negative effect on objective data.
- As argued for the VDA System, a well-accepted warning system could lead to longer-lasting improvements to stop driver distraction (e.g. to stop using a phone while driving) and to an overall more cautious behaviour reducing the amount of eyes off the road.
- Identification of research needs such as validating the results of the VDA-study in on-road naturalistic driving studies

C. *Broad safety management implications*

- Clearly communicated explanations of an ADAS function should be essential prior to system usage, in order to prevent drivers from seeking information about warnings during driving (paper II)
- ADAS such as VDA Systems or B-FCW systems can significantly benefit by combining them with a BBS program The BBS-ADAS approach was identified as a holistic behavior based feedback process which is assumed to result in a large safety improvement beyond the effect of ASAS effects alone. One example of a BBS-ADAS technique: weekly performance feedback (e.g. BBS in form of aggregated attention scores) in combination with ADAS warnings *coupled with* BBS one-on-one coaching (e.g. top prioritized risky behaviours previously identified in meetings) used as input for personalized ADAS warnings (paper V)
- Key developments and trends in accident prevention strategies before, while and after driving have the potential to be, as a whole, a more effective safety management strategy. The DO-IT BEST Feedback Model is a holistic user-centered driver behaviour feedback model that is relevant to researchers in academia, and Human Factors Specialists in the industry (*paper IV)*.
- Identification of research needs such as: “How accepted are the feedback summaries of attention and driving performance provided to the fleet safety manager, employers or parents?”

D. *Traffic psychology research implications*

- On-road field operational test studies can obtain valuable insights in driver responses to warnings in a way that was not intended by the system developers.
- It is recommendable to evaluate the HMI of ADAS in two separate analysis steps: threat-period during a warning and the post-threat-recovery period immediately after a warning

- ADAS user testing in a within-subject experimental design is suitable to acquire knowledge on behavioural adaption effects in various performance measures (vehicle control, visual behavior and subjective performance)
- Research questions on drivers responses to new in-vehicle technologies can be generated by using the "Joint Conceptual Theoretical Framework (JCTF) of Behavioural Adaptation in response to Advanced Driver Assistance Systems" which identifies relevant internal and external factors associated with behavioural adaptation
- Novel input on concepts like behavioural transfer and behavioural adaptation to new in-vehicle technologies are needed

8.3. Limitations and research needs

In the following, some limitations of the thesis as well as further research needs are identified. To begin with, ADAS of various kinds, and particularly on-board driver monitoring systems, have only been emerging the market in recent years and most of the technologies are still in the development stage. The findings of the present work indicate that it is important to further develop B-FCW systems and VDA Systems. Furthermore, it is important to beare in mind the specific experimental settings of the studies. In the B-FCW study, as it was a field study, the drivers showed (assumingly) very natural responses in their daily driving environment, however the VDA System study was an experimental study in a controlled simulated environment. Both types of experimental settings, simulator studies and naturalistic driving studies, have advantages and disadvantages (for a discussion on behavioural change in laboratory settings vs. naturalistic settings see Dotzauer et al., in press). On the one hand, as presented in *paper II,* naturalistic observations have strong construct and face validity for the following reasons: first, important information lies within the complex circumstances and scenarios that lead to real world warnings. Second, naturalistic observations are collected in the setting in which the behavior of interest occurs, for example it is difficult to attain "true distraction" in an (semi-) artificial setting (Ahlström et al., 2011). Third, no matter how realistic a simulated setting is, artificial collision events do not replicate the same amount of risk inherent in a collision on an actual highway (Eby, 2011; Lind, 2007). Fourth, in naturalistic driving studies the tested sample of participants is usually an actual system user, for example commercial truck drivers, who show a unique interaction with the device (Hanowski et al., 2007).

