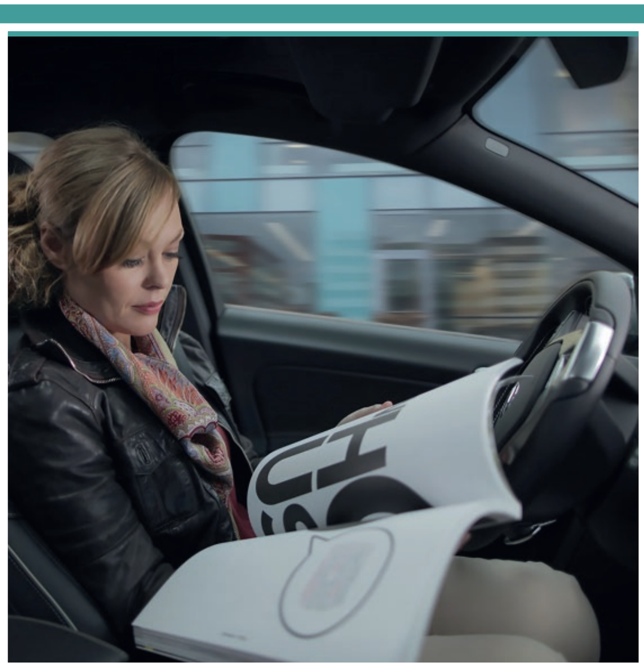
THE 6TH INTERNATIONAL CONFERENCE ON DRIVER DISTRACTION AND INATTENTION

DDI2018 GOTHENBURG

BOOK OF ABSTRACTS



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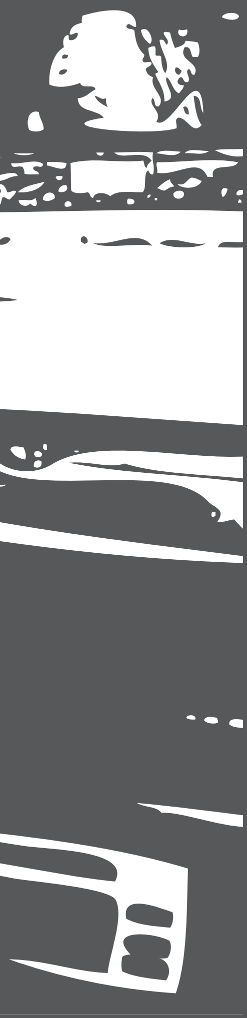

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Different Types of Distraction Causing Accidents

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Keywords: Accident; Accident Causation; Distraction; Five-Step Method; Information Reception

EXTENDED ABSTRACT

Introduction

More and more studies constitute that crash causation has shifted in the past years towards more driver-related factors [1]. Distraction is one of the main reasons to cause accidents. Researchers estimate that the crash risk doubles due to distraction [1]. However, the scope of the estimated contribution of distraction to accidents varies between a few percent to over fifty percent [2]. Besides studies that use data from naturalistic driving studies [1, 3], some studies are based on data from police accident reports [4, 5]. Other sources of information are observational studies that mainly focus on the use of cell phones [3, 6] and studies using questionnaires [7]. However, those kind of studies do not have a direct reference to crash causation. Accident research offers a better opportunity to identify accident causes.

Audi Accident Research Unit

Focused on the objective to enhance general road safety the Audi Accident Research Unit (AARU) was founded in 1998 as an interdisciplinary research project of the Regensburg University Medical Center in cooperation with Audi. The project is supported by the federal state ministries of Bavaria. The AARU team includes engineers, physicians and psychologists engaged with in-depth accident analysis. Each accident supplies approximately 2,000 technical, medical and psychological data. For the psychological research subjective information from accident participants regarding the pre-crash-phase is gathered using standardized telephone interviews. This data is matched with objective information from technical accident reconstruction to get a deeper insight into the course of the accident as well as the accident causation.

Accident causation

The extensive interdisciplinary approach is a unique feature of AARU. Due to this interdisciplinary analysis, it is possible to get objectified accident causation codes based on the five-step method [8, 9, 10]. This coding system is based upon the human errors taxonomy of Rasmussen [11] and the subsequent adaption of this taxonomy by Zimmer [12] and was conducted in collaboration with GIDAS (German In-Depth Accident Study).

The basic assumption of the accident coding process is that the causes could have come from three different areas: human factors, technology and the environment. Within each of the three groups, there are also specific subcategories of causation. For instance, accidents caused by human factors can be divided into five different categories: information access, information reception, information processing, objective and action. These five categories are based upon the sequential perceptual process, from perception to action. This method of classification highlights the exact location of the error in the perceptual process (e.g., the driver did not perceive the necessary information although it would have been available). Each category itself can also be divided according to the reason that led to the error in the accident sequence. For example, the reason for a problem within the information reception might be that the driver was distracted inside the vehicle. Finally, the last level of the accident causation code describes the reason for the error, being as specific as possible (e.g. the driver was distracted through a conversation with a passenger). Using this process there are more than 180 different codes to describe the causation of a traffic accident. Up to three accident causation codes can be encoded for each accident participant. Therefore, this causation code system enables the accident researcher to describe causes of the analyzed accidents in a very detailed manner. On the other hand, if there is not enough information to describe the accident causation in detail this procedure allows a more general approach, too. In case of a lack of reliable information, there is the possibility to attribute the error to at least one of the three main areas without any further classification.

Results

By now, there are more than 1,200 in-depth analyzed accidents within the AARU database using the five-step method. The purpose of this paper is to give a general overview of all encoded accident causation codes and to focus on the role of distraction. Hence, the analysis includes all codes of each accident participant, because in some cases more than one error contributed to the accident.

First results show that less than four percent of the accident causation codes are assigned to the main area of the environment. On the contrary, errors due to human failure account for almost ninety-five percent. However, in almost a fifth of the causation codes the data reveal a human error without being able to classify the human error in detail. The analysis of the accidents with a detailed coding among the five categories of human failure reveals that the main reason why accidents happen is due to problems within the information reception. In more than fifty percent of these accidents, the information that would have been necessary to prevent the accident was available, but was not perceived by the drivers. One of the reasons why the drivers did not perceive the information is distraction. However, there are three types of distraction that can be differentiated as influencing criteria within the category of information reception: distraction inside the vehicle, distraction outside the vehicle and mental/emotional distraction. Besides those criteria, there are three more that could lead to an error in this category: activation too low, incorrect identification due to excessive demands and inappropriate focus of attention.

Further analysis of the AARU data shows that the main reason for an error in the information reception is due to a lack of activation. More than twelve percent out of all accident causation codes fall into that category. The two most important influencing factors are alcohol and fatigue. With more than eleven percent out of all causation codes, distraction is the second most frequent reason for an error in the information reception. Of the three types of distraction, distraction inside the vehicle is the most common cause. The sources of this kind of distraction are mainly passengers and operation of devices. Mental and emotional distraction was encoded less frequently, but had a larger share than distraction outside the vehicle. However, there are quite a few accidents where the information gathered from and about an accident participant only enables to encode an error within the information reception without any further classification. Therefore, the number of accidents that happen due to distraction might be even higher assuming that a driver causing an accident due to distraction might not always admit that he or she had been distracted.

Conclusion

The data collected by AARU shows that most of the analyzed accidents happen due to human failure. Within the human perception process, errors in the information reception are most common. The dominant error consists in a lack of activation. Distraction is the second most frequent reason with a large share of distraction inside the vehicle. However, since there are quite a few cases in the database where a detailed encoding was not possible due to the information provided the impact of distraction might be even higher. Compared to studies using naturalistic driving data, accident research has the disadvantage that it has to rely on the reports of the accident participants. On the other hand, compared to studies using police reports the information gathered from the accident participants are more reliable and honest due to a very high level of confidentiality within the research project. Based on the interdisciplinary approach the AARU is able to validate the reports of accident participants with objective information. Hence, this way of research offers a very good insight into the causation of accidents.

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Using counterfactual simulations to evaluate the impact of drivers' glance behaviors on safety: A study of between-driver variability

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Keywords: Counterfactual simulations, driver variability, crash risk, glance behavior

Introduction

Counterfactual (computer) simulations is a new method to evaluate how driver behaviors, such as driver glance behavior during interaction with driver-vehicle-interfaces, may affect safety outcomes [1, 2]. Kinematics (positions, speeds and accelerations) from real-world crashes and/or near-crashes are typically the core of such simulations. These are used together with counterfactual behaviors, for example, driver evasive maneuvers (e.g., braking) are removed from the original event's kinematics, after which counterfactual (what-if) behaviors is applied instead (e.g., an off-road glance is placed at an inopportune time). The simulations using the kinematics with replacement behaviors, together with mathematical models of driver reactions to critical situations, provide insights into what the original situation could have been, had drivers acted differently [2-4].

In this paper, kinematics from crashes and near-crashes from the Second Strategic Highway Research Program [SHRP2; 5] naturalistic driving data were used together with a set of driver glance-behaviors associated with secondary tasks, acquired in an on-road experiment.
The paper's main objectives are to demonstrate, and propose a method for, the evaluation of the effect of glance behavior variability on secondary task safety-impact estimates. The paper thus addresses methodological aspects and previous critiques of rulemaking and guidelines [6].

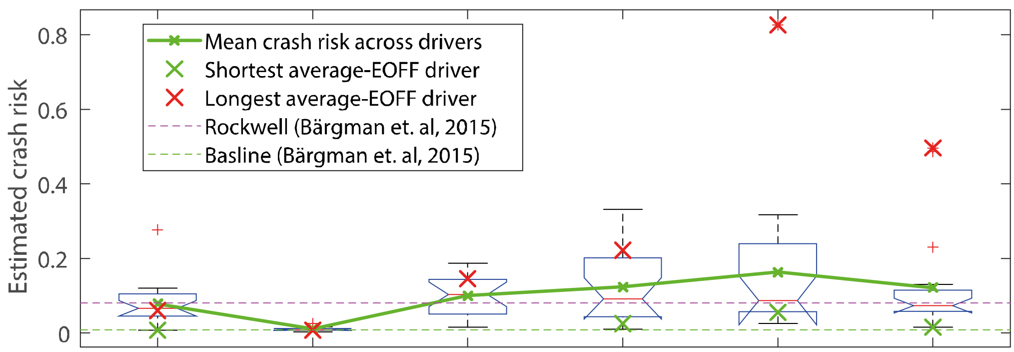
Method, materials and analysis

This study used the same SHRP2 dataset of 46 rear-end crashes and 211 near-crashes, and the same counterfactual method as was used in [2]. Using this method, each set of glance behaviors (i.e., glances during secondary tasks) produced one single estimate of crash risk. This risk can be interpreted as the probability of a crash, if a random safety critical event occurs (e.g. a leading vehicle suddenly brakes hard) when the driver is engaged in a task/glance-behavior. Each task's glance behavior is described by an off-road glance distribution (EOFF), percentage of glances that were on road during the task (%EON), and the total task time (TTT). The estimated crash risk is the mean of the risk of crashing across all the 257 crashes and near-crashes, if the tasks were performed with the glance behavior data.
Glance behaviors from five secondary tasks were collected in an on-road experiment by Volvo Car Corporation during 2016. Twenty test participants performed five secondary tasks on a motorway alone in the vehicle. One of the tasks was a manual radio tuning task (modern radio, hereafter called ManualFM), here used as a reference task. The other four tasks were selected to give large between driver variance and thus test the capability of the counterfactual method. Participant selection criteria followed the "test participant recommendations" in the NHTSA guidelines [6]. Glances were determined by human review and annotation of videos of the driver. In addition to the secondary task glance behaviors, glance behavior of baseline driving, where no specified secondary task was performed, was used as a reference. Three sets of

counterfactual simulations where performed. First, simulations were run where the crash risk was estimated using the aggregate glance behavior across all the 20 drivers, for each task. Second, the crash risk was estimated (though counterfactual simulations) for each driver's individual glance behavior (distribution and %EON), for each task. A high-risk and a low-risk driver's crash risk is also shown, along with boxplots, as are the risks associated with the Rockwell radio task [7], and baseline.Third, crash risk was calculated for the aggregate glance behavior of 100 random samples of 15 drivers, selected from the original 20 drivers. The 100 simulations, for each task, were then sorted by increasing crash risk.

Results

Between-driver variability across tasks varies widely (Figure 1). For example, Task 2 and 3 have a much wider interquartile range, and higher-risk outliers than ManualFM or baseline. The means of the tasks with larger variability is naturally higher, but note that the median crash risk is much more similar across the tasks than the mean is. The mean crash risk for the modern radio task (ManualFM) and the legacy analog radio tuning (Rockwell) are surprisingly similar, as is the crash risk between the SHRP2-baseline and the baseline glances from the experiments in this study. The traditional glance behavior safety metrics a) average percent on-road glances, and b) percent eyes-off the roadway greater than two seconds (Figure 1), are in line with the results from the crash risk estimates. For example, a low proportion of glances less than two seconds and a high %EON produce low crash risk (e.g., baseline), and vice versa (e.g., Task 3). Also, the driver with the highest mean (across all tasks) off-road glance duration (i.e., the red X is one driver – the "riskiest" (with traditional metrics) driver across all tasks) produces the highest crash-risk for high variability tasks. For the "safest" driver, all tasks were completed with risks lower than the ManualFM task.



Task:	ManualFM	BaseLine	Task1	Task2	Task3	Task4
TTT:	20.7s	38.1s	22.1s	18.4s	17.3s	6.4s
% EOFF >2s:	9.6%	0.7%	17.6%	15.6%	22.9%	15.6%
%EON:	28.1%	77.7%	24.1%	23.5%	23.4%	20.9%

Figure 1. Box plots of the estimated crash risk across the individual drivers, for each task and baseline. Also, the lowest and one highest glance-risk driver (across all tasks) are shown, as are the mean crash risks for the Rockwell radio task and baseline from the Bärgman et. al (2015) paper.

Figure 2 shows how driver variability differs across tasks, and more specifically, how a random sample of drivers (15 out of 20 randomly sampled 100 times) affects crash risk estimates. Some tasks (e.g., Tasks 3 and 4) have a much wider range between the (random) set of drivers with the lowest and the highest risk, while for other tasks, the risk is much more even (e.g., ManualFM and Task 1). The least risky set of drivers for Task 4 is as safe as the most risky set of drivers for ManualFM, while the difference in lowest ManualFM and the highest Task 4 is a factor of two in crash risk.

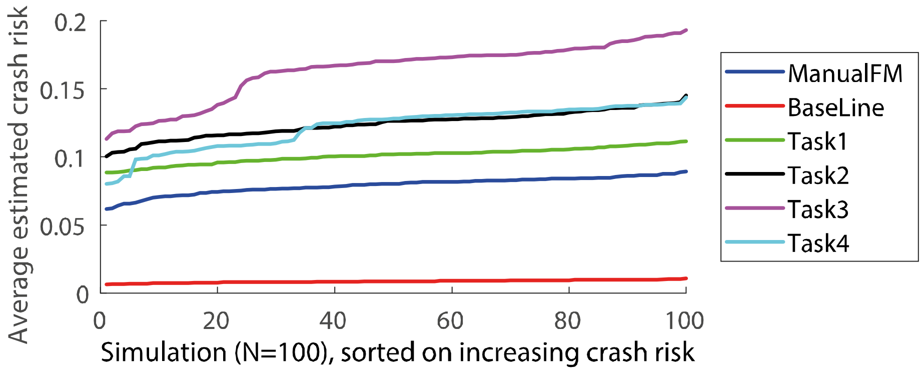


Figure 2. Mean MCR for 100 sets of randomly sampled drivers (15 of 20), for the tasks and baseline, sorted on increasing risk.

Discussion and conclusions

The variance of driver behavior differs widely across tasks, and the crash risk associated with task engagement is correspondingly different across tasks. This is particularly problematic when metrics are used as thresholds in requirements and guidelines. The NHTSA guidelines for in-vehicle driver-vehicle interface designs (glance behavior) has been critiqued in several scientific publications [8-10], among other things for its high sensitivity to the sample of drivers (a few drivers with long glance behaviors affects the outcome too much). The boxplots in Figure 1 and the random sampling example in Figure 2 demonstrate the between-task sensitivity to driver samples, on crash risk. Figure 2 also shows that some tasks have a more stable (flatter) mean crash risk over the 100 sampled sets of drivers than other tasks. The riskiest and least risky driver (Figure 1) are clearly very different in their behaviors. It is important for designers and evaluators of systems to understand this variability.

This study uses a simplified model of driver behavior and crash causation – one that only consider eyes-off-road as a cause for rear-end crashes and assumes that when and how drivers engage in secondary task is a random process. However, even with its limitations, the current study illustrates the effects of driver variability in safety evaluation of tasks glance behaviors. The relationship between driver glance-behaviors and crash risk was analyzed without considering the risk reduction from driver support systems such as emergency braking or adaptive cruise control, which should be the next obvious step. This could include comparing some counterfactual risk metric of glance behavior in manual driving, and the same risk metric of glance behavior in automated driving with automated systems (virtually) active in the simulations. Such analyses would address the effect on safety of the interaction between the glance behavior in automated driving, and the risk-reducing performance of the support systems.

The use of counterfactual simulations has showed promise in previous scientific publications and this paper provides further evidence of the relevance of the crash risk metric. The crash risk estimates are in line with the assumed increased risks associated with metrics based on of the proportion of percent off-road glances. With further evidence of real-life safety, counterfactual simulations can become an effective safety tool in assessment of in-vehicle glance behavior.

Acknowledgements

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Assessing the Effect of In-Vehicle Task Interactions on Attention Management in Safety-Critical Events

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Keywords: Attention management; Driver distraction; Safety-critical events

EXTENDED ABSTRACT

Introduction
A recent analysis of safety-critical events from the 100-Car Naturalistic Driving Study revealed the importance of on-road glance length in-between off-road glances in the moments preceding near-crash and crash outcomes [1]. In the 25s of time prior to these events, drivers involved in near-crashes (i.e., averted crashing) had significantly longer on-road glances, and looked less frequently between on- and off-road locations as compared to those involved in crashes. The authors showed that patterns of glance between on- and off-road locations differentiated safety-critical events (SCE) due to cumulative effects produced from the length of time drivers glanced to each location, evident in consecutive time-bins of mean single glance duration (MSGD) and in output produced from the AttenD algorithm [2]. Based on these findings, they called for the use of metrics and analytic techniques that allow for a comparison of different glance sequences to multiple locations to complement existent assessment methods focused on single-region (off-road) glance allocation [3].

Aim
To further examine the extent to which the duration of on-road glances threaded between off-road glances produce patterns linked to safety-critical outcomes, the same analytic techniques introduced in [1] were applied to an analysis of a subset of SCEs from the Strategic Highway Research Program (SHRP2) naturalistic driving study [4] contained within The Naturalistic Engagement in Secondary Task database (NEST). The consideration of data from NEST allows for a more in-depth analysis on the extent to which the glance behaviors evident in the safety-critical epochs from the 100-car dataset are descriptive of a normative pattern of attentional mismanagement in the moments prior to crashes and near-crashes, or, are preconditioned on interactions unique to secondary task type.