On the other hand, the driving simulator has traditionally been the most appropriate setting for testing new technologies and their effects on driver behaviours and attitudes (Huth et al., 2012). Not only does the driving simulator allow to create extended periods when the driver is distracted, but also any risk for the driver and other road users are avoided (Chang et al, 2006). In a next step, it will however be necessary to replicate the results obtained in the VDA System study in test track studies and/or on the open road. In this regard, the drivers' attitudes and assessment of the VDA System may come closer to what can be expected when the system is on the market. Real-world testing of the VDA Systems should include testing of drivers actual need for warnings in comparison to the degree of disturbance and/or annoyance the warnings might cause. Naturalistic driving studies could also investigate practical issues. For example, as drivers apparently have ´need for comprehension´, do informing systems require a training phase so as to fully reach their assistive potential? Do drivers need an ADAS learning phase in order to benefit from assistance by a warning system?

One particular advantage of naturalistic driving studies is the possibility to assess behavioural changes over an extended period of time. It is therefore suggested that, at a later stage, the long-term effects of the B-FCW usage and long-term effects of the VDA System usage should be investigated. In this regard, valuable information on how drivers behaviours evolve over time when getting more familiar with the ADAS.

Regarding the relevance of reliable warning systems, more research is needed e.g. “Is it true that drivers accept an imperfect system?” The results of this thesis (*paper IV*) point out that drivers accept a VDA System even if imperfect, which is a confirmation of findings from the SAVE-IT study (Donmez, Boyle, Lee, & McGehee, 2006). An interesting aspect that should be evaluated is that probably with more advances in technology, ADAS might become even more reliable than they already are today (less false positive warnings). And, with possibly better driving through BBS, the frequency of warnings will probably decrease. A warning might become a very rare event. As such, when it appears in really critical moments, will drivers know what to do? In other words, is it possible to adapt to very rare events?

Although in *paper V* it is clearly indicated that the BBS-ADAS approach would complement each other, more solid evidence has to be sought in extensive experiments on the BBS-ADAS approach. As such, the possibilities of the BBS-ADAS approach as a holistic driver feedback process should be further explored. For example, in other areas that the DO-IT BEST Feedback model can be applied to, for example better fuel consumption in vehicles. Probably the most crucial of all limitations is the fact that the model has not been validated on empirical data such as questionnaire data from user tests, which allows determining the true safety benefits of the model. Moreover, future research should investigate the extent of the relation between the accident prevention strategies in the model. There is a need for more detail among the elaborations that support each accident prevention strategy and for unambiguous and traceable references. One particular concern is that precise assessment of *the practicality* of some strategies are still needed. Just to mention a few examples: “Can safer driver behaviour be encouraged involving in-person meetings?”, “How accepted are feedback summaries of attention and driving performance that are provided to the fleet safety manager, employers or parents?” And connected to this: “What are the legal issues concerning ethical problems when storage private data?”

Another limitation concerns the transferability of the present results to other ADAS. Future studies should investigate if similar phenomenon of drivers ‘need for comprehension’ are to be found in other warnings systems presenting visual warnings as well. The phenomenon was found in the B-FCW system study, however not in the VDA System study. The drivers using a VDA

System found the warnings understandable. This might be an artefact many product assessment studies in simulators carry with them.

Even though the problem of driver distraction and inattention is high on the political agenda (e.g. Engström et al., 2013), there are not yet well established standards for B-FCW and VDA System design. In order to counteract the contributing factor of "distracting ADAS", design guidelines are beginning to catalogue the range of display issues that need to be considered in the design of in-vehicle information systems (NHTSA, 2012; Campbell et al., 2007). The following principles for in-vehicle information systems have been identified being important in the design and evaluation of in-vehicle telematics: compatibility with driving; simplicity; consistency and self-descriptiveness (ISO EN ISO 15005, 2002). NHTSA (2013) has recently published guidelines for in-vehicle electronic devices wherein it is recommended that devices shall be designed for drivers to complete a task while driving with glances away from the roadway of 2 seconds or less and a cumulative time spent glancing away from the roadway of 12 seconds or less. Additionally the European Statement of Principles (ESoP, 2009), the Alliance of Automobile Manufacturers guidelines (AAM, 2010), the Japan Automotive Manufacturers guidelines (JAMA, 2009) and international standards (ISO EN ISO 15005, 2002; SIS-ISO/TR 16352, 2006) are published. However, well developed guidelines and HMI standards specifically for ADAS are still needed. For a more detailed statement of importance of guidelines and standarts on safe ADAS HMI see ITU-T Focus Group on Driver Distraction report 2013

The results of the VDA System study (*papers III and IV*) need to be consolidated with more extensive studies in real driving environments, dedicating efforts on the adjustment of the GHSG-warning algorithm. The systems need to be (technically) optimized in order to enhance user acceptance. Therefore, further development of the warning algorithm is necessary. Although this work clearly indicates that the SG-warning algorithm is less effective than the GHSG-warning algorithm, it would be convenient to confirm this result in further studies (e.g. by setting a new threshold such as 3.0 seconds) before dismissing this warning algorithm completely. Additionally, the issue of warning type on a distraction warning should not be underestimated. In the conducted study the warning algorithm that improved attention allocation most effective was a glance history warning *coupled* with a single long glance warning. The glance history warning was never provided in the absence of single long glance warnings– a shortcoming that was later compensated in the study by Lee et al. (2013). It is noteworthy to mention that even tough false positive warnings were found not to be an issue for the subjective performance ratings and system acceptance ratings, clearly, for real-world ADAS application a general principle the rate of false warnings should be low (ECE, 2001).

Studies found that an estimated 80 percent of near-accidents are forgotten after two weeks (Chapman, & Underwood, 2000). This suggests that a drivers' memory of their glance and driving performance needs to be refreshed retrospectively. Drivers might have forgotten about the warning which identified a behavioural event previously. McGehee, Raby, Carney, Lee, and

Reyes (2007) conducted a naturalistic driving study over the period of 6 months and showed an 89 percent decrease in the number of incidents when retrospective feedback was provided.

The detection of the nature of dangerous glances is expected to guide crash research in the future. The prediction of crash risk coupled to off-road glances has been studied in simulator experiments (e.g. Ahlström, Kircher, & Kircher, 2001; Pradhan et al., 2005) as well as recently in field operational test studies (Liang, Lee, & Yekhshatyan, 2012).

More work is needed with larger naturalistic driving datasets to examine the relative contributions of the single off-road glance and the effect of glance history (for example by removing the last glance from the analysis). The outcome of this analysis has major implications for the targeted countermeasures.

The common criticism on VDA System technology is that drivers may use such systems as an ‘alarm clock’ to keep attention. Vincent, Noy, & Laing (1998) presented a study showing that heavy truck driver’s use unpaved shoulders (or rumble strips) in such a way. They state that such unintended use of fatigue warning systems is an instance of behavioural adaptation. Drivers might also consider pre-crash mitigation systems such as a FCW-system as a watchdog for last-minute crash-intervention and do not actively change their behaviour. The purpose of ADAS should not only be a watchdog as pre-crash mitigation technologies would (orange area in DO-IT BEST Feedback Model, Fig. 6) but could warn much earlier in the trip cycle for inappropriate behaviors such as a VDA- system (on-board driver monitoring system) would (yellow area in model). The main purpose of the visual distraction alert is to help distracted drivers to realize that they are being ´tricked´ into glancing away from the road for too long and/or too often. The alerts should train them to recognize a limit of inattentive glance behaviour. As such it is a preventative warning system without direct coupling to near-crash situations.

There is a need to continue to study the potential of driver feedback to induce safer glance and driving behaviour. Poor feedback about how distractions affect safe driving leads drivers to believe their driving performance is better than it actually is (Horrey et al., 2009). Drivers overestimate their ability to multitask, even though they are aware of the risks involved and report concern about the dangers of others doing it (Regan, 2010). Drivers may not realize the potential hazards created from decisions to engage in a distracting activity, may not always make the safest choice in doing so, and often experience no negative consequences for a poor choice (Donmez, Lee, & Boyle, 2008).