Method
The NEST dataset contains Crash and Near-crash epochs curated so as to only contain incidents linked to secondary task activity, as well as four Baseline epochs (i.e., epochs not containing SCEs) from each driver for his/her independent observations in the SCE (Crash and Near-crash epoch) set. All the SCE epochs contain secondary task activity, which we categorized as visual-manual (e.g., any reaching, adjusting, manipulating, or holding activity, auditory-vocal (e.g., any conversation activity), or “mixed-mode,” containing more than one kind of secondary task activity. Baseline epochs were a mixture of those containing secondary task activity and those without (see [4] for details).

In cases where a single driver had both Crash and Near-crash epochs, the Crash epochs were removed, so that all statistics were computed on independent samples. This filtering yielded a set of 78 Near-crash epochs, 133 Crash epochs, and 940 Baseline epochs. For visualizations and statistical comparisons, epochs were further aggregated within drivers, yielding a set of 67 Near-crash drivers, 127 Crash drivers, and equivalent Baseline epochs.

Glance behavior in NEST is provided in a sample-by-sample format, at 10 Hz, with each sample coded with an area-of-interest. For the purposes of this analysis, all windshield glances were considered on-road glances, and all other glances off-road. From these periods of glance behavior, two glance statistics were computed: mean single glance duration and AttenD buffer value (see [1] for detailed methods).

Results and Discussion

For mean single glance duration (MSGD), mean statistics were computed for on-road glances and off-road glances, as well as for Crash, Near-crash, and Baseline epochs. Statistics were computed separately for SCE epochs that contained Auditory-Vocal tasks, Visual-Manual tasks, or a mix of the two. Glances were "binned" based on the time point at which the glance was initiated; for example, a glance initiated 18 seconds before the end of the epoch was placed in the 15-20 s bin. While long glances may straddle multiple 5 s bins, glances are only placed in the bin in which they are initialized; because glances can be long (especially on-road glances), mean glance duration tends to drop as bins get closer to the end of an epoch due to the temporal limit on how long they can be sustained within a given window. Average glance duration is presented in Figure 1. For the purpose of contrasting typical, non-SCE driving performance to SCE glance behavior linked to different categories of secondary tasks, the same "Baseline" MSGD value (for off-road glances, left panel; for on-road glances, right panel) is plotted across all task compositions.

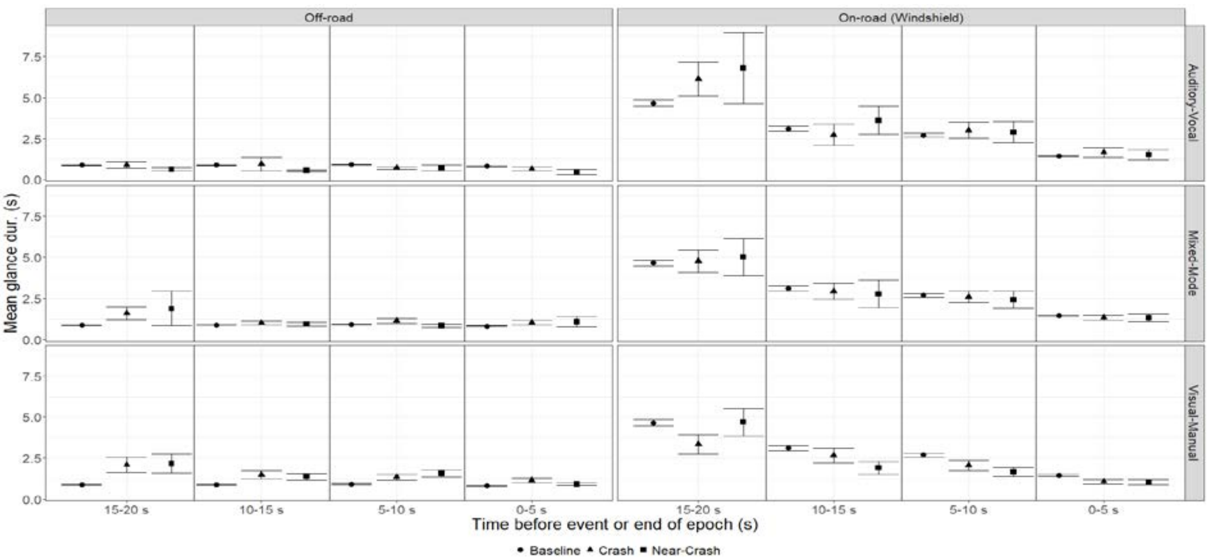

Figure 1. Mean off- and on-road glance duration. Error bars represent standard error.

The greatest differences between SCE and Baseline glance duration occurred in the bins farthest away from the end of the epochs (i.e., farthest away from the precipitating event): the 15-20 s bin. Paired t-tests revealed that for Visual-Manual SCE epochs, all of the Crash bins had significantly longer off-road glances than the Baseline bins; all but the latest (0-5 s) Near-Crash bins had significantly longer off-road glances than Baseline. For Mixed-Mode epochs, only the Crash 15-20 s bin and Crash 0-5 s bins had marginally significantly longer off-road glances than Baseline. Only Near-crash off-road glances in the 5-10 s bin were significantly different than Baseline glances—but in this case, they were shorter.

Mean on-road glances were shorter in Crash visual-manual than Baseline epochs in the 15-20 s, 5-10 s, and 0-5 s bins; for Near-crash, significant differences were observed in the 10-15 s, 5-10 s, and 0-5 s bins; notably there was no effect in the farthest bin, suggesting that one critical difference between Near-crash and Crash epochs containing visual-manual activity is that the differences in glance behavior, compared with Baseline, extend only to time periods closer to the SCE. No significant differences were observed between Near-crash and Baseline and Crash and Baseline epochs containing Auditory-Vocal or Mixed-Mode compositions of tasks; statistics suggest that, for SCEs containing Auditory-Vocal tasks, the trend is in the opposite direction, in the bins farthest from the precipitating events, with on-road glancing being longer in the SCE conditions than typical Baseline driving.

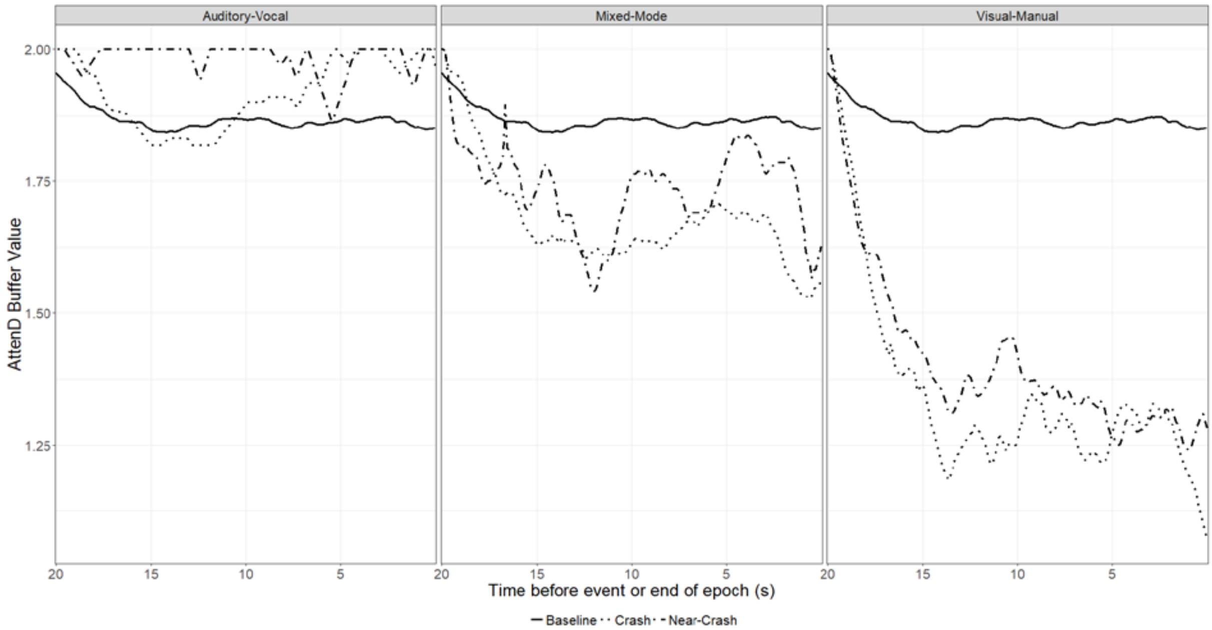

Figure 2. Mean AttenD buffer values by type of epoch and secondary task interaction.

Figure 2 depicts the average AttenD buffer value, for the different types of epoch, over time. The “Baseline” line indicates attentional performance in typical, routine driving, regardless of secondary task composition. Higher values indicate better on-road attention; for visual-manual and mixed-mode epochs, Baseline tended to have the highest values, followed by near-crash epochs (in which crashes were averted), and finally crash epochs. This trend is especially strong for SCE epochs linked to visual-manual tasks, and fits the findings of on- and off-road mean glance durations, with early on-road glances being the shortest and off-road glances being the longest in Crashes, together yielding the largest drop in AttenD buffer value across all conditions. For these participants, the loss of attention never recovers, and further drops in the moments preceding crash. Near-crash visual-manual drivers show a similar pattern, but with a less severe initial drop, and no end-of-epoch drop. These patterns produced for SCEs containing visual-manual in-vehicle interactions most closely match those from the 100-car SCEs [1]. Auditory-vocal epochs, on the other hand, show high buffer values for both Crash and Near-crash epochs, consistent with a narrowing of gaze hypothesis associated with the cognitive demand of some auditory-vocal tasks [5]. Mixed-mode epochs, which showed a mix of auditory-vocal and visual-manual behavior, show a trend that appears to occupy middle ground between the other two conditions.

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A Sociotechnical Systems Approach to Distraction
Theory, Methods & Recommendations

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Keywords: Countermeasures; Driver Distraction; In-vehicle technology; Legislation; Mixed methods; Sociotechnical systems.

EXTENDED ABSTRACT
This presentation will provide an overview of a body of research conducted into the application of, and insights generated from, taking a sociotechnical systems approach to driver distraction. The focus within this will be the implications of built-in and portable technologies that provide drivers with multiple sources of distraction. It will discuss the theoretical implications for the research in this domain, the methodologies used to study the phenomenon as well as providing recommendations.

Scope
Technologies have contributed to the development of vehicles through the provision of information-based systems, control-based systems and other functionalities that do not support the driving task [1]. It is these other functionalities that do not directly assist the driving task, and may actually adversely affect the drivers safe monitoring of the driving task, that are of concern to the driver distraction domain. In-vehicle systems now provide drivers with an array of information, entertainment, communication and comfort features to enhance the driving experience [1][2]. As technology has developed, so the variety and complexity of these features has increased [3]. Yet, the distractive effects of these devices must be taken seriously.

To manage the issue, legislation and regulations must adapt to incorporate technological distractions, yet there is critique that policy change may be somewhat of an afterthought, playing catch-up only after gaps within existing policy have been found [4]. With developments in technology occurring at a rapid pace, it is hard for policy to regulate its use. This is evidenced by the recent change in UK legislation that raised the number of penalty points from 3 to 6 (where 12 points incurs a ban from driving for a year) and increased the fine to £200 if drivers are caught using their phone while driving. This is in response to previous penalty increases made in 2013 (£100), 2007 (£60) and 2003 (£30). The need for these continual increases in penalties suggests these measures to be ineffective.

Theory
Countermeasures to distraction which focus on penalising the driver descend from a traditional, or 'old view'[5][6], of accident causation, that view the driver as unreliable and the main threat to safety. This is opposed to 'new' systems approaches that consider accident causation to be a consequence of the interrelationships within the sociotechnical system. It values the interactions between multiple elements that comprise a system, as well as the wider environment within which they are located, rather than focusing on individual elements, (e.g. [7][4]).

The systems approach is now a dominant approach in accident analysis research [8][9]. The potential for the application of a systems perspective to driver distraction has been suggested in recent years [10]. Yet, the rapid development of technologies that have found their way into the vehicle is thought to increase the need to review the behaviour from this perspective [6]. Human needs are now considered to be determined by technological advancement [11]. Rather than controlling the individual, the advent of Human Factors research in the 21st century focuses on controlling the technology, the environment and the system that they reside in.

The Prioritise, Adapt, Resource, Regulate, Conflict (PARRC) model of distraction [12] emerged from work conducted in this project and was the first model to incorporate the sociotechnical system into the study of driver distraction. The model highlights 5 key factors that emerged from the literature on driver distraction from in-vehicle technologies and the important interconnecting relationships between the factors that are attributable to the wider system surrounding the events in the lead up to distraction related incidents. The validation of this model through its application to a semi-structured interview study [13][14], and driving studies conducted in a full-car driving simulator as well as on the road, credit the application of the model and the insights it can contribute to the wider system surrounding driver distraction.

Methods

One objective of this work was to review the methods that are employed by researchers' in the study of driver distraction and determine how the sociotechnical system surrounding the behaviour may be assessed. Methods that focus on the cause/effect relationship between the driver and distraction have a tendency to focus on the adverse actions of the driver and thus have resulted in recommendations that have predominantly targeted the driver. The application of the sociotechnical systems theory to the study of driver distraction should allow for the wider pool of actors involved in distracted driving to be considered and offer countermeasures which focus on such actors. This requires methods that allow for an understanding of all causal factors that give rise to distracted driving to be realised in order to tackle the issue at the source, rather than once it reaches the end user.

Studies were conducted that aimed to determine the influence of actors within the wider system that impact on the driver in the emergence of distraction related events. An insight into the drivers' subjective experience of engaging with distractions was assessed to determine the influence of actors in the wider context surrounding the behaviour. Semi-structured interviews provided data from drivers on their likelihood of engaging with technological tasks across road types [14]. Verbal protocol analysis allowed the assessment of their intention to engage with distracting tasks while they were performing the driving task in both a full-car simulation and on the road. The findings from these studies will be presented to show how they are able to capture the drivers' motivation to engage with technological devices while driving and the impact of actors across the wider sociotechnical system. This includes that development of a hierarchical thematic framework that considers the systemic factor that influence the drivers' engagement with distractions (context, infrastructure, driver, other road users and the task) and the multiple factors associated with these systems factors [13]. Application of this hierarchical framework to the PARRC model of distraction [12] reveals how key systemic actors are influencing the factors that contribute to driver distraction. Gaining an awareness of these actors in this way allows for their impact on driver distraction to be analysed to determine appropriate countermeasures.

Recommendations

The work conducted within this project sought to provided recommendations to novel ways of countering the behaviour through the theory, methods and practises that are applied.

***Theoretical*:** The research conducted in this project developed a theory of driver distraction to incorporate sociotechnical systems thinking and the role of systemic actors rather than solely focusing on the driver. This will be of use to research practitioners who should be aware of the influence of the sociotechnical systems approach to driver distraction. The work conducted, and the insights that were gained, also led to the development of a novel definition of driver distraction that seeks to build on those that have already been suggested within the literature. Yet, importantly it includes the role and responsibility that the wider sociotechnical system has in the emergence of the behaviour, its adverse consequences to road safety and subsequently the mitigation tactics that can be implemented to prevent it.

***Methodological*:** Work conducted in this project sought to apply novel methodologies to the study of driver to distraction in order to provide novel insights into the motivation, intention and responsibility for driver distraction from a sociotechnical systems perspective. The assessment of the drivers' intentions to become distracted across research settings was a novel approach and the utilisation of a combination of methodologies to develop and validate a novel method of driver distraction showed the utility of subjective and qualitative assessment of driver distraction.

***Practical*:** The practical contribution of this work predominantly relates to the endorsement of countermeasures to prevent, or limit, the distractive effects of in-vehicle technology. Historically, popular measures to mitigate against the distractive effects of technology include legally banning their use and enforcing penalties on those that are caught breaking the law. Yet, analysis within this body of work determined that the focus on specific devices within legislation is neglecting the rapid development of other technologies that may be viewed as comparatively less risky. The realisation that legislation may actually be creating the conditions for driver distraction suggests that novel countermeasures are required that focus on other levels of the systems hierarchy [15]. This includes, but is not limited to, the role of manufacturers who permit their devices to interact with the driver despite being aware that the driver should not interact with the device. The systems-based hierarchy developed by Rasmussen [16], and expanded within this work [15], is used to graphically represent how multiple actors within the sociotechnical system hold some influence over the emergence of driver distraction from technological sources, not just those setting the law and the end-user who must obey the law.

Conclusions

This presentation provides an overview of a body of work conducted into the possibilities of applying a sociotechnical systems approach to driver distraction. This includes the benefits of the approach to the theory developed, methods used and practises that are recommended. Throughout, a review of the current and historical approaches to the phenomenon are also reviewed.

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Attentional Demand of Driving as Uncertainty in Predictive Processing

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Keywords: Attention; inattention; distraction; measurement; operationalization

EXTENDED ABSTRACT

In this paper, I discuss the problem of definition and operationalization of attentional demand of a task, and accordingly, of inattention and distraction. A plausible solution to this problem is proposed based on the theoretical framework of predictive processing [1][2].

The research gap and how to close it

There is no clear consensus about the definition of driver inattention or distraction [3][4][5]. Among the most popular definitions is the one by Regan et al. [5], defining inattention as "*insufficient, or no attention, to activities critical for safe driving*" and distraction as its sub-category, or cause (i.e., the diversion of attention away from the critical activities toward a competing activity). The definition is incomplete, likewise the authors themselves acknowledge, in at least three ways. First, it does not define the critical activities for safe driving. Second, it does not define how much attention is sufficient to devote on these activities for safe driving. Third, one can ask if there are situational and individual variations in this attentional demand for safe driving [4][6]. Regan et al. [5] as well as Kircher and Ahlström [4] further discuss how the existing definitions often suffer from hindsight bias. The bias refers to defining inattention posteriori by referring to what happened. For instance, "the driver was inattentive because he hit the lead car while using his smartphone". This is not an appropriate definition as we should know even without the crash if the driver was attentive or not. The US-EU Inattention Taxonomy [3] was intentionally developed to avoid the hindsight bias. This report also tries to define "*activities required for safe driving*" at a conceptual level. However, the taxonomies have not offered a clear operationalization and quantification of driver inattention.

In order to know if someone is inattentive in a task, we should first know how much attention the task requires in order to achieve the goals of the task [4]. Further, in a dynamic task with variable demands, such as driving a car, it is not sufficient to know how much attention the task requires on average but we must know how the situational demands vary in order to know if the human operator is attentive enough at a particular situation [4]. At an even deeper level, one can ask what is attention. There is no exact definition of attention even among the researchers who are studying the phenomenon and its neural correlates [7]. There is no well-established computational model for quantifying the attentional demand of a task, which would rely on a sound theory of human attention with a credible basis on the findings of cognitive neuroscience. This research gap has led to various, and often inadequate, operationalizations of inattention and distraction. Questionable operationalizations can lead to unreliable and even contradictory research findings.

However, there is gleaming light at the end of the tunnel. Recent developments in cognitive sciences have led to converging empirical evidence (e.g., [10-11][10]) and theoretical frameworks of cognition suggesting that brains are an advanced prediction engine (e.g., [1][2][11][12][13][14]). Based on the successes of this predictive processing framework in explaining various mental phenomena and neural data, I propose here a theoretical account based on the framework and its recent application to driving [15] that may offer a solid basis also for quantifying the attentional demand of a task, and thus, inattention.

Definition of attention based on the predictive processing framework

Based on the predictive processing framework by Clark [1][2], the prediction models of the brain are hierarchical generative models, which try to continuously generate predictions of, and thus explain away, the sensory signals at the lower levels of the information-processing hierarchy. Engström et al. [15] provide practical real-world examples of different levels of this information-processing hierarchy in car driving. For instance, looming of a lead car (i.e., "*visual expansion of an object registered by the visual sensory system*") represents a low-level sensory signal. At the other end, overtaking a lead car represents a higher-level event (i.e., "*increasingly abstract and multimodal features extending over larger spatiotemporal scales*" [2]). The predictions are based on the learned statistical regularities and causal relationships in the world. The predictive processing account suggests that only the prediction error between the predicted and realized events is processed in the brain, not the whole sensory signal [2][11]. Most of our sensory experience is thus generated by top-down predictions of what the sensory data is expected to be at any moment in time. Only the sensory signals that represent error on the top-down predictions of what was anticipated, and if given weight (i.e., attended), propagate up in the hierarchy of prediction models for an event and thus get processed at the higher levels of the hierarchy. Thus, from the perspective of predictive processing the target of attention is prediction error. Attention selects its target by modulating the gain of the error signal(s) available (i.e., selective enhancement) [2][11][13]. Processing can then be focused on, for instance, a spatial or temporal location, on a feature of a stimulus, or a body movement. Attention is the weighting mechanism enabling varying confidence between a prediction (top-down information) and the prediction error (bottom-up information) based on the requirements of the task at hands [2][11][13].

Definition of attentional demand as the probability of unexpected event

Senders et al. [16] were the first to suggest a connection between the uncertainty of task-relevant information and the attentional demand of the task of automobile driving. Later, researchers have built a number of computational models of human visual attention allocation in which uncertainty plays a central role (e.g., [17-21]). Here, the concepts of attentional demand and uncertainty are unified, assuming that the uncertainty of a prediction is a direct causal reason for attentional demand. That is, the higher the probability of an unexpected task-relevant event, the higher the attentional demand for attending the prediction error (see Figure 1: left).

Here, following the probabilistic accounts by Sullivan et al. [20] and Engström et al. [15], subjective uncertainty is defined as "*the variance of the probability distribution associated with a belief that the world is in a particular state*". It is suggested that this subjective uncertainty is one of the key factors driving the attention allocation of a human operator in a task. However, there are two types of uncertainty [15] (see Figure 1: right); 1) the objective uncertainty of the prediction, that is, the objective probability of prediction error, and 2) the subjective (i.e., estimated) uncertainty encoded in a prediction model in brains (as defined above). If e_i is an observable event and p_i is a prediction about e_i, then objective uncertainty of p_i [i.e., $U(p_i)$] equals the probability of $e_i \neq p_i$ and if the probability of event e_i getting value p_i [i.e., $P(e_i=p_i)$] varies between 0 and 1, then $U(p_i) = ei \neq p_i = 1 - P(e_i=p_i)$. Here, $U(p_i)$ is the objective uncertainty of prediction p_i for observable event e_i, and $P(e_i=p_i)$ is the objective probability of event e_i getting the value p_i given the objective probability distribution for e_i. The subjective uncertainty (i.e., the estimated uncertainty encoded in a prediction model) can be defined as $U(p_i)' = 1 - P(e_i=p_i)'$, where $U(p_i)'$ is the subjective uncertainty of p_i and $P(e_i=p_i)'$ is the individual person's subjective probability estimate of event e_i getting the value p_i. The subjective uncertainty is an inner force driving one's attention allocation to the prediction error. However, from the point of view of optimal task performance this subjective uncertainty is not necessarily in line with the objective probability of prediction error. From the viewpoint of controlled task performance the objective uncertainty of a prediction determines the (objective) attentional demand for the related prediction error.

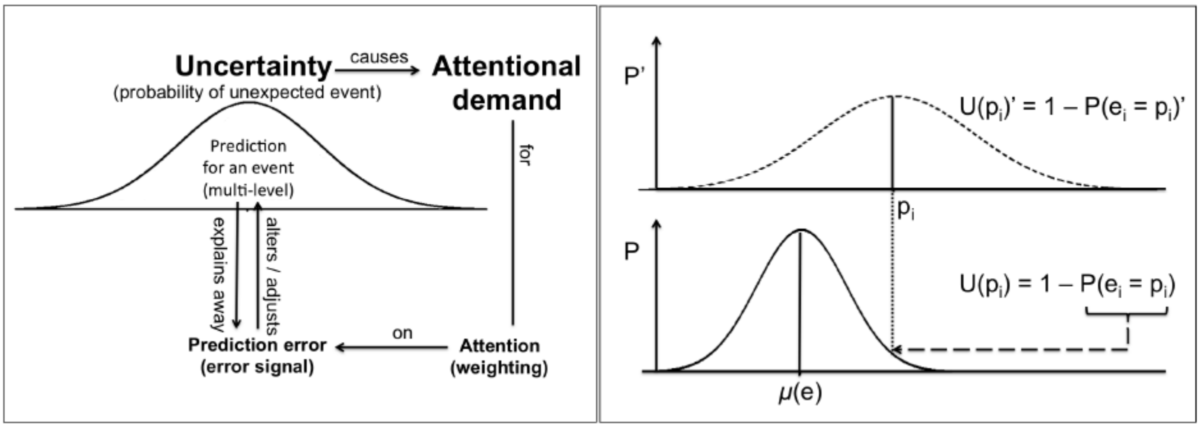

Figure 1. Left: Schematic of attentional demand as uncertainty. Right: Illustration of the relationship between subjective uncertainty [$U(p_i)'$] and objective uncertainty [$U(p_i)$].

A definition and operationalization of inattention

Based on this probabilistic account of attentional demand for a task-relevant event, it becomes possible to define inattention and compute the level of inattention of a human operator towards the event. The attentional demand varies between 0 (no attention is required from the operator) and 1 (operator's full attention is required). If the operator devotes less attention to the event (i.e., the related prediction error) than the attentional demand, the operator is inattentive towards the event. For a naïve example, the movements (or brake lights) of a lead car at insufficient time headway on a congested road may require 99% of the reckless driver's gaze dwell time in order to maintain the capacity to avoid a rear-end crash by reacting to prediction error. The driver's high-level prediction here is that the lead car will not suddenly break with force [with $U(p_i) = .99$]. A cautious driver in a similar scenario may have set the goal (and prediction) of a sufficient headway to the lead car. The longitudinal movements of a lead car fluctuating between little less and more than sufficient headway may require only occasional visual sampling (e.g., 200 ms every 2 seconds, that is, 10% of the total dwell time, $U(p_i) = .10$), in order to regularly minimize the uncertainty of the headway and thus, to be able to react to prediction error for keeping the headway sufficient. Any deviations below these attentional demands may be considered as inattention in the relevant tasks. The drivers' subjective estimates of the uncertainties may easily deviate from the objective uncertainties (i.e., uncertainty mismatch) due to false beliefs and lead to this inattention [15]. When a cause of the inattention is a competing activity, such as reading a text message, the inattention can be labeled as distraction [3][5].

This approach is well in line with the Minimum Required Attention (MiRA) framework by Kircher and Ahlström [4]. They call for traffic situation -specific analysis for the minimum level of attention required to drive safely through the situation. The proposed approach presented here may offer a way to quantify these minimum demands. Furthermore, the approach is able to take into account the individual variations in the attentional demand (i.e., other drivers having different or more accurate predictions than others). This definition of inattention is not affected by hindsight bias as the attentional demands for a task can be computed a priori. The quantification of $U(p_i)$ could be achieved, for instance, by simulating the task with machine learning methods. As an example, for a task in which the prediction equals the task goal, such as in the latter example above, a reinforcement learning agent [22] could be rewarded for achieving the task goal (e.g., sufficient headway) and penalized for failures, while conducting a secondary task associated with its own rewards. The agent would be able to make observations to produce corrective actions only when its attention (i.e., task focus) is allocated in the primary task. Through a great number of simulations, the model would find the optimal policy for allocating attention on the primary task to maximize the reward (given the set task constraints). Situational $U(p_i)$ could then be estimated based on this optimal policy, that is, based on the residual probability of failure in the primary task as a function of attention allocation actions.

Conclusions

I have addressed a theoretical research gap on the definition and operationalization of inattention. Inaccurate and ambiguous operationalizations of inattention may lead (and have led) to unreliable research findings and inconsistent guidelines for the stakeholders (e.g., [23]). To solve the problem, I have proposed definitions of attentional demand and inattention based on the predictive processing (PP) framework [1][2] and its application to the automotive domain by Engström et al. [15]. The approach is in line with the MiRA framework for driving [4] but may be applied to any other dynamic task (e.g., bicycling). The theory seems to work best with visual tasks likewise the PP framework [2] but may well be applicable to other modalities as well as for modeling cognitive (internal) distraction. A lot of work has to be still done to make the theory useful in practice. Methods have to be developed to model and simulate dynamic attentional demand of driving-related events as the outcome of individual predictions and paying attention to prediction error in varying task environments and conditions. Furthermore, the basic predictions of the theory have to be carefully tested.

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Is Bigger Better? – Visual Distraction Effects of an In-Car Infotainment Application Compared to Smartphone Applications

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Keywords: Visual demand; visual occlusion; occlusion distance; acceptance testing; screen orientation; screen size

EXTENDED ABSTRACT

Recently, there has been a growing interest in distraction effects of smartphone usage while driving. Several naturalistic and simulator studies have shown the association between smartphone usage and safety-critical events (e.g., [1][2][3]). Yet, the range of smartphone applications used by drivers while driving varies from instant messaging services, such as WhatsApp, to games, such as PokémonGo [4].

The user interfaces (UIs) of smartphone applications are rarely designed to be visually and cognitively low demanding. This lack of driver-friendly user interfaces raises a need for in-car systems that are optimized for the automotive context and which can provide easy access to information and entertainment that drivers need on the road. These interfaces could also decrease the use of smartphone applications on the road. However, a little is still known about the exact UI design factors, which have the greatest effects on driver distraction.

In this paper, we studied a novel Android-based infotainment application called Carrio that is designed for in-car use. We compared Carrio's visual distraction potential to native Android smartphone applications in two experiments with 48 participants. The research questions were: 1) Are there significant differences in the visual distraction potential and experienced workload between Carrio application and Android smartphone applications, 2) If there are differences, what are the design factors that make the difference?

General method

For measuring the visual distraction potential of different in-car tasks, we used a method introduced by Kujala and Mäkelä [5]. This method utilizes visual occlusion technique, originally introduced by Senders, Kristofferson, Dietrich and Ward [6]. Visual occlusion refers to a condition where the driver's vision is occasionally occluded and the duration of the self-selected occlusion is measured. In this context, visual occlusion is used to measure the distance (*occlusion distance*, OD) that is driven during the occluded period, not time. This enables free control of speed for the driver. The testing method is based on an experiment where 97 drivers' occlusion distances on simulated highway and suburban roads were measured [7]. These occlusion distances were mapped on the test routes and used during the distraction testing: the highway routes for participant sample validation and the suburban roads for the actual distraction testing. The participant sample validation with their ODs ensures that the driver sample includes both, "short-glancers" and "long-glancers". This validation is an important part of the testing method since previous studies have indicated that drivers have individual off-road glance duration tendencies ([8][9]) and these individual differences in durations could affect the results of the distraction testing ([10][11]).

During the distraction testing, the in-car glances (i.e., glances that are directed to the in-car device) can be categorized as *green* or *red glances* based on the original 97 drivers' occlusion data [5]. The categorization is based on the distance driven during the in-car glance from a particular route point where the glance is initiated. A green glance refers to an in-car glance length that is at or below the baseline data's median occlusion distance for the route point and therefore can be considered as acceptable glancing behavior. A red glance refers to an in-car glance length that exceeds the 85^{th} percentile of the original 97-driver sample's occlusion distance on the route point. Red glances can thus be considered as inappropriately long in-car glances in relation to the visual demand of the given driving situation.

Experiment 1

A within-subject design was used with the platform (Carrio vs. smartphone) as the main independent variable. The NHTSA [12] recommendations on the driver sample were followed as closely as possible. In the first experiment, 24 participants conducted three different tasks: 1) to read 20 emails and search for answers to questions, 2) to switch between different views or applications (15 times), and 3) to search and play 4 songs as well as to look for related album or artist information in Spotify. There were differences in the task procedures depending on which platform was used (see Table 1).

Table 1 Task procedures

Experiment 1	Email	View-switching	Song search
Carrio	Carrio read selected emails out loud	Participant swiped either to left or right	Participant used voice recognition and a few buttons for searching
Android smartphone	Participants read emails by themselves	Participant pressed a button on the left lower corner of the phone and browsed/selected the windows	Participant used keyboard and a few menus for searching

Materials

The experiments were conducted at the University of Jyväskylä's driving simulator laboratory with a medium-fidelity driving simulator equipped with a 2-DOF motion platform. Ergoneers' Dikablis 50 Hz head-mounted eye-tracking system was used to record eye movements and SAE-J2396 [13] definition was followed when scoring in-car glance lengths. In the experiment, Carrio was running in 7" Lenovo TB3-730X tablet (Android 6.0). Samsung Galaxy A3 smartphone (4.5", Android 6.0.1) was utilized to run the different Android applications. Both devices were placed on a holder on the right side of a steering wheel. Carrio was used in a landscape mode for which the application is optimized for, whereas the smartphone was in a portrait mode (the most typical mode of use for smartphones).

Results

Based on Kujala et al. [7], the in-car glances in both experiments were categorized as *red* or *green* glances: the verification thresholds for the red glances was set to 6 % (max) and for the green glances to 68 % (min) ([14][15]). One-sample sign test indicated that Carrio's overall red glance percentage did not differ significantly from the threshold of 6 % and therefore the tasks barely passed the verification criterion (Mdn = 6.64 %, p = 0.89). However, the phone tasks exceeded significantly the threshold and did not pass the verification criterion (Mdn = 15.44 %, $p < .001$). The difference between Carrio's and phone's red glance percentages was significant (Z = 3.163, p = .002, d = 0.768, Wilcoxon's signed-rank test). Furthermore, all the differences in the red in-car glance percentages between Carrio and phone applications per task type were significant. Both, Carrio and phone tasks, failed the verification criterion for green glances (Carrio *Mdn* = 54.29 %, $p < .001$; phone *Mdn*: 33.06 %, $p < .001$). The difference between Carrio's and phone's green glance percentages was significant ($Z = 3.802$, $p < .001$, $d = 1.149$). With ANOVA, a significant main effect of trial was found in the experienced task workload (NASA-TLX [16]), $F(4.110, 86.302) = 16.554$, $p < .001$, partial $\eta^2 = .441$. Carrio's view-switching task was experienced as the least demanding and the phone's Spotify task as the most demanding task of all. Significant differences were found between Carrio's and phone's view-switching tasks ($MD = 12.08$, $p < .001$, $d = 0.893$) and between Carrio's and phone's Spotify tasks ($MD = 13.56$, $p = .001$, $d = 0.761$). After Bonferroni correction, there was no difference between Carrio's and phone's email task ($p = .046$, $\alpha = .002$).

Experiment 2

Due to the several confounding factors, the first experiment did not specify why the studied Carrio tasks had lower distraction potential. Thus, we decided to do another experiment with 24 new participants using the same testing method. In the second experiment, also Carrio will be running in an Android phone. We will also change the position of the phone from a portrait mode to a landscape mode for all the conditions. By these changes and by comparing the outcomes with the results of the first experiment, we can control and analyze if the screen size or orientation had effects on the first results. In addition, we can analyze the reliability of the testing method. In the second experiment, we will keep the tasks 1 and 3 (Table 1) identical but we will replace the view-switching task with a task where participants reply to an email with Carrio's voice recognition and with Android phone's keyboard. We hypothesize that the screen size or orientation do not have significant effects on the test results. Instead, we expect that the lower visual distraction potential of Carrio can be explained by the voice recognition and read-aloud features as well as the low number of visual-manual interactions required for the tasks. This explanation would be further supported by the added keyboard text entry task getting the highest percentage of red in-car glances of all the tasks due to the highest number of visual-manual interactions. At a meta-level, we expect good test-retest reliability of the testing method.

Main conclusions

Since several studies have shown the distraction effects of smartphone usage while driving (e.g., [1][2][3]), there is a need for in-car systems that are optimized for the automotive context. Therefore, we studied a novel in-car application called Carrio. In the first experiment, Carrio was running in a tablet and we compared its visual distraction potential to similar tasks conducted with an Android smartphone's native applications. The tested Carrio in-car tasks passed the verification criterion for the red in-car glances, but the phone tasks did not. Carrio tasks decreased the percentage of inappropriately long in-car glances by 57 % compared to the phone tasks. However, due to confounding factors, the exact contributing design factors cannot be highlighted based on the first experiment. For these reasons, we are currently running another experiment with 24 new participants, controlling for two of the main confounding factors; screen size and orientation. This helps us to more carefully indicate the most relevant design factors for decreasing the visual distraction potential of touch-screen based in-car applications. The final results are reported in the presentation.

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Texting while driving with Level 2 automation: A distraction or an opportunity?

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Keywords: Distraction; Driver support; Secondary task; Simulator; Texting-while-driving

EXTENDED ABSTRACT

Introduction

In-vehicle connectivity is becoming more and more important to car and truck drivers, and their willingness to pay for a successful connected driving experience is increasing [1]. They are accustomed to the modern-day luxury of always being connected, and therefore base their expectations on experiences from consumer electronics [2]. According to the investigation by [3], such an experience relies on that the system is Simple, Seamless and Safe. *Simple*, meaning that users of modern vehicles demand out-of-the-box, intuitive usability ("Nobody reads a manual"), *Seamless* meaning that different technology eco-systems need to talk to each other seamlessly ("In a connected world, we don't want our interactions to stop when we get in our car"); and above all *Safe* – since "everyone is ultimately aware that driving is dangerous" [3].

Drivers' increased safety awareness has likely been influenced by the recent years' increased focus on the relation between driver distraction - that is, when the driver is focusing on other things than driving - and traffic accidents. Visual distraction has been shown to be especially risky, e.g. in the study by Victor et al. [4], where a large number of real rear-end collision events was studied and where it was established that crashes occur when the driver looks away from the forward roadway at the wrong moment. There are also scholars that believe that cognitive distraction can be as dangerous as visual distraction, although this has been debated [5]. Distraction guidelines as the ones published by the European Commission [6], National Highway Traffic Safety Administration (NHTSA) [7], or Japan Automobile Manufacturers Association (JAMA) [8], highlight the fact that in-vehicle devices that vehicle manufacturers equip their vehicles with are a part of the distraction problem. Taking this into account, it might be tempting to suggest that interaction with in-vehicle interfaces while driving should be restricted as much as possible. However, an increasing number of similar "secondary tasks" are also being incorporated in the driving environment by the driver; devices such as smartphones, tablets and navigation systems are also calling for the driver's attention. There are studies showing, for example, that as much as 80% of the drivers use smartphones while driving (see [9]). If the in-vehicle interface is too restricted, or does not live up to the driver's expectations, the driver will likely prefer carrying out a certain task with a brought-in device (even if it's risky). Safer methods for text-input while driving are needed.