Provided that a VDA System provokes safer behaviours, at least regarding the situations it is supposed to tackle, the objective should be to induce the driver to keep the system active during the highest possible share of their driving time. From previous research by Victor et al. (2010) we know that drivers see a need for a VDA System. A well perceived VDA System, however, would probably offer the possibility to activate and deactivate the system at any time. However, taking into account that drivers underestimate the risk of distraction (Horrey et al., 2008) and think their driving performance is better than it actually is (Horrey, 2008), and that the need to be warned precisely exists in those situations, it is worth aiming for a permanent use of the VDA System and hereby increase its safety potential. A system acceptance model on Advanced Rider Assistant

Systems (Huth, Biral, Martín, & Lot, 2012). Huth et al. identify promising starting points for the enhancement of the acceptance of assistance systems, leading to higher usage rates. As such, personalized warning thresholds, customizable interfaces etc are proposed to increase drivers intention to use the system during most of their trips. Distraction-adaptive collision warnings adjust the timing and/or intensity of warnings, such forward collision warnings, on the basis of whether or not the driver is attentive to the roadway. Such a system, can give additional safety benefits like or reducing false warning.

The specific needs of distracted drivers should be carefully addressed regarding practical issues. In that context, it could be a problem for drivers to feel annoyed or disturbed by the VDA System warnings. Despite the criticism on drivers reliance, drivers workload might increase. However, Birrell and Young (2011) showed that real-time delivery of driving information did not increase driver workload or driver distraction. The positive findings on acceptance of the VDA System (even when unreliable warnings are provided) might be due to a generally positive attitude towards any technology in general and new assistant systems in particular.

It is noteworthy to mention that this thesis followed an academic research approach rather than an engineering approach. The *human* (responses and activities as well as capabilities and constraints) was in focus when investigating human-machine interactions. Ultimately, it is the human that is responsible for designing *and* operating machines. Any gain in terms of safety is induced by technology however processed and learned by the human.

In closing, as this thesis presented the research findings on how to prevent driver distraction and inattention within the driver behavioural adaptation context, it should be mentioned that various countermeasures have great safety potential and thereby: the future driver will most certainly be assisted by one or the other of the presented countermeasures – either related to ADAS technology and/or related to behaviour-based safety. It is hoped that the present findings will advance academic research in the field of traffic psychology and facilitate practitioner to better design safety systems with the human factor in focus. Above all, a driver's *"adaptive eyes"* are essential for the ability to adapt to new technologies in the future. A driver's *"adaptive eyes"* are the key to support this decade of action for road safety (WHO, 2013).

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CURRICULUM VITAE

Claudia Andrea Wege

Date and place of birth: 13. August 1984, Burgstädt Nationality: German

Work Experience

2010 -	Human Factors Specialist Volvo Technology, Volvo GTT, Göteborg, Sweden
2009 - 2010	Scientific Researcher Chemnitz University of Technology, Germany
2006 - 2009	Scientific Research Assistant Chemnitz University of Technology, Germany, and University of Oklahoma, USA

Education

2009 -	PhD (Dr. rer. nat.) Chemnitz University of Technology, Germany, and Volvo Technology, Volvo GTT, Göteborg, Sweden
2009	Master in Psychology (Dipl.-Psych.) Chemnitz University of Technology, Germany, and University of Oklahoma, USA
2004	Diploma of Graduation (Abitur) J.-W.-v.-Goethe Gymnasium Chemnitz, Germany, and Stockdale High School Bakersfield, CA, USA

Scholarships and Honors

2010 - 2013	Marie Curie Research Fellowship of Excellence Scholarship, European Union 7th framework program
2006 - 2007	DAAD – Scholarship, Federal Republic of Germany
2006	Honor Student University of Oklahoma, USA

EIDESSTATTLICHE ERKLÄRUNG

Hiermit erkläre ich, Claudia Andrea Wege, geboren am 13. August 1984 in Burgstädt, dass ich die vorliegende Arbeit selbstständig verfasst und keine anderen als die angegebenen Hilfsmittel verwendet habe.

Claudia A. Wege

Göteborg, Oktober 2013

"For hitting a home run your eyes need to look where the ball is going to be, not where it is nor where it has been!" [*]

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Picture on front cover: The DO-IT BEST Feedback Model (Wege, & Victor, 2013)

[*] Bahill, A.T., & Laritz, T. (1984). Why can't batters keep their eyes on the ball? *American Scientist, 72*: 249–253.