Alongside the development of connectivity solutions, new driving assistance functions that partly take over the driving task are being introduced in passenger cars as well as trucks. While automatic longitudinal control functions (cf. automation Level 1 according to the SAE classification scale [10]) have existed some time on the market, lateral control functions, i.e. active/automatic steering support is today also becoming common, allowing for higher levels of automation (cf. automation Level 2 and higher according to the SAE classification scale [10]). Such systems are gradually relieving the driver from the primary task of controlling the vehicle, and thus have the potential to change the general behavior of the driver. For example, they may increase boredom and favor secondary task engagement, but there is also evidence that the exposure to critical situations is reduced when driving with these functions [11]. A study by Morando et al. [12] suggests that the vestibular/somatosensory cue from the automatically controlled longitudinal deceleration acts as pre warning and allows the driver to make timely responses to critical situations.

The potential change in drivers' behavior and the whole driving situation when using driving assistance systems could suggest that the current guidance on in-vehicle interaction design is no longer appropriate. As more and more knowledge is gained from the domain of driver-automation interaction, the design of the digital user experience of secondary tasks must follow and make use of this knowledge. Currently, ESoP [6], NHTSA [7], and similar guidelines/standards that address secondary task interaction design provide no guidance on how such designs should take into account advanced driver assistance systems, let alone higher degrees of automation.

Aim and research questions

This study explores how driver behavior and experience of secondary task interaction changes when systems that simultaneously support both longitudinal and lateral control of the vehicle (Level 2) are active in passenger cars and trucks, as compared to manual driving without any additional support. In particular, it investigates how drivers' self-assessed experience of the ease and enjoyment of typing while driving are affected by characteristics of typing interfaces. For truck drivers, the effect of system feedback placement is also explored, see Figure 1.

The main hypothesis is that Level 2 automation will enable drivers to type while driving without inhibiting safety. As such, the study provides knowledge on how texting as secondary task should be designed to allow for a simple, seamless and safe interaction while using support systems of automation Level 2 in passenger cars and in trucks.

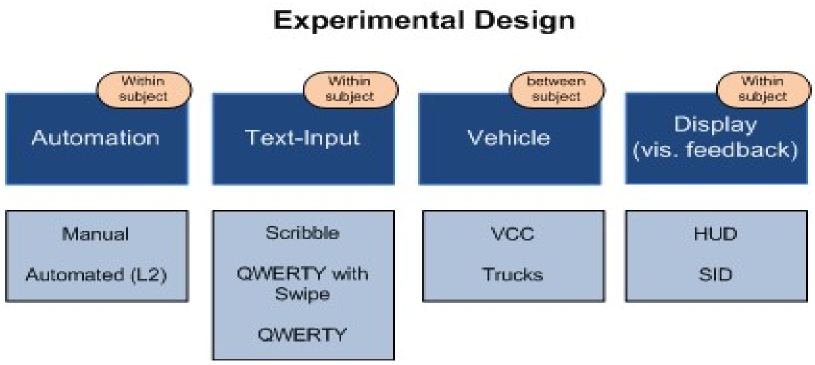


Figure 1. Experimental design

Methodology

Driver behavior and experience was compared in a texting-while-driving task with and without Level 2 automation active. The study was carried out in a fixed-base truck-cab driving simulator and involved 31 car drivers (8 female, 23 males; average age: 40 years) and 20 truck drivers (5 female, 15 males; average age: 42 years). The experimental design is illustrated in Figure 1. Each driver completed three driving conditions: a) driving without any automation and without any secondary task, b) driving without any automation while texting, and c) driving with Level 2 automation active while texting. The conditions b) and c) were randomized. These two conditions consisted of three texting sessions each where the drivers completed the texting task by using the following interfaces in a randomized order: Scribble (a smartphone application that enables texting by tracing a finger over the screen), QWERTY (a regular smartphone keyboard), and QWERTY with swipe (a regular smartphone keyboard with extended functionality that require just a swipe of the finger to enter letters), see Figure 2. All these interfaces were placed on the mid-right side of the steering wheel, accessible by the drivers' right hands. The car drivers experienced only one location of the system output, head-up display (HUD), and their experiment took about 100 minutes to complete. The truck drivers, on the other hand, experienced feedback in a HUD as well as in a side display (SID) in a random order, which resulted in an experiment of ca 150 minutes.

A combination of qualitative (drivers' self-assessed a priori and posteriori experience) and quantitative (eye-tracking, vehicle speed, deceleration, etc.) data were collected. In this paper, we have however chosen to mainly focus on the subjective experiences. In the a priori questionnaire, the drivers were asked about their background and experience regarding texting and driver support systems. During each typing session, the drivers' situation awareness was explored using a real-time probe technique based on the Daze method [13]. However, the probing questions were asked by one of the test leaders present in the truck cabin. The drivers were asked if they had noticed traffic safety relevant objects (e.g. signs, vehicles, and animals) present on the shoulder of the highway along the way. The a posteriori questionnaires were issued after each typing session and contained questions on how the drivers perceived their driving, the texting task, the texting interface, and the vehicle automation. Each questionnaire took about 1-2 min each to complete. At the end, the drivers completed a summarizing questionnaire.

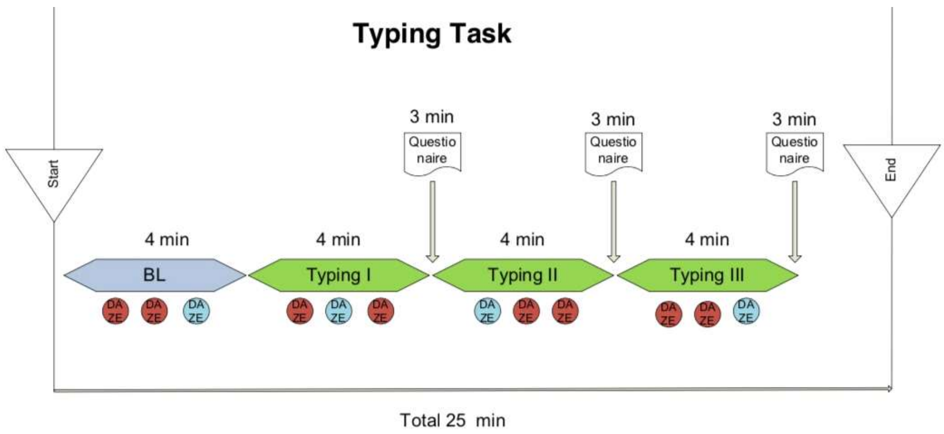


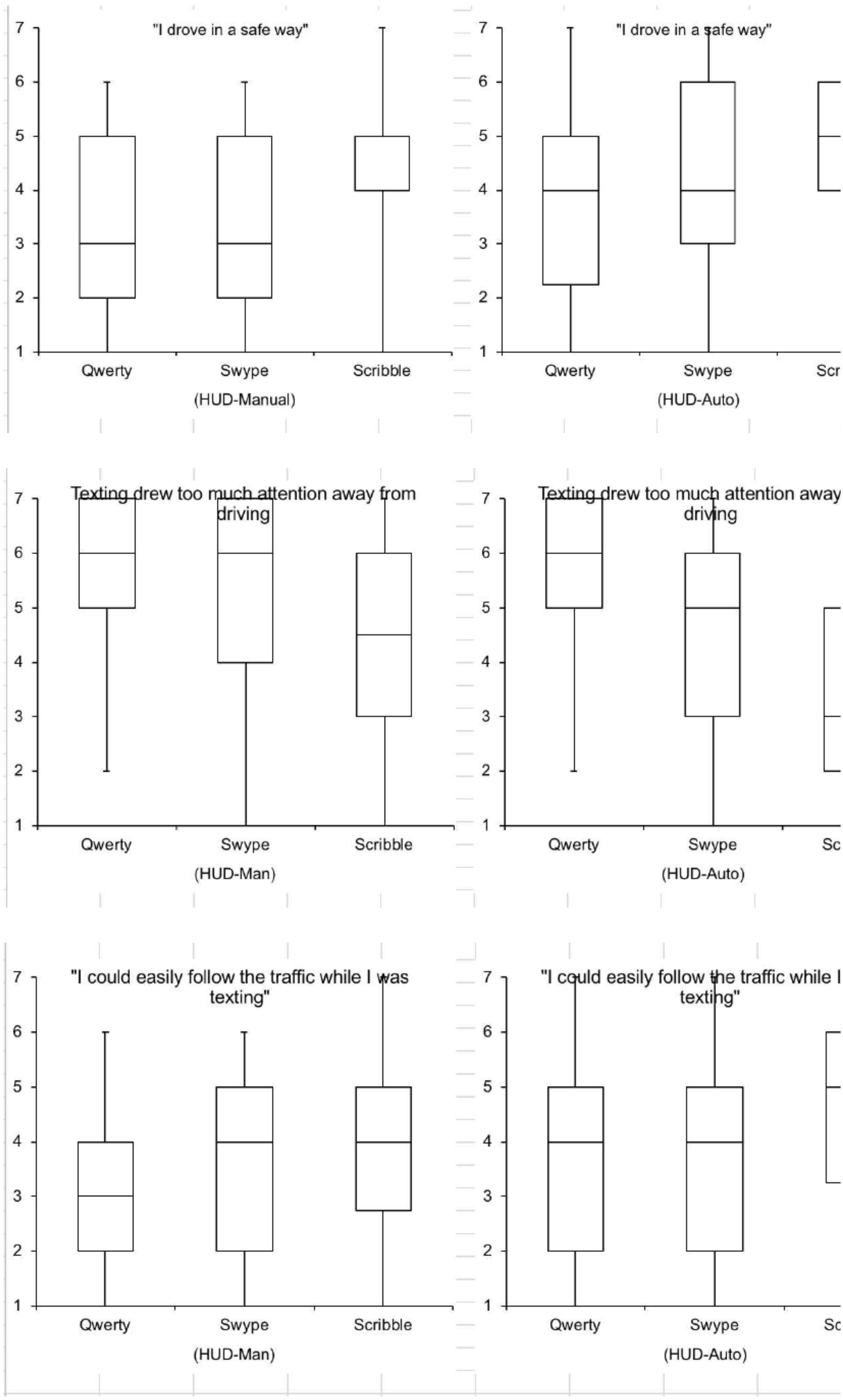
Figure 2. Timeline describing secondary tasks. The three typing tasks are repeated for each driving condition.

Preliminary results

The data collection has been completed very recently and the data analysis has just started. The results that are presented here are thus preliminary and based only on a fraction of the data collected.

Overall, a great majority of the car drivers (N=20) and truck drivers (N=11) stated that their favorite typing interface was Scribble. Eight car drivers and six truck drivers stated that Swipe was their favorite, while only 3 car drivers and 4 truck drivers preferred Qwerty over the two other input interfaces. This is manifested also in drivers' self-assessed safety, where they frequently stated that they drove safest when using Scribble. It also outperformed the other interfaces in self-assessment of attention allocation (the drivers stated that the texting with Scribble took at least attention from the primary driving task), at the same time as the drivers stated that it was easiest to follow the traffic in front of them when using Scribble. These trends seem to be even more emphasized when driving with the Level 2 automation active. That is, the automation seems to have a (slightly) positive effect on the drivers' experience, and it is again Scribble that outperforms the competing interfaces.

These overall trends will be further explored using statistical analyses and added to the final paper. We aim also to further explore difference between HUD and SID feedback, something that is left out here.


"I drove in a safe way"
7
6
5
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3
2
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Qwerty
Swype
Scribble
(HUD-Manual)
"I drove in a safe way"
Qwerty
Swype
Scr
(HUD-Auto)
Texting drew too much attention away from driving
Qwerty
Swype
Scribble
(HUD-Man)
Texting drew too much attention away driving
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(HUD-Auto)
"I could easily follow the traffic while I was texting"
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Design concept for a tactile and visual take-over request in a conditional automated vehicle during non-driving-related tasks

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Keywords: conditional automation; human factors; tactile; vibration mat, visual, take-over request, driving simulator

INTRODUCTION

Automated driving is currently one of the most important driving factors in the automotive industry. The technical development proceeds progressively ahead and first automation systems are already available in certain driving situations. Nevertheless, there will be situations where such systems reach their limits in conditional automated mode and won't be able to work reliably. In these cases, the driver must intervene and take control of the vehicle as quickly as possible and with a high take-over quality.

In this manuscript, the analyzed investigation context of automated driving is based on the automation levels of SAE [4]. In addition to Manual Driving (Level 0), Assisted Driving (Level 1) exists since the adaptive cruise control system was introduced in 1998. In Partial Driving (Level 2), the vehicle autonomously assumes stabilization and the driver monitors the system at the track guidance level [1]. In Conditional Automation (Level 3) it is assumed that the driver can face away from active driving for a certain period of time and devote himself entirely to non-driving related tasks (NDRT). According to the definition of SAE[4] and the NHTSA [3], the driver still has a duty in Conditional Automation to take over vehicle control within a certain period of time as requested by means of a take-over request. In this case, humans act as a fallback for the automation system.

A take-over request intends to generate an adequately timed response to the driver. Consequently, this request must be perceived explicitly by the driver. In the first step, we need to examine the perception of stimuli themselves. The take-over information is perceived by the human sensory organs, which fulfill the task to differentiate according to their modality.

The purpose of this paper is to present the development of three different take-over requests. Furthermore, a comparison between a tactile, a visual and a combination of both and additionally an acoustic take-over request will be drawn. For this purpose, three independent subject studies were performed, see Table 1.

Applied take-over request studies		Test environment	Non-driving related tasks	Participants
1	Vibration mat	Vehicle mockup without driving simulation	-	15 ♂ / 6 ♀ MN = 27,3 years SD = 9,5 years
2	LED light strip	Vehicle mockup with driving simulation	private Smartphone use	14 ♂ / 5 ♀ MN = 24,7 years SD = 5,7 years
3.1	Vibration mat	Vehicle mockup with driving simulation	n-Back - Test	Study will be done in January 2018
3.2	Vibration mat, LED light strip & acoustic warning sound	Vehicle mockup with driving simulation	n-Back - Test	Study will be done in January 2018

Table 1. Overview of the three studies used to evaluate a take-over request

EXPERIMENT SET-UP

Experiments were conducted in a high fidelity static driving simulator at the Institute of Ergonomics & Human Factors at the Technische Universität Darmstadt. The driving simulator consists of a full vehicle mockup (Chevrolet Aveo), a field of view of 180 degrees front projection and a representation of all driving mirrors due to three rear projections. The simulation is realized with Silab 5.1 (WIVW) and a self-developed automation controller based on the definition of SAE [4] Level 3 Conditional Automation.

For Study (1), only the tactile vibration mat was tested independently from a simulated driving task. For Study (2), (3.1) and (3.2), a total of three different critical route scenarios were created:

(I) Outage of automation controller on a country road, after a 110 seconds drive through the city

(II) Controller failure after 208 seconds automated driving due to insufficient perception of the environment based on no road markings on a country road

(III) Controller fault after 350 seconds automated driving due to insufficient handling options caused by a crashed vehicle in the city. A non-intervention leads to another accident

The subject group tested the respective scenarios in permutated order in conditional automation mode according to SAE Level 3. In all four scenarios, the driver has to switch from the non-driving related activity to the traditional manual driving task.

DEVELOPED TAKE-OVER REQUESTS

Visual take-over request via LED light strips

A visual information and warning system was developed at the Institute of Ergonomics & Human Factors at the Technische Universität Darmstadt. For this purpose, three LED light strips (LPD8806) were installed at the driving simulator mockup. It was ensured that these were mounted in the driver's perspective. One on each driver and passenger door and a third one on the dashboard at the height of the windscreen. With the help of an Arduino microcontroller they can be dynamically controlled in brightness, color and blinking frequency and be connected to the simulation software.

Tactile take-over request via vibration mat

A vibration mat including 21 eccentric mass rotation actuators (Precision Microdrives 320-102) in a 7x3 arrangement was independently developed as a further take-over request.

The mat is able to transmit both dynamic and static vibration patterns and can be used on the driver's seat in a driving simulator or in field tests. Each of the actuators can be controlled separately. Electronics and actuators were designed so that a wide vibration intensity spectrum can be covered. The control of each actuator is realized by means of another Arduino microcontroller with a self developed software to ensure the connection to the simulation software.

MEASUREMENT METHOD

All data was recorded in driving simulator experiments. In order to compare the different take-over requests with each other, subjective and objective measures were collected during each of the studies. A self-developed questionnaire was distributed to the subjects after every take-over request. With the questionnaire subjects assessed the take-over request according to its urgency, the pleasantness of the feedback and the willingness to buy such a system. Furthermore, objective driving data from the simulator was recorded, including the reaction time between a sudden take-over request and either the contact with the steering wheel, followed by its turning or hitting the brakes.

EXECUTION OF NON-DRIVING RELATED TASKS BEFORE TAKE-OVER REQUEST

During the automated ride, the test subjects were asked to engage in non-driving related activities. When investigating the visual take-over request (2), the subjects should actively distract themselves from the driving activity and interact with their own smartphone. In the study with the vibration mat (3.1) as well as with the multimodal take-over request (3.2), subjects had to perform a cognitively demanding dual n-back test [2] during automated driving on a tablet (Huawai MateBookE).

RESULTS

With results from Study (1) the drivers perceptibility and judgment in terms of transmitted vibration intensity as well as spatial and temporal resolution capability was attested. A dependence of the subjects gender and their intensity perception can be indicated. In addition the minimal temporal and spatial perception thresholds of two separate vibration signals was evidenced.

The take over time with a visual take-over request while using a smartphone as a non-driving related task (Study 2) reached a mean value of around 2 seconds, see Figure 1.

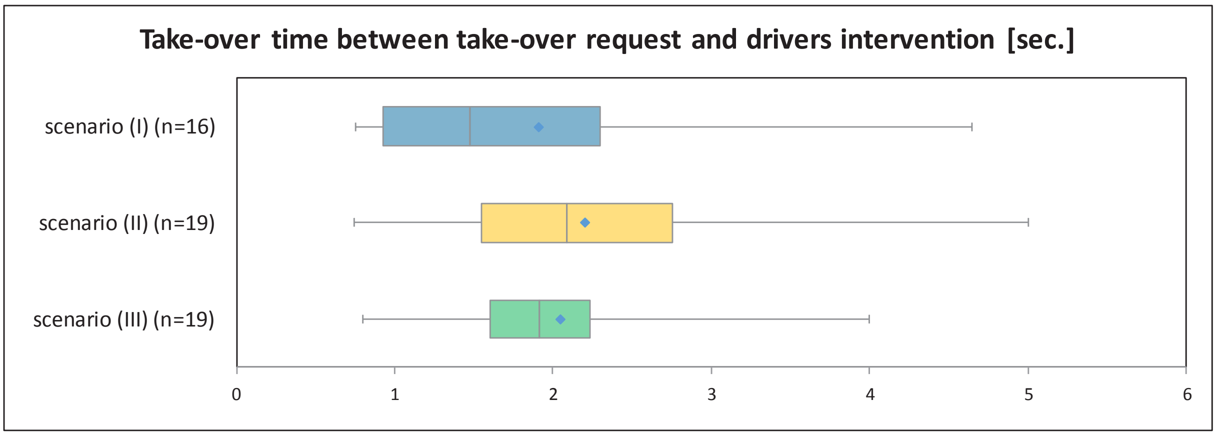

Figure 1. Reaction times from visual take over request in study 2

Take-over times from the tactile take-over request (Study 3.1) and the multimodal take-over request (Study 3.2) will be available mid march 2018 and will be compared with the results from the visual take-over request (Study 2). A recommendations for a take-over request will be derived as a conclusion.

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Change the way to manage an in-vehicle menu selection and thereby lower cognitive workload?

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Keywords: IVIS; Cognitive Workload; Working Memory; Text Input; Modalities; Menu Hierarchy

INTRODUCTION

Current in-vehicle information systems (IVIS) provide a great amount of possible secondary tasks while driving. The suitability of these systems for the driving context has been examined very often by measuring their *visual* workload (see e.g. Heinrich [1]). Today, there are approaches that also consider *cognitive* workload in the vehicle. Strayer et al. [2] showed, that cognitive distraction varies depending on task type (e.g. calling) or the mode of interaction (center stack, auditory vocal, center console).

The research reported here aims to investigate in more detail cognitive workload of IVIS. Therefore, various operating concepts for one specific task are tested. In detail, a function selection is implemented as a hierarchical menu selection or as a search function with text input. The text input modes are varied between speech, touch keyboard and touch gesture (handwriting). The driving simulator study conducted in December 2017 proves, if there are differences of these operation variations concerning cognitive workload.

METHOD

Subjects

Participants were recruited by newsletter for all employees of Porsche AG at Weissach, Germany. In sum 36 persons participated in the study, all persons had no connection to IVIS development. Ten cases were excluded because of simulator sickness or data logging issues

The final sample consisted of 26 persons, 17 males and 9 females. One person was below 25 years old, seven participants were between 25-39, 15 between 40 and 55 years and 3 persons were beyond 55 years.

Apparatus

The experiment was conducted in the driving simulator of Porsche AG with motion dynamics. The mock-up was equipped with two stacked touchscreens in the center console. The lower screen was used for text input by touch gesture, other interactions were executed on the higher screen. The IVIS software prototype was especially programmed for this experiment. Touch gesture input was processed by automatic text recognition, speech input recognition was realized as a Wizard-of-Oz approach directed by a research assistant.

Gaze data (Dikablis Professional binocular eye-tracker), driving data and IVIS events were collected with a 60 Hz sampling rate and were logged within the D-Lab 3.45 software suite (time synchronized).

Tasks & procedure

As primary task, the participants were driving on a three-lane German highway, following a lead-vehicle. The lead-vehicle travelled with a speed varying between 65 and 75 mph. Participants were instructed to keep a constant distance between those two cars (similar driving task in Large et al. [3]).

The secondary tasks were arranged in two blocks: n-back tasks and IVIS tasks. The n-back tasks were used to generate benchmark data to compare with the IVIS Tasks. Three different levels were used: 1-back, 2-back and 3-back. For further information of the n-back tasks please see Mehler et al. [4]. For this experiment the translated version and audio files by the Chair of Ergonomics, Technical University of Munich, were used.

The IVIS tasks consisted of four different approaches to manage a menu selection: search via a menu hierarchy, search via speech text input, search via text input over keyboard on touchscreen and search via handwriting text input gesture on touchscreen. An example for a task is “Please change the interior lighting color to blue”. For exemplary procedure please see Figure 1.

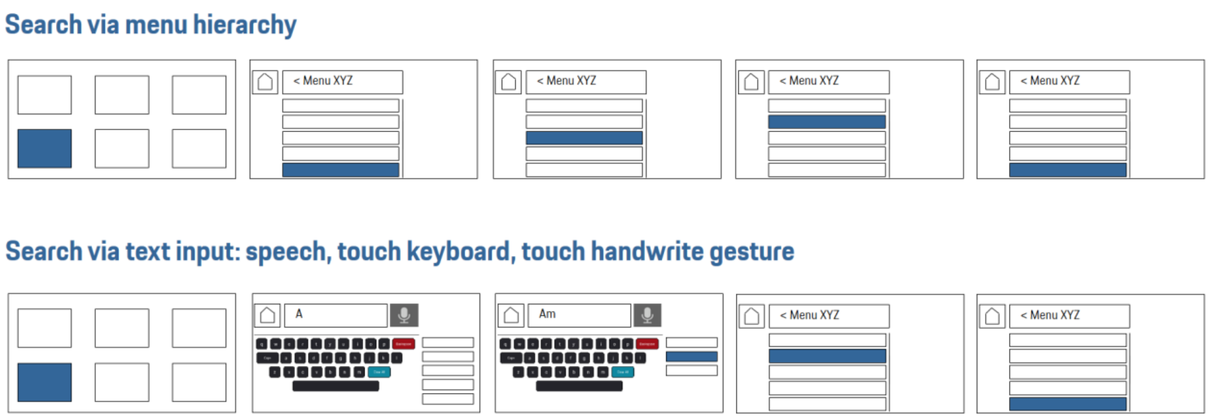

Figure 1: Exemplary procedure of IVIS tasks

The experimental protocol started with a training phase to get used to the n-back and IVIS tasks. After a 5-minute test drive without secondary tasks, four blocks of secondary tasks followed: Block A with n-back tasks, Block B1 with IVIS tasks, Block B2 with a repetition of the IVIS tasks and Block B3 with a second repetition of one of the IVIS tasks. Between the subjects, Block A and B and the tasks within the Blocks were in randomized order. Between the tasks there were recovery phases without secondary tasks. The experiment had a duration of approximately 75 minutes.

Data analysis

Cognitive workload was measured by three different types of measurement: physiological data, performance metrics and subjective ratings. (O'Donnell and Eggemeier [5]).

Regarding physiological data, blink-related measures (Marquardt et al. [6]) were recorded. However, due to several data-logging issues, this data is not part of the analysis. In order to measure performance within the primary task, driving data was observed. The standard deviation of distance to the lead vehicle and the standard deviation of lane position was measured (Rauch & Gradenegger [7]). Concerning secondary task performance, error-rate, number and duration of IVIS interaction events were measured. Regarding the subjective ratings, the mental dimension of the NASA TLX (Hart & Staveland [8]) was used.

To analyze differences between n-back tasks, IVIS modes and IVIS repetitions, non-parametric tests (Wilcoxon) were executed and can be found in the appendices.

RESULTS

Table 1 presents the results of the n-back tasks as well as the of interaction use cases. As cognitive workload measurements, the NASA TLX mental dimension, the variability of lane position and distance keeping and error rates are reported.

Task	N	NASA TLX [mental]		Distance	Lane position	Error-Rate	
		Mean	SD	SD	SD	Mean	SD
1-back	23	6.4	2.6	45.8	0.18	0.05	0.09
2-back	25	12.6	4.0	35.9	0.26	0.14	0.14
3-back	25	15.8	4.0	47.1	0.19	0.31	0.27
Menu 1	26	9.5	5.1	33.7	0.26	0.45	0.61
Menu 2	26	7.4	4.5	22.3	0.19	0.35	0.69
Menu 3	7	10.7	6.6	30.6	0.28	0.30	0.41
Keyboard 1	26	8.5	4.1	27.4	0.29	0.55	0.66
Keyboard 2	26	7.0	4.0	19.3	0.24	0.52	1.01
Keyboard 3	6	5.6	4.0	17.2	0.21	0.10	0.17
Gesture 1	26	8.3	4.7	38.8	0.31	1.57	1.70
Gesture 2	26	6.5	3.5	29.3	0.25	0.33	0.55
Gesture 3	7	5.0	2.7	23.4	0.25	0.00	0.00
Speech 1	26	5.6	4.2	23.2	0.24	0.01	0.20
Speech 2	26	4.5	2.6	21.6	0.20	0.00	0.13
Speech 3	6	5.7	2.6	15.2	0.14	0.06	0.13

Table 1: Cognitive workload of interaction methods

NASA TLX values and error-rates are quite robust indices for the increase in cognitive workload regarding the three N-Back levels, as can be seen in Table 1. There are significant differences between level 1 and 2 and between level 2 and 3. This is indicated by NASA TLX values (means: 6.4; 12.6; 15.8) and by error-rates (0.05; 0.14; 0.31).

Concerning the modes of interaction within the IVIS, only speech appears to be different to the others regarding the cognitive workload. NASA TLX ratings as well as error-rates are significantly lower than these of the three other modes.

Training effects can be observed at the menu and gesture task. There the cognitive workload appears to be significantly lower at the repetition of the trial.

An additional analysis of error-free task trials shows, that the impact of operating errors on the cognitive workload should be considered. Workload between the alternatives is more aligned in comparison to trials that includes errors.

DISCUSSION

The study examines the cognitive workload of interaction variations of an IVIS. Results show, that cognitive workload of the search function with text input mode via speech is lower than of the remaining variants: hierarchical menu selection, search with text input via touch keyboard and search with text input via touch gesture. Strayer et al. [2] also found a difference between voice interaction and interaction via center console, which supports this finding.

There seem to be no differences in cognitive workload between the haptic interactions presented in this experiment, although conceptual differences seem to be quite large (text input versus menu navigation). This could offer a high degree of freedom with focus on cognitive demand when designing IVIS interfaces.

Furthermore, our results show that there are training effects regarding cognitive workload of the hierarchical menu selection and text input by touch gestures. Maybe hierarchical menus need some training to know more about the logic of the structure and touch gesture inputs need some training how characters can be recognized by the system. The implemented speech task was quite fault-tolerant because of its Wizard-of-Oz approach. Text input by touch keyboard is often used by smartphone users, which could explain, that there are not so many training effects concerning these variants.

Finally, impact of operating errors on cognitive workload seems to be high and should be researched in further studies.

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Introduction

Information systems, which are widely integrated in vehicle, usually involve visuo-manual non-driving tasks, increasing visual demand and decreasing driving performances [1,2]. In this context, the display position is important as it may strongly influence the visual demand. Existing Guidelines assume that installation lower than 35° of vertical eccentricity have a detrimental effect on driving performance [3,4]. This effect results from time transition between eyes fixation towards road and information display and increase in cognitive load [5]. For example, when using GPS system, drivers need to move their eyes from the electronic map toward the real road environment to make two distinct cognitive processing: physical control of the vehicle and mental strategic decisions. As the effort required for these processing increases, the overall visual demand also increased [6]. Thus, assessing visual demand due to specific display installation with accurate tools is a fact of matter for traffic safety.

However, very few studies have assessed the visual demand involved by display installation. In a related experiment [5], the authors deducted effect of display position from breaking-reaction time to a visual stimulus, driving performance, and subjective rating while performing a non-driving task. Detection Response Task (DRT) should be an efficient and reliable tool for that purpose. The DRT is a standardized method, which consists in recording stimulus-response time during a secondary task: longer reaction times and reduced hit rate are indicative of higher cognitive load. Many researches showed that DRT is sensitive to the level of visual demand and cognitive load implied by non-driving task [ie. 7,8,9,10,11]. Different versions of the DRT, which use visual displays, are especially appropriate to capture the visual demand of a non-driving task. The stimulus can be a red light located on the dashboard (Remote DRT: R-DRT), or mounted on a head display (Head-mounted DRT: H-DRT) (Fig. 1), or a tactile stimulation (Tactile DRT: T-DRT).

Fig. 1. Left: head-mounted display; right: remote display

Sensory interference should mainly occur for the R-DRT because the stimuli appears in the visual periphery, or entirely outside the field of view, as gaze is directed away from the location of the DRT stimulus [12]. The H-DRT should be less sensitive to sensory interference since the stimulus remains in the same position within the field of view [12]. However, if the eyes move relative to the head, the H-DRT is potentially sensitive to visual eccentricity, due to the reduced sensitivity in the visual periphery [12]. Thus, R- and H-DRT may potentially be used to capture specific related-effect of the visual display eccentricity.

The present study aimed at investigating how visual demand is increased by the display position, using two visual versions of the DRT. Three visuo-manual tasks involving different levels of visual demand were compared. These tasks were performed with a display installed in two different positions. The hypothesis was that DRT would demonstrate a higher visual demand for the lower position than for the higher position.

Method

Sixteen drivers (25 to 45 years old) drove on a 2x2 highway in a driving simulator (CARDS3, Technocentre Renault). They were asked to perform three non-driving tasks: two modalities of a standardized task, and one navigation entry. Tasks were performed with an interface located in either a low or high position.

The DRT consisted in pushing a button when a red light appeared. The button was attached to the participant's index finger. For R-DRT, the red light was set on the dashboard. For the H-DRT, it was set on a head-mounted display (see Fig. 1). Reaction time and hit rate were recorded. Visual demand was assessed by performing the two DRT versions concurrently with the three non-driving visuo-manual tasks.

The standardized task was the Surrogate Reference task (SuRT: [13]). It is a self-paced search task with visual and manual components. It consists in locate a target (a big circle) among distractors (smaller circles). To indicate target location, the participants pressed the left-right keypad buttons to move a gray outline bar to the region that contained the target circle and pressed the "enter" key to confirm their selection. Two levels of complexity (easy and hard) were set in order to vary the level of cognitive load: difference in size and number of distractors made target easier to discriminate for Easy SuRT than for Hard SuRT condition. Task lasted 60 sec. Number of targets correctly detected, errors, and hit rate were recorded.

Navigation entry consisted in texting a destination with a navigation system. Drivers activated the system by touching icon of the application., a text zone and a keyboard were Then displayed. The city name was 7 letters long. After validation, the street name was 9 letters long. After validation, navigation started. Time from activation to starting navigation was recorded.

All tasks were performed with an interface located in high or low position (respectively 15° or 30° of visual angle below the view axis (see Fig. 2). Navigation entry and SuRT were expected to be more demanding in low than in high position.

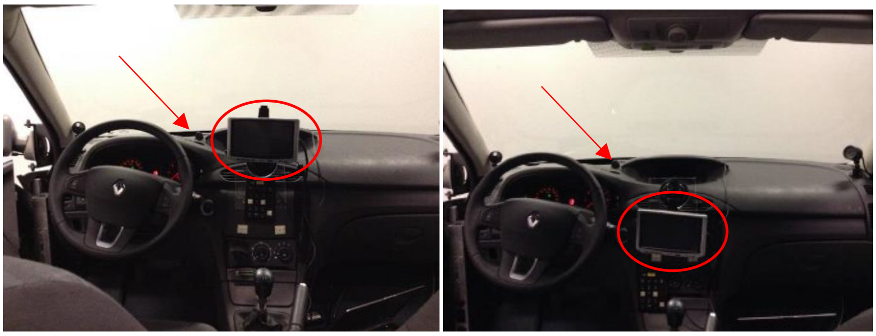

Fig. 2: experimental setting; display in high (left) and low position (right); arrow indicates localization of the remote stimulus for R-DRT

Results

H- and R-DRT indicated that visual demand was higher when participants operated with the display in the low position rather than in the high position (see Fig. 3): reaction times were slower ($F(1,15)=9.84$; $p<.007$), and hit rate was lower ($Z=2.85$; $p<.004$).

This result was supported by tasks performance: in low position, hit rate for SuRT was lower ($Z=2.94$; $p<.003$) and navigation entry was slower ($F(1,15)=7.74$; $p<.02$).

There were some differences between H- and R-DRT. First, reaction time for H-DRT tended to be faster than for R-DRT ($F(1,15)=3.96$; $p=.065$), but there was no significant difference according to the display position. Then, hit rate was lower for R- than for H-DRT in low position ($Z=3.39$;

p<.001). In-depth analysis showed that this effect was significant when performing navigation entry (Z=2.03; p<.05) and Hard SuRT (Z=2.41; p<.02). Finally, no difference was found for Easy SuRT, nor for H-DRT, according to display position.
Additional results suggested that H- and R-DRT discriminated visual demand involved by the different tasks. Thus, hit rate was significantly lower for Hard SuRT than for Easy SuRT (Z=3.53, p<.001), and lower for navigation entry than for Hard SuRT (Z=3.28; p<.001). There was no difference between H- and R-DRT. Reaction time was also slower when performing Hard SuRT than Easy SuRT (p<.01), but not influenced by display position. No more difference or interaction has been founded.

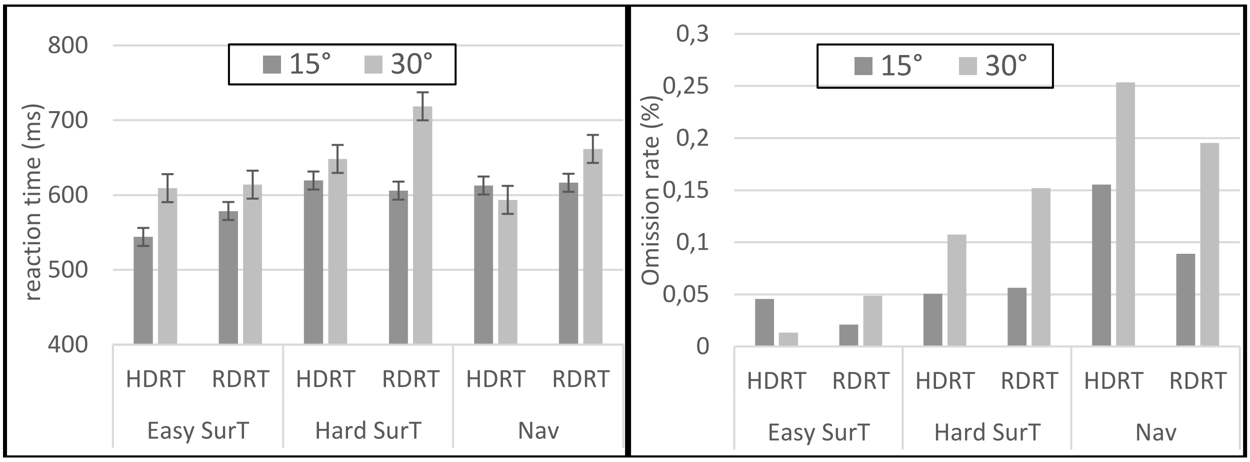

Fig. 3: left: reaction time for Task x DRT x display position; right: omission rate for Task x DRT x display position; Nav = navigation task

Discussion

Results show some effects of the display position. Reaction time and hit rate were both affected by a change of 15° of visual angle to perform a non-driving task. This effect confirmed results showed by [5] and indicates that DRT is an effective and reliable tool to assess visual demand involved by display position.
H- and R-DRT seemed to lead to some particularities in the task processing. While using R-DRT in a low position, lower hit rate and slower reaction time indicated that distance between DRT stimulus and display had an influence on the processing. It is consistent with the founding of Conti et al., and Vilimeck et al. [8,11]. However, the lack of interaction suggests that H-DRT was also, in some respect, subject to visual eccentricity effects.
Hit rate also indicated some difference in visual demand of the task. Navigation entry and Hard SuRT appeared more complex than Easy SuRT. However, this difference was observed in lower position only. Moreover, difference in DRT reaction time was found for Easy SuRT, but did not depend on display position. Taken together, results suggested that task performance involved specific aspects that were difficult to discriminate in the present study.

Conclusion

As expected, DRT appeared to be a relevant tool to assess visual demand involved by display position. This is an important result since installation of information system may impact traffic safety. The method provides benefits as it is inexpensive, easy and quick to implement. Moreover, these results have implication on the use of DRT itself. Installation of the tested-task interface should be carefully determined because it modulates visual demand assessment. Specific aspect of the tested task should also be taken into consideration.

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The TEORT Problem: Finding a Path to a Solution for Modern In-Vehicle HMIs

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Keywords: Attention management; Driver distraction; Glance metrics; Guidelines

EXTENDED ABSTRACT

The National Highway Traffic Safety Administration (NHTSA) of the U.S. Dept. of Transportation issued a set of voluntary visual-manual distraction guidelines for in-vehicle electronic devices in 2013 [1]. They were developed in response to a growing concern regarding the effects of distraction on motor vehicle safety [1-3]. This initial phase of a broader set of planned guidelines applies to original equipment in-vehicle human-machine interfaces (HMIs) operated through visual-manual means (i.e. involve a driver looking at a device, manipulating a device-related control, and/or looking for visual feedback/content) to engage in activities secondary to the primary driving task (e.g., communication, entertainment, information gathering, navigation). The purpose of the guidelines is to promote safety by discouraging the introduction of overly distracting devices in vehicles.

Functionally, the guidelines quantify visual-manual demand in terms of objective visual behavior. One method of meeting the guidelines is to demonstrate that at least 21 out of 24 participants from a defined age and gender balanced sample must fall at or under defined thresholds for three off-road glance metrics (mean single glance duration (<2 seconds), percentage of glances greater than 2 seconds (≤15%), and total eyes off road time (TEORT) (≤12 seconds)) during use of the HMI in specified driving simulation conditions [1].

While NHTSA describes these guidelines as being built upon principles developed as part of the earlier Alliance of Automotive Manufacturers (Alliance) guidelines [5], some important differences stand out, particularly as they impact the TEORT metric. One has to do with the definition of "eyes off road". Under the Alliance approach, metrics consider only glances to any controls or display associated with a device. In contrast, NHTSA's "off-road" designation applies to any glances not directed on the forward roadway. Thus, driving task-relevant glances to the instrument cluster to check vehicle speed, or to mirrors or out a window to check surrounding traffic all count as off-road glances under this definition.

NHTSA provided a pragmatic argument for this approach [6]. NHTSA-supported efforts ([6] footnote 105) found that eye tracking systems then in use did not have "enough accuracy to reliably characterize whether eye glances are focused toward the device upon which the task is being performed or toward some other in-vehicle location", but were practical to use when categorization was limited to on or off forward roadway regions. Recent analyses of field data [7-8] have found that during standard visual-manual HMI tasks such as manual radio tuning, drivers almost exclusively limited their glances to the forward roadway and to the HMI under test, thus making the off-the-forward-roadway simplification realistic for such assessments. Nonetheless, HMIs have evolved significantly in recent years and may include both visual-manual and auditory-vocal (i.e., multi-modal) interactions. The previously mentioned work [7-8] also shows that multi-modal HMIs frequently include glances to safety-relevant off-road locations (e.g. mirrors, etc.). The need to evaluate HMIs

that include substantive auditory-vocal (voice-based) components that seem to engender such driving relevant glances bring into question the use of glance metrics that monotonically assign "off-road" glances during the period of a secondary task interaction to the "minus" column of TEORT. A series of field studies [9-16] looking at actual production voice-based HMIs suggest that many multi-modal HMIs would have significant difficulty meeting the NHTSA TEORT metric if it were applied (Figure 1).

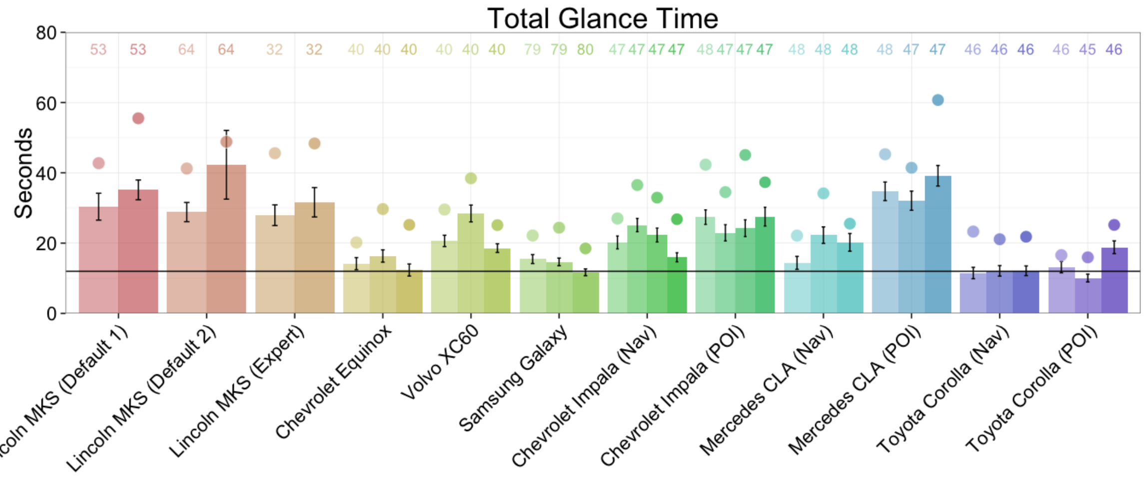

Figure 1. TEORT collected in the field across seven studies and six vehicle models during voice-based, multi-modal navigation address and point of interest entry [9-16]. Colored bars represent the sample mean, vertical lines the standard error of the mean, and colored dots the 85% point in the sample distribution for individual tasks. The horizontal line shows the threshold at or under which approximately 85% (21 out of 24 participants) (dots) should fall if the NHTSA metric were applied.

The Alliance guidance [5] from 2006 specifically recognized that the then just-emerging voice-based HMIs might require future modifications in guidelines. The subsequent NHTSA Phase I guidelines [1] specifically state that they are not "currently" applicable to the auditory-vocal portions of HMI devices. This begs the question of how "portions" are functionally segregated in a multi-modal HMI where varying degrees of supporting information may be displayed or remain on a display during "speaking" or "listening" portions of a task. It is critical to consider the totality of glance behavior during a multi-modal HMI interaction in order to more fully take into account potential impacts on functional distraction. Voice-based interfaces should not be given a "pass" simply because auditory-vocal components are present (see also [17]).

Recent efforts have explored the utility of reconceptualized and modified versions of Kircher and Ahlström's AttenD algorithm [18] to more broadly consider how attention is distributed across space and time, and to better understand how various features of resulting "attention buffer" metrics are associated with actual crash risk in naturalistic data [19-21]. Adjusted buffer metrics highlight substantive differences in patterns of glance behavior characterizing voice-based vs. primary visual-manual tasks across multiple HMIs (Figure 2). Reanalysis of existing field data indicates that further enhancements to the attention buffer model are sensitive to varying levels of cognitive load associated with auditory-vocal task engagement of working memory [22].

In brief, it can be argued that the TEORT metric has logical safety relevance in the context of classic visual-manual interfaces [23] that do not provide inherent task pacing. However, TEORT as used within NHTSA guidelines penalizes driving relevant glances to mirrors, the instrument cluster, etc. that are often present during longer multi-modal interface tasks. Further, it does not take into account the significance of on-road glance characteristics and the interleaving of off-road and on-road glances in impacting overall situation awareness [19]. The TEORT 12 second metric developed around the model of standard visual-manual radio tuning does not logically have the same applicability if appropriate-length glances off-road are interspaced with sufficient on-road glance time, which, as threaded in sequence, reflect attention management more similar to baseline driving. The modified attention buffer takes these factors into account and has been demonstrated to have safety relevance to actual crash risk [19-21].

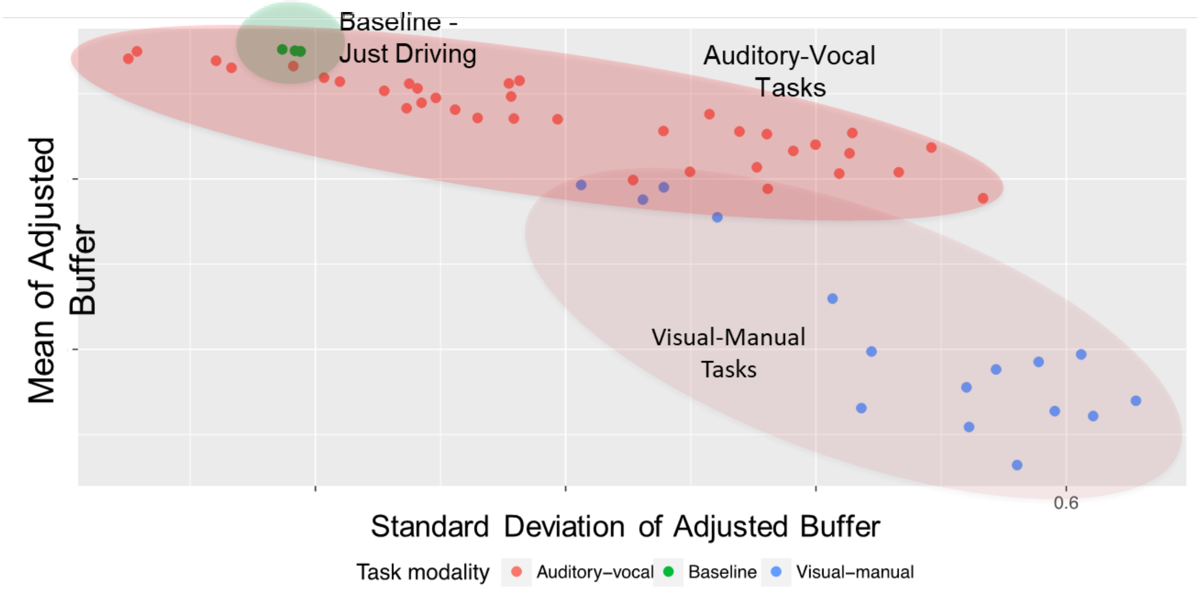

Figure 2. Attention buffer values for 56 HMI tasks across multiple vehicles in on-road studies.

This paper is intended to stimulate discussion and further efforts along a possible path toward a solution to the TEORT problem. Current NHTSA guidelines provide two options for assessing visual demands of HMIs: 1) Occlusion method, and 2) off-road Glance Metrics (mean single glance duration, percentage of long duration glances, and TEORT). Rather than replacing either of the existing options, this approach proposes adding a third. Under Option 3, the mean single off-road glance duration and percentage of long duration glance metrics would still apply (as both capture safety-relevant aspects of off-road glance behavior); however, TEORT (which can unfairly penalize modern, multi-step, multi-modal tasks) would be replaced by an attention buffer metric (which considers the strategic nature of how glances are distributed both off and on-road over the course of an HMI interaction). The rational for such an attention buffer metric would include, in part, a demonstrated link to safety in existing or to be developed naturalistic data. It is emphasized that this proposal does not call for removing or modifying the existing options, but to add an option that should allow for more appropriate assessment of the visual demand associated with multi-step, multi-modal tasks such as voice-based entry of addresses into a navigation system.

This proposal is referred to as a “path to a solution” as there is still work to be done on advancing a refined attention buffer model, developing guidance around a buffer metric, and developing basic science to support suggesting a threshold value for a new assessment option. While mean attention buffer values have been shown to differ significantly between crash and near-crash events [19-21], efforts are actively underway exploring a further hybrid measures that may provide more sensitivity in discriminating meaningful, safety-relevant HMI demand differences. Further collaborative investment by industry, academic partners, safety advocates, and governmental bodies are likely to enhance our shared understanding around how to reduce distraction and enhance supportive attention management in the vehicle.

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Using Visual Occlusion to Identify Performance Thresholds Associated with Search-and-Select Target Acquisition on an Automotive Touchscreen Interface

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Keywords: Distraction; Occlusion; Predictive Modelling; Touchscreen HMI; Visual Demand

EXTENDED ABSTRACT

Touchscreen human-machine interfaces (HMIs) are commonly employed as a secondary control interface within vehicles. While the benefits of using touchscreens in an automotive domain are frequently cited, they inherently demand some visual attention and therefore have the potential to distract drivers' visual attention away from the road scene. Experimental techniques and testing protocols, such as Eye Glance Testing Using a Driving Simulator (EGDS) [1], provide a robust methodology to assess the visual demand associated with such interfaces, but can be time-consuming and costly to conduct. Moreover, empirical approaches such as these may fail to satisfactorily address the potential effects of individual differences in participants' visual behaviour. For example, the inclusion of several 'long-glancers' [2] within a cohort of EGDS test subjects (i.e. individuals who are naturally inclined to make off-road glances in excess of 2.0s while driving), will increase the spread of distribution of glance data, potentially leading to erroneous results and assumptions if used to directly evaluate HMIs, determine acceptability, or build predictive models ([3, 4]).

In contrast, the occlusion technique [5] determines visual demand by controlling the pace and focus of primary/secondary task allocation. This is achieved by imposing regimented, periodic cycles of vision and blindness, intended to simulate the natural gaze pattern of a driver looking at an in-vehicle system ('shutter open') and then back at the road ('shutter closed'). Occlusion testing theory assumes that the mean duration of every glance away from the forward road scene is 2.0s, with 0.5s of this assumed to be expended by the driver transitioning their eyes away from (0.25s), and back to (0.25s), the roadway, prior to and after viewing the object/interface, thereby making a 'shutter-open' time of 1.5s. Using this technique, visual demand is typically measured in terms of the total time taken to complete a task when vision is available (total shutter open time, TSOT, i.e. number of cycles × shutter-open time), and task resumability (the ratio of TSOT to total task time when the task in undertaken with full vision). The occlusion technique is well-founded, with findings validated by naturalistic driving data [6], and naturally lends itself to modelling (i.e. without the need for hi-fidelity prototypes or extensive user trials) and summative evaluation. Moreover, by using the data obtained to inform predictive models, different stakeholders are able to consider the inherent visual demand of a large number of HMI, intended for in-vehicle placement, much earlier within the design cycle.

However, the predictive capability of occlusion is limited by its dependence on chunking vision into 2.0s glances. For example, it is quite feasible that a single button press could be achieved in a glance of less than 2.0s; applying the occlusion protocol, this action would likely be designated a full glance, and thus assigned a visual cost of 2.0s. To gain a more accurate assessment of the total visual demand associated with tasks/devices, it is important that the visual demand of specific actions or elements (particularly those requiring less than 2.0s) can be accurately determined.

Building on previous investigations [7, 8], we modified the occlusion technique by varying the shutter-open times (from 0.3 to 1.5s) to determine the shortest ‘glance’ that enabled ‘acceptable’ performance: this was defined by the time at which the error-rate performance dropped below the 85th percentile – an approach commonly employed to determine engineering and driving-related ‘acceptance’ criteria [see: 1, 9]. Examining single point-and-select target selections, we varied targets based on size, the number and array size/layout, and the presence or absence of structuring – factors that have been shown in previous studies to have a significant effect on visual demand [8]. The aim of the study was to extract accurate glance-time data associated with the underlying demands of the interface that are independent of the effects of individual differences, and could be subsequently used to inform existing predictive methodology (for example, the Extended Keystroke-Level Model (Extended-KLM) [7]).

Method

Sixteen participants (13 male, 3 female, aged between 18 and 55) took part in the study and received a £10 (GBP) shopping voucher as compensation for their time. Participants were asked to sit in the driver’s seat of a right-hand drive Honda car driving simulator to ensure that the experience was immersive and that the in-vehicle touchscreen (located in the centre console) was appropriately placed. In addition, participants were asked to locate their left hand (used to undertake target selections) on the steering wheel at a position approximating to ‘10 o’clock’ on an analogue clock face (marked by tape to ensure consistency); this also ensured that the distance to each target could be accurately determined for each participant. The targets were presented on an Apple iPad tablet using an interactive Microsoft PowerPoint presentation developed for the study. Vision was occluded using CogLens Occlusion glasses.

Targets were presented as either a single item, or multiple items in both structured and unstructured arrays. To investigate the effect of target size on performance, single targets (6, 12, 18 or 24mm squares, selected based on previous studies, e.g. [7]), were located randomly on the touchscreen. When vision was enabled (‘shutter-open’), the participant was required to locate and select the target as soon as possible by touching it. In situations when the shutter-open time was insufficient to complete the target selection (i.e. the participant’s hand had not yet made the selection), participants were instructed to attempt to complete the selection without vision. The dependent variable was thus defined as each participant’s success or failure to acquire the target (this was highlighted on the touchscreen and manually recorded by the experimenter).

To investigate the effect of multiple targets, arrays of 24mm ‘buttons’ (labelled with consecutive numbers) were arranged in 2×2, 3×3 and 4×4 matrices. For structured arrays, adjacent targets were numerically sequential; numerical labels were randomly assigned for unstructured arrays. During testing, the required target was randomly assigned and announced verbally to the participant (prior to the provision of vision). In addition, participants were advised of the size and layout of the array before vision was provided. When vision was enabled (‘shutter-open’), the participant was subsequently required to find and select the target containing the correct number. Participants experienced each matrix configuration on 3 consecutive occasions. A within-subjects design was employed for the study, ensuring that all participants experiencing all 3 tasks (single items, multiple-structured and multiple-unstructured) using each of the seven shutter-open times (0.3, 0.5, 0.7, 0.9, 1.1, 1.3 and 1.5s). The order of presentation of the tasks was randomised.

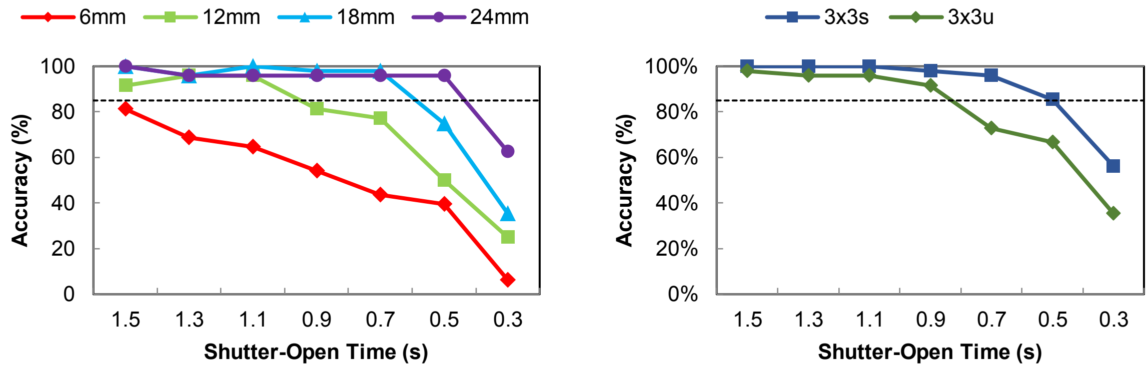

Figure 1. Performance associated with single targets (left) and multiple targets for 3×3 structured (s) and unstructured (u) arrays (right), showing 85% threshold.

Results and Discussion

Performance (% accuracy) was measured by determining whether participants successfully selected the required target. The results and analysis approach are therefore predicated on the assumption that failure to successfully select the target during the designated shutter-open time indicates that the time was insufficient, i.e. the target size and/or configuration demanded more vision (e.g. a longer glance). Mean performance was determined for each condition/target size and plotted against shutter-open time.

For single-target selection, mean performance was compared between the four target sizes (6, 12, 18 and 24mm) (Figure 1-left). Performance was generally lower for smaller targets throughout, suggesting that these are more difficult to acquire, as might be expected. In addition, as the shutter-open time decreased, the differentiation between target sizes generally became more pronounced. Moreover, the time interval at which the 85% performance threshold was transgressed varied considerably, occurring between 0.9 and 1.1s shutter-open time for 12mm targets, between 0.5 and 0.7s for 18mm targets, and between 0.3 and 0.5s for 24mm targets. Results also show that for the 6mm target size, performance never reached the 85% threshold, even with the longest 1.5s shutter-open time, suggesting that targets of this size are unsuitable in an automotive domain (i.e. too small to be accurately selected during a 2.0s off-road glance).

For multiple target arrays, performance was generally lower for unstructured layouts (compared to structured) and also degraded sooner. In addition, the differentiation between structured and unstructured performance became more pronounced as the shutter-open time decreased. Again, the time interval at which the 85% performance threshold was breached varied considerably, with performance dropping below this level between 0.7 and 0.9s for 3×3 unstructured arrays, compared to at approximately 0.5s for the 3×3 structured array (shown as an example in Figure 1-right). Similarly, for 4×4 arrays, performance dropped below 85% between 1.3 and 1.5s for the unstructured array, and between 0.5 and 0.7s for structured arrays. These results highlight the importance of structuring layouts to improve performance, particularly with larger array sizes.

In addition to general design recommendations, the results can be used to assign new visual demand operators, based on target size and configuration, to inform predictive methodology. Future work will aim to incorporate the findings within the extended-KLM model and consider a wider range of touchscreen gestures.

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Behavioural Fidelity of Driving Simulators for Prototype HMI Evaluation

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Keywords: behavioural fidelity, driving simulator, HMI prototyping

EXTENDED ABSTRACT

Introduction

The use of driving simulators in the context of driver-HMI interaction has been established both in industry and academia for driving behaviour studies both for prototype interface evaluation and driver distraction research. In both contexts, the aim is to provide critical information for the driver's safety, hence the results are required to be as reliable and accurate as possible. Research on the behavioural fidelity of driving simulators (commonly referred to as behavioural validity), i.e. the degree to which they can elicit a driving behaviour similar to that observed in real world conditions has been documented in the past (e.g. [1]) in order to evaluate the reliability of driving simulators as evaluation tools. Furthermore, experimental guidelines [9] have been formulated in attempts to establish a robust testing regime for prototype HMI evaluation. However, there has been minimal research on whether the minimum requirements on a simulator may vary with performance metrics being studied.

The present paper provides an overview of the main metrics that have been considered in the context of prototype HMI evaluation, and the level of behavioural fidelity that can be expected in different types of driving simulators, based on a review of the existing literature, complemented with a new simulator study, to fill in an identified gap.

Review of relevant literature

The literature search regarding behavioural fidelity of different simulator settings was restricted to publications directly comparing real world with simulated driving in the context of HMI evaluation (using visuo-manual HMI tasks). This yielded 5 relevant papers (see [2, 5, 6, 7, 8]), the results from which were used to infer driving simulator behavioural fidelity for different metrics and settings.

The prevalent analysis conducted in those papers was statistical analysis of variance (ANOVA). The significance scores in those cases were used to infer behavioural fidelity (a significant difference here could only be an indication of a possible absolute behavioural fidelity since we did not have an estimate of effect sizes).

The most common types of simulators used are fixed base and fully-moving base simulators. No testing has been published that was conducted in a hexapod-only driving simulator. Such simulators show great potential since they provide some motion but at lower cost than the bigger motion systems with translation capabilities.

Driving study design, tools and methods

The testing environments used were a real-world test track and a simulated version of that test track in the University of Leeds Driving Simulator (fixed base and hexapod motion configurations). A total of 23 participants took part in this study, 12 in the simulator and 11 in the test track. The primary driving tasks throughout the whole study and across all conditions were car-following (at a constant headway) and lane keeping.

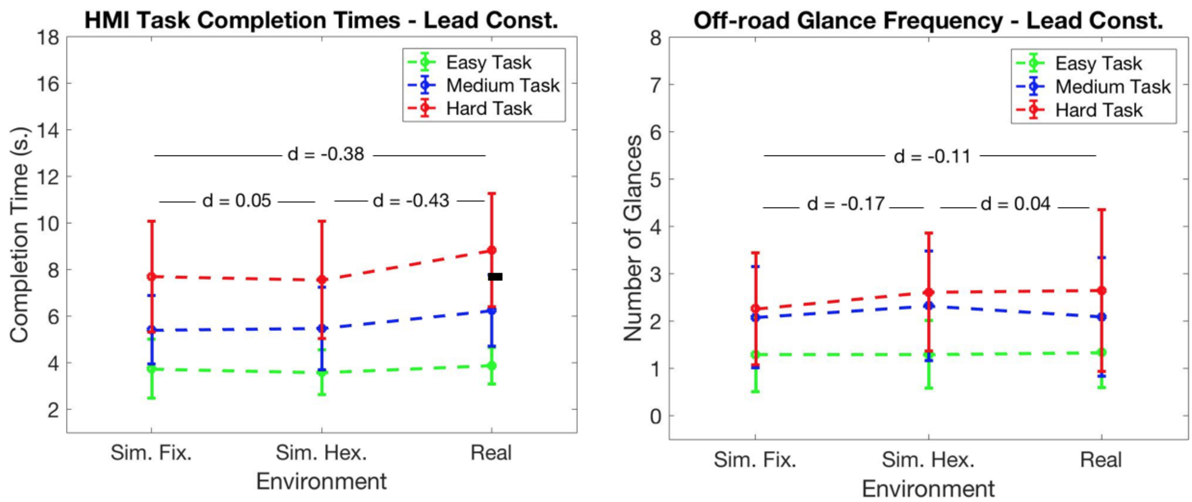
Two different scenarios were implemented in the study, under each condition:

1. the lead vehicle travelled at a constant speed of 50 mph and
2. the lead vehicle travelled at a varying speed between 60 and 70 mph, following a semi-randomised speed profile

Three HMI, visuo-manual tasks of varying difficulty, similar to ones that are usually found in production vehicle interfaces, were used in this experiment.

Behavioural fidelity analysis

The analysis focused on identifying how big the differences were between simulator and reality across different driving scenarios and HMI tasks, for various performance metrics, as well as whether these differences were statistically significant or not. In particular, the statistical analysis aimed at identifying main effects of Environment (real world, fixed base and hexapod), HMI Task and Scenario, as well as the effects of their two-level and three-level interactions. A mixed effects model analysis [4] was conducted, where all fixed and random effects along with all level interactions were investigated. Effect sizes of differences between the various conditions were measured using *Cohen's d* [3].



(a) (b)

Figure 1 Sample effect plots for different metrics, used to infer driving simulator bhavioural fidelity.

Magnitudes of effect sizes were used to infer the level and type of behavioural fidelity of each simulator setting, for a multitude of performance metrics. A small effect size (d < 0.2) was interpreted here as absolute behavioural fidelity, a medium effect size (0.2 < d < 0.5) as possibly absolute behavioural fidelity, and a large effect size (d > 0.5) as indicating absence of absolute fidelity. The paper will discuss why, in investigations of behavioural fidelity, it is important to consider effect sizes and not focus solely on significance testing. For relative behavioural fidelity, the relative differences between conditions must be preserved.

Figure 1 provides two example results from the study. Figure 1(a) shows that the relative differences in task completion times are preserved throughout all conditions; i.e. indicating relative behavioural fidelity. Given the medium effect sizes, also a possible absolute behavioural fidelity can be concluded. Figure 1(b) on the other hand shows a strong indication of absolute behavioural fidelity for glance count, given the small effect sizes between each simulator setting and reality.

Conclusions

Table 1 provides an overview of the combined results, from literature review and study, on behavioural fidelity for various metrics given different simulator capabilities.

Dark green	Absolute
Light green	Possibly Absolute
Dark blue	Relative
Light blue	Possibly Relative
Grey	No relevant literature

		Simulator Type								
Test Target	**Typical Metrics**	**Occlusion**	**Desktop**	**Cabin with narrow field projection**	**Cabin with wide field projection**	**Hexapod**	**Hexapod and lateral motion**	**Hexapod and longitudinal motion**	**Full motion**	**Virtual Reality**
HMI Task Execution	Completion time	Relative	Relative	Possibly Absolute	Possibly Absolute	Possibly Absolute	Absolute	Absolute	Possibly Absolute	No relevant literature
Gaze behaviour	Total Glance off road time	Relative	Possibly Relative	Possibly Absolute	Possibly Absolute	Possibly Absolute	Possibly Absolute	Possibly Absolute	Absolute	No relevant literature
	Total Glance on road time	Relative	Possibly Relative	Possibly Relative	Possibly Relative	Possibly Relative	Possibly Relative	Possibly Relative	Possibly Relative	No relevant literature
	Single Glance off road time	Relative	Possibly Relative	Possibly Relative	Possibly Relative	Possibly Relative	Possibly Relative	Possibly Relative	Possibly Relative	No relevant literature
	Off road glance frequency	Relative	Possibly Relative	Possibly Relative	Possibly Absolute	Possibly Absolute	Possibly Absolute	Possibly Absolute	Possibly Absolute	No relevant literature
	Percentage of long off road glances	No relevant literature	No relevant literature	No relevant literature	Possibly Relative	Possibly Relative	Possibly Relative	Possibly Relative	Possibly Relative	No relevant literature
Lateral Control	SDLP	No relevant literature	Relative	Relative	Relative	Relative	Absolute	Absolute	Possibly Absolute	No relevant literature
Longitudinal Control	Speed / HW variation	No relevant literature	Relative	Relative	Relative	Possibly Relative	Relative	Relative	Possibly Relative	No relevant literature
	Average speed	No relevant literature	Relative	Relative	Relative	Possibly Relative	Relative	Relative	Possibly Relative	No relevant literature
Steering Control	SWRR	No relevant literature	Possibly Relative	Possibly Relative	Absolute	Absolute	Possibly Absolute	Possibly Absolute	Possibly Absolute	No relevant literature

Table 1 The matrix illustrates the different types fo behavioural metrics that could be investigated in a prototype HMI evaluation study along with the level of behavioural fidelity that could be achieved under different driving simulator configurations,

For cells in the matrix where no data were available a logical assumption was made as to the level of behavioural fidelity, based on surrounding observations.

A main finding from our own study was that there was no perceivable difference in behaviour between the fixed base and the hexapod configuration, indicating that an affordable fixed based simulator can be used in many cases. Moreover, the majority of our behavioural fidelity findings for the fixed base simulator, aligned with what has been previously reported; the observed differences could be attributed to either the small sample size (especially this having been a between-subject design) or individual differences betwwen the subjects.

The main conclusion from the work carried out here is that there is no single answer to what kind of simulator one would need to perform reliable HMI evaluation. Instead, it is highly dependent on the types of performance metrics that are of interest, as well as the level of behavioural fidelity that needs to be achieved. The results in Table 1 indicate that relative fidelity conditions, which may be sufficient for many HMI testing applications, can for many metrics be achieved with very simple, hence cost-efficient simulator types.

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Self-regulation of mobile phone use while driving: reflections from a PhD research project

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Keywords: Behavioural Adaptation; Risk compensation; Research design; Human-machine system; Inattention; Dual-task

EXTENDED ABSTRACT

The relationship between mobile phone use while driving and road safety is a topic of much debate in the human factors literature. A clear example of this is the lack of consensus across research studies. For example, the NHTSA [1] compiled results from naturalistic studies and concluded that mobile phone conversations seem not to be directly associated with crash risk. This finding is not isolated and similar results have been described previously [2, 3]. However, cognitive distraction due to mobile phone conversations is a significant concern as noted in numerous studies [4, 5]. There is no doubt that further research is needed to reduce uncertainty and disagreement about how the use of mobile phones influences driving behaviour and safety.

A recurrent issue in the distracted driving literature is that, under certain circumstances, distracted drivers' behavior seems to be intended to mitigate safety threats. These allegedly safe driving behaviours include reduced speed [6-8], increased headway [9], and hard braking [10, 11], among others. On the other hand, empirical research has shown that drivers engaged in mobile phone distraction could prioritize their driving task over their mobile phone use [12]. However, at this stage, there is little confirmation that any behavioural changes in mobile phone distracted driving could decrease crash risk/injury severity or compensate for the distraction.

"Risk compensation" implies knowledge that the mechanisms/processes involved in the behavioural change are leading towards a safer net effect, which is rather speculative in this case. In this research, these seemingly safe behaviours are labelled as "behavioural adaptations". In road safety research, the term "behavioural adaptation" is mainly used to signal unexpected or unanticipated behavioural changes that appear in response to a change in the transport system. Mobile phone use while driving changes the structural complexity of the driving task and potentially results in a new net level of safety performance [2]. Drivers are expected, as the principal component of the system, to use behavioural responses to moderate the changes in demand [13]. In particular, Young and Regan [14] proposed that drivers can engage in a range of behavioural adaptations to mitigate risks associated with competing demands (also called self-regulation). The Behavioural Adaptation Theory (BAT) is a descriptive label for Young and Regan's [14] postulate that self-regulation by distracted drivers occurs at three distinct levels: operational, tactical, and strategic.

Operational self-regulation includes changes in the driving performance (lateral and longitudinal vehicle control) intended to manage the additional workload due a mobile phone task. This investigation proposed that operational self-regulation resembles a Human-Machine System (HMS). This means that both driving and mobile phone tasks are closely related in that the mobile phone task is benefited if driving performance decreases and vice versa. This is quite logical given that the mobile phone and vehicle are competing simultaneously for the driver's cognitive and physical resources.

Tactical self-regulation includes prioritisation of driving by splitting mobile phone tasks into multiple parts. At a tactical level, drivers select where and when to engage in mobile phone tasks and use the phone while the vehicle is running under certain circumstances.

Strategic self-regulation describes the decision to never engage in mobile phone tasks while the vehicle is running (e.g. turn the phone off while entering the vehicle or pulling over to interact with the phone). Additionally, BAT explains that self-regulation is the product of changes in the secondary task demands, the driver characteristics, and driving task demands.

Aim and scope of the study

This PhD research project explored the HMS framework and BAT in the context of mobile phone distracted driving. Relationships between these frameworks have been organised into a new model as seen in Figure 1. This new model includes the role of driver characteristics, secondary task demands, and driving task demands at the three levels of self-regulation: strategic, tactical and operational. Knowledge about the mechanisms by which drivers self-regulate mobile phone usage while driving is vital for the effective design of system-wide countermeasures [15].

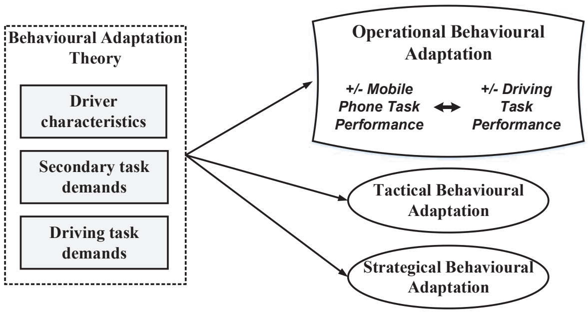

Figure 1. A new model for behavioural adaptation in distracted driving.

Materials and methods

This extended abstract reports on a PhD research project that employed four methods: a systematic review, a driving simulator experiment to examine operational decision making, another driving simulator experiment to investigate strategic and tactical decision making in addition to operational self-regulation, and a cross-sectional questionnaire. The systematic review technique included a systematic review of original research articles and meta-review of other literature reviews. A systematic classification scheme of articles was designed using the HMS framework. Two driving simulator experiments were conducted in the CARRS-Q Advanced Driving Simulator. In experiment 1, participants were asked to drive in two scenarios while conversing with a handheld and hands-free mobile phone without stopping the task to investigate effects on the driving performance. In experiment 2, participants were given a set of four tasks (1. to ring the Doctor’s office and cancel an appointment, 2. to text a friend and tell him/her that they will be arriving 10 minutes late, 3. share the Doctor’s phone number with a friend, and 4. take a selfie) that they could perform in any order and at any moment that they considered appropriate. Finally, a cross-sectional study examined decisions to engage in mobile phone distraction in South East Queensland.

Results and Conclusions

Consistent with previous research, this PhD research has confirmed that distracted drivers initiate operational changes in driving to integrate the secondary task. First, results showed that while engaged in uninterrupted mobile phone conversations, drivers reduced their driving speed. This result added further confirmation to the findings of naturalistic studies [8, 16], experimental investigations [17, 18], and self-reported experiences [19, 20] corroborating that mobile phone distracted driving results in drivers decreasing their driving speed. Reduced speed could offer safety advantages in terms of crash likelihood or injury severity. Second, this research also confirmed the appropriateness of using a HMS framework to study operational self-regulation. Mobile phone distracted driving affects both driving and performance in the secondary task. Specifically, this research confirmed and explained theoretical changes in secondary task performance as being part of operational self-regulatory strategies. Findings from the second driving simulator experiment showed that when possible, some drivers decide to suspend a mobile phone task and re-engage in it at a later time. These results support previous research, which showed that drivers conversing on a mobile phone have suboptimal speech production rates and less accurate cognitive processing [12].

Evidence for tactical and strategic self-regulation was observed in this PhD research. Tactical self-regulation corresponds to the decision that drivers make about when or where to engage in mobile phone distracted driving. Using self-reported data, this thesis demonstrated that a driver's intentions to engage in multitasking can vary from location to location. While driving in a controlled environment, drivers showed a preference for engaging in mobile phone use at times when the vehicle was stopped, e.g. waiting at a signalised intersection. Confirming the existence of tactical self-regulation has important implications for police enforcement and road safety research. Additionally, this thesis has confirmed the need for making fair comparisons in the estimations of crash risk due to mobile phone distracted driving. Given that this thesis found that drivers use their phones in specific contexts, their decision-making process should be included in risk assessment activities (e.g. to match baselines and mobile phone use while driving sequences on a scenario basis as suggested by Tivesten and Dozza [21]).

Strategic self-regulation is defined as the decision to avoid mobile phone usage while driving. Data from this thesis confirmed that nearly 50% of drivers never engage in mobile phone tasks such as looking at a handheld phone for more than two seconds or speaking with a handheld mobile phone. The findings of the current study were consistent with other studies in Australia which found that 29% of drivers reported using a hand-held mobile phone for conversations and 28% reported sending a text message [22]. Although it is positive that strategic self-regulation is utilised by a substantial proportion of drivers, the number of drivers engaging in visual-intensive mobile phone tasks remains significant.

The proposed new behavioural adaptation model for mobile phone distracted driving assumes that personal characteristics have an influence on self-regulation. This was consistently supported by empirical outcomes in each of the phases of this thesis. Two main elements were considered: demographic characteristics (e.g., age, gender, driving experience) and cognitive resources (e.g. attitudes and beliefs). Younger and less experienced drivers tended to modify their driving behaviours towards a safer position to perform mobile phone tasks. Female drivers were more likely to engage in mobile phone tasks such as talking and texting while driving than males. On the other hand, drivers with more positive safety attitudes made decisions such as: (1) reducing their driving speed while using the phone [23], (2) were less likely to engage in a mobile phone task at any given time, and (3) were less likely to use strategic self-regulation for tasks such as texting/browsing.

Secondary task demands were hypothesised to influence self-regulation in distracted driving. This investigation explored a wide range of tasks (e.g. texting, ringing, etc.) and interfaces (e.g. handheld, hands-free, etc.) as proxy measures of secondary task demands. In terms of mobile phone tasks, findings confirmed that drivers are more likely to make decisions to never use the phone (strategic self-regulation) or to never engage at any location in visual-manual tasks such as texting compared with talking (tactical self-regulation) [24].

Driving task demands were also included in the new model of behavioural adaptation for mobile phone distracted driving. Two main strategies were used to study the impact of driving demands on self-regulation. First, the traffic complexity features that influence self-regulation were identified and their impact on self-regulation was measured. In the case of mobile phone conversations, drivers substantially modified their speed in the presence of urbanisation, ongoing traffic, and winding roads [25]. Second, driving complexity was measured as perceived workload. Results confirmed that, generally, a large perceived workload is associated with less self-reported likelihood of engaging in multitasking.

This research advances prior empirical work on self-regulation and mobile phone distracted driving. However, it is important to bear in mind that the operationalisation of the variables was adapted from previous research studies or through the original contributions of the author. Hence, it could be possible that refinement or improvement of the methods and tools used in this thesis could better describe the relationships identified in this research.

Acknowledgment: This work was derived from a PhD research, supervised by Dr. Md. Mazharul Haque, Dr. Mark J. King, and Prof. Simon Washington, at Queensland University of Technology (QUT), Australia.

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Extended Abstract for the 6th International Conference on Driver Distraction and Inattention (DDI2018)

Digitalisation in the infotainment: Driver needs and requirements - an explorative approach

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Keywords: Conjoint Analysis, Driver Needs, Infotainment, Online Survey, Smartphone, Workshop.

AIM & SCOPE

As the automotive world faces the digital revolution, new and extended functions, will be available both on smartphones and in the in-car infotainment systems [1], increasing the amount of information provided to the driver [2]. Furthermore, drivers today use their mobile phones and personal digital assistants more frequently while driving [3, 4, 5]. As a visually-manually focused task [2], driving interferes with any other task demanding the same modalities [6]. According to the Task-Capability-Interface-Model, an imbalance between a driver's capabilities and the task demands can lead to a loss of control [7]. Although drivers are well aware of the distracting effect, they do engage in secondary tasks nonetheless. The recent US-American naturalistic driving study SHRP2 found an increase in crash risk due to operating in-vehicle devices by an odds ratio of 2.5, leading to 3.53 % of all observed accidents [8]. Further, the usage of nomadic devices while driving was found to have an odds ratio of 3.6 causing 6.40 % of all observed accidents [ibid.]. Equally, the European naturalistic driving study UDRIVE found the most distracting activities to be primarily located in the middle console [9]. One motivation for engaging in secondary tasks while driving can be the context, which influences the driver's needs [10, 11, 12, 13].

In order to understand driver's needs and requirements in extending infotainment functions, an explorative approach, consisting of creativity workshops, focus group and an online survey, was pursued. The following research questions were posed (Figure 1):

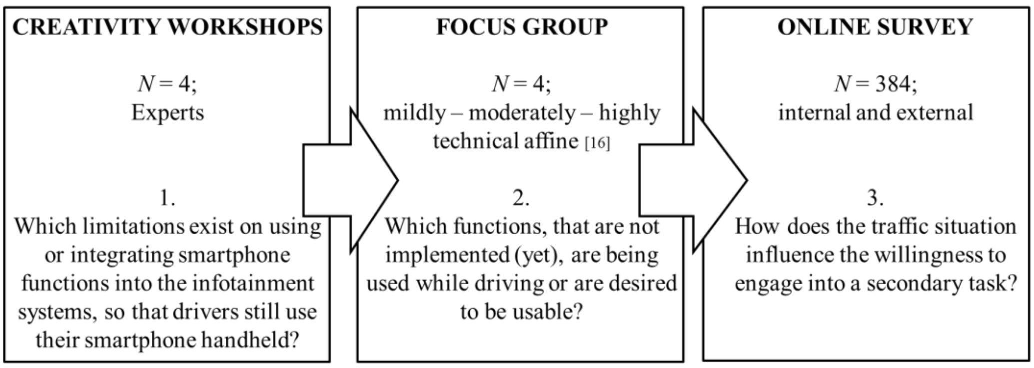

Figure 1. Methodology of the explorative approach.

METHODS OF THE EXPLORATIVE APPROACH

Creativity workshops

Two creativity workshops were conducted with N = 4 experts in infotainment HMI engineering. The first workshop used the Double Reverse Technique [14], and was intended to identify elements of smartphone functions that make these functions uncomfortable to use or restrict them from using while driving. Smartphone functions were categorised into communication, navigation, media, browsing and other. The second workshop used the Brute Think Technique [ibid.] to identify HMI characteristics that can be used to implement these solutions.

Results. For the in-car use while driving, too much information is shown. In addition, many input steps are necessary to execute the intended function. Using the smartphone while driving is uncomfortable; not only because of hand position, the position of the center-stack display, or the provoked distraction, but also because of the cognitive dissonance perceived by drivers.

Focus group

A focus group [15] was conducted to further investigate driver's motivation to use a smartphone while driving. Based on an online screener, N = 4 participants were chosen based on their technical affinity, which was assessed using the Questionnaire on Technical Affinity (TA-EG [16]). According to the distribution, one participant of the 33rd, one of the 66th, and two of the upper percentile participated. Three male and one female participants took part, with a mean age of M = 43.5 years (SD = 13.08, range = 26-54 years).

Procedure. The first part consisted of participants individually filling a worksheet asking for currently in-car used nomadic devices, desired functions, strategies to avoid distraction and potential designs to improve usage. The second part consisted of an open discussion, debating an order and requirements for preferred implemented features.

Results. The two technically less and moderate affine participants mentioned avoidance of smartphone use while driving, since their cars' infotainment systems lacked phone projection applications. The other two, technically high affine participants use AndroidAuto or Apple CarPlay daily, but still missed some functionalities. Therefore, they intentionally disconnect their smartphones due to restricted functions, i.e. scrolling down long lists, or not implemented functions, i.e. recording voice messages. All participants stressed the wish to use the smartphone while driving to communicate and to navigate, especially when their in-car navigation systems did not provide live traffic. Participants reached consensus on the need for a less distractive system that still fulfils their needs. Therefore, the usage of the infotainment system shall be easy and intuitively understandable. Further, one participant mentioned to *"use the smartphone to receive, read and write text messages, which is not optimal in every traffic situation"*. Participants agreed that one main factor for the decision whether or not to use their smartphone while driving was the driving situation.

Online survey

In order to investigate the effect of the driving situation on the willingness to engage in a secondary task an online survey was conducted.

Participants. All participants held a valid driver's license. N = 384 persons (23.7 % female) took part in the online survey. Participants were M = 45.08 years old (SD = 9.57, range: 20-75 years).

Measures. Technical affinity was assessed using the TA-EG [16]. Driving Style was rated using the short version of the Multidimensional Driving Style Inventory [17], adapted to and validated in Europe by [18]. Two items on the wish to use and connect the smartphone with the infotainment system were included [13]. The knowledge on and usage of new media were assessed. Further, the willingness to engage in a secondary task depending on the traffic situation was investigated.

Context. Traffic situation profiles were generated using the context factors adapted from [10]. A traffic situation was defined by street (city, rural, highway), landscape (flat, hills, trees), traffic density (low, moderate, high), weather (dry, rain, snow) and daytime (day, night).

A choice-based conjoint analysis (CBCA) was chosen to assess willingness to engage in a secondary task in a traffic situation. Participants were asked to choose the one traffic situation in which they would not engage in the secondary task. Alternatively, they could choose the none-option of "*I would use the function in each of the traffic situations*". Whether the task was to be executed on an in-vehicle display or a hand-held device was not of importance.

Secondary Tasks. Following the Multiple Resource Theory [6] secondary tasks covering the four modalities and both encoding strategies were evaluated. The six secondary tasks were *reading a text message* (visual, verbal), *typing a text message* (visual-manual, verbal-spatial), *watching a video* (visual-auditory, verbal-spatial), *talking on the phone hands-free* (cognitive-auditory, verbal), *mentally making a shopping list* (cognitive, verbal) and *adjusting the music volume* (manual, spatial).

Results. Figure 2 shows the results of the CBCA on willingness to engage in the secondary task while driving. A higher percentage indicates a higher probability of a decision against engaging in the secondary task.

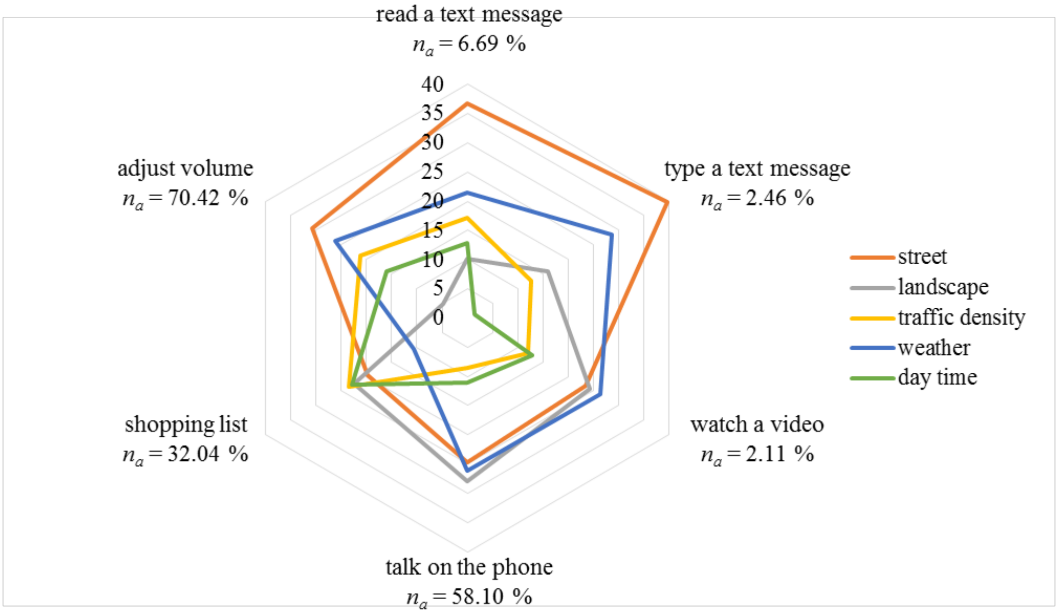

Figure 2. Relative importance of context factors on willingness to engage in a secondary task in percent. *Note.* n_a = percentage of participants willing to use the function in each of the given traffic situations.

CONCLUSION

The expert workshops and the focus group revealed, that spending the driving time usefully was the main motivational factor for participants to use their smartphones while driving. Nonetheless, they did not want to be distracted. The need to be informed about the environment, including participant's social network and traffic circumstances, was highlighted. The online survey found differences for the interactions between type of secondary task and traffic situation. Context factors were found to have different effects on the willingness to engage in the secondary task in question. Especially for the context factor street type, the demanded modality (secondary task) effect showed the highest impact. Both the focus group and the online survey confirmed [10, 11, 12, 13] findings on the context-depending changes of driver's needs and requirements.

The cascade of the explorative approach, consisting of expert workshops, a focus group and an online survey, provided a feasible way to obtain a comprehensive understanding of driver needs and requirements in extending infotainment features. For automotive manufacturers, designing an infotainment system that fulfils both the need for information and reduction of distraction is desirable.

In order to resolve the contradiction of wanting to be connected without being distracted, compensatory behaviour of drivers while engaged in secondary tasks in different traffic situations needs to be explored and understood. As a further step, current infotainment systems can then be designed and adapted accordingly.

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Phone use and motives of professional drivers: a focus group approach

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Keywords: Distraction, mobile phone, professional drivers, focus groups, survey

INTRODUCTION

Professional drivers differ from other drivers in many ways. In addition to their greater level of exposure (i.e. they drive many more kilometers than the average driver does), they are often required to plan or manage part of their professional activity while driving. A French national survey show that 69% of employees call or answer the phone during their business trips [1], while 38% of all French drivers use their phone while driving [2]. Although phone and GPS use is considered by French business leaders as the main cause of professional road accidents, before stress and fatigue [3], more than half of employees who use a professional vehicle believe that their professional needs include answering to the phone while driving [1]. Professionals are then distinguished from other drivers by a much more frequent use of the phone [2,4,5], which becomes a key media to reach colleagues, customers, suppliers or companies, while maintaining a link with the private sphere. In this context, it is likely that their attitude towards phone use also differentiates them from the rest of the population. Unfortunately, there is very little knowledge about professional phone practices according to their profiles, particularly because of the great diversity of professionals.

In this context, the TELPROF project funded by the DSR (French Ministry of the Interior - Delegation for Road Safety) aims at describing phone use while driving by professional drivers, in order to understand better the diversity of their needs and motives, in relation to their characteristics.

Two main groups of professionals have been investigated [6], commuters being excluded. The study therefore focuses on a) professionals of the road, whose main task and job is to transport goods or people, and on b) mobile professionals who move to pursue their occupation or activity.

METHOD

Two complementary approaches are used. First, a qualitative exploration of attitudes and behaviors is carried out through focus groups. Four groups are investigated: two groups of professionals of the road, and two groups of mobile professionals (27 participants: 20 men & 7 women, age 24 to 52). The first group brought together deliverymen/women who make frequent stops on moderate distance journeys. The second brought together professionals who spend the majority of their working time in their vehicles, including truck drivers (long journeys), and taxi or Uber-like drivers. One group of mobile professionals was long-haul salespeople and the other service employees and technicians who made shorter but more frequent journeys.

This first step served as a basis for designing a questionnaire that is administered as part of a large-scale online survey (930 respondents), which constitutes the second step of the study. Analyzes are in progress and not reported here. However, main results should be provided soon.

MAIN RESULTS

Oral phone conversations. If phone conversations are frequent while at the wheel, they take very different forms according to the groups, the type of journeys and the professional functions of the driver.

- When conversations are chosen by the drivers, they are usually long if not extremely long. They are sometimes considered as a critical need: to occupy a long and monotonous driving time (truck drivers or salespeople), to fight against falling asleep while at the wheel (truck drivers) or as a valve of freedom to withstand stress and loneliness (deliverymen). These conversations are usually uncomplicated, without much personal investment and tend to substitute radio listening. To that extend, they do not raise a high cognitive demand and their effect on the driving could be low.
- Imposed conversations (incoming or outgoing calls) are usually shorter, but complex. For some salespeople and technicians, these conversations are extremely numerous. They are experienced as painful, exhausting and incompatible with a safe driving. Some drivers even declare that they need to stop or reduce speed when they occur. Even when infrequent (deliverymen or truck drivers), they require responsiveness that generates stress because they are often related to destination, or planning.
- Group communications are also reported (truck drivers and salespeople). They are often described as opportunities to exchange with colleagues that sometimes considerably simplify their work.

Written phone exchanges and use of applications. The written is also present. While professionals of the road tend to practice more SMS and private exchanges, mobile professionals do much more professional exchanges and e-mails. A significant number of participants say that they read a lot of e-mails while driving and some of them also write.

Smartphones do not only allow the drivers to access their e-mails while driving, but to use lot of applications including social network application or instant messengers (eg WhatsApp). While some drivers use them mainly for recreational purposes, these new opportunities are largely invested for business purposes especially by mobile professionals. In that context, phone features are more or less known and used depending on the groups. The biggest users of complex functions are usually those who know their smartphone best. This knowledge sometimes allows them a safer use (use of voice commands for example).

Such types of exchanges confirm the status of a working tool to the phone, which makes the driver reachable and productive even while driving. The portability of the data, the fact the phone centralizes all information (contacts, diaries, documents, applications) give a greater responsiveness to the drivers and reduce the time considered as lost while driving. Moreover, it seems that such a responsiveness could be seen as the expected standard at work. It is worth mentioning that most drivers have complained about a dual constraint imposed by their enterprise, which ask them to avoid using the phone while driving but want them to give immediate reply if asked.

Phone pressure. In this context, the issue of the phone pressure while at the wheel is not experienced in a uniform way. It depends on the frequency and on the complexity of the exchanges, whether they are mandatory or not, and on the urgency of the expected reply.

- For some drivers, the link with the company and/or the customer is necessary to accomplish the daily tasks (deliverymen and truck drivers). However, this link is not always oppressive; it becomes so when the drivers face a lack of information on the place to delivery or when a call generates a change in the destination.

- Pressure and urgency are especially important for resource professionals, or those at a decision-making node, such as some salespeople. Essential points of exchange, they are indispensable in maintaining the activity of their collaborators.
- Phone pressure is also present for those who perform technical functions, who may experience real harassment on the phone while driving. They are the ones who express the most negative experience with the phone while driving.
- Finally, taxi drivers and especially Uber-like drivers also face a dual constraint: having to answer calls to avoid losing a client, and to not disturb their customers likely to leave an assessment of the service.

CONCLUSION AND PERSPECTIVES

The analysis of these four focus groups reveals a great heterogeneity of the professionals regarding their phone use and their attitude towards phone while driving. The phone-related pressure takes specific forms depending on the activities carried out. Being at a decision-making node, having to give urgent reply to customers or suppliers are key factors. While it remains difficult to generalize from these results with 27 participants, there seem to be major discrepancies between groups that will be addressed in a quantitative manner by the large-scale survey administered in the second step of the study.

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Driving with kids: distracted and unsafe?

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Keywords: Child passenger; Distraction; Driver's gender; Fatal crash; Fatigue; Young driver

Aims

Although the effect of passengers on driving safety has been studied extensively, only few studies have examined how presence of child passengers affects the driver. The aim of this project was to examine the prevalence, characteristics and risk of fatal motor vehicle crashes involving child passengers among male and female drivers. This submission summarizes the existing and preliminary findings of the project.

Background

According previous studies parents of small children seem to be motivated to drive responsibly [1, 2] and drivers in crashes involving child passengers are rarely under influence of alcohol or speeding [3]. However, studies based on naturalistic settings have indicated that child passengers in the vehicle can be potential source of distraction [4, 5]. This might be the case especially when driving with a crying infant who wants to get attention from caregivers [6]. Previous studies have also showed that parents of small children often suffer from sleep deficit [7, 8] which may be linked to a higher risk of crashes [9, 10]. Also new mothers' hormonal conditions e.g. postpartum depression may further add to the risk of a crash [11, 12].

Results/Study 1

Our first study [13] was based on the comprehensive data of fatal crashes in Finland during 1988–2012. All fatal crashes in Finland are studied in depth by multidisciplinary road accident investigation teams. These teams select one driver whose actions contributed most to the origin of the crash. We defined those as culpable drivers and the others involved as non-culpable drivers. Only drivers aged 26–47 years were included to analysis representing the typical age of parents of 0–9 year old children. The drivers with specific risk behaviors (substantial speeding, driving when intoxicated, unbelted, or without license) were excluded from analysis. The culpability rate was defined as the percentage of culpable drivers and rates were compared for drivers with a child/teen passenger aged 0–17 year, with an adult passenger without children and when driving alone, grouped by child age and driver gender.

According to our results, male drivers were less often culpable when driving with child passengers in the car than alone or with only adult passengers. This was not the case with female drivers. The gender difference in culpability rate was largest with a small child of 0 to 4 years old in the car. Female drivers' culpability rate with a 0-4 year old child passenger was higher compared to female drivers without passengers or with only adult passengers. Although our study cannot establish causal link between the crashes and driver distraction, the results suggest that especially mothers are potentially sensitive to child passenger related distraction while driving.

Study 2

Our second study [14] was based on the more numerous crash data from the U.S. Fatality Analysis Reporting System for 1994–2013. The prevalence, characteristics and risk of fatal motor vehicle crashes with an infant passenger of less than one year old for young (16–24 year) and older (25–39 year) female drivers were examined. Only female drivers were included in this study as the number of male drivers with an infant and without an adult passenger in the vehicle was low in the database. The ratio of at-fault drivers to non-at-fault drivers was used as the crash risk estimate and allocation for at-fault and not at-fault drivers was adapted from the Braitman et al. [15] study. Crash risk was also verified in the analysis which we included only non-junction front-to-front crashes of two passenger vehicles where one and only one of the drivers was marked with a “failure to keep in proper lane or running off road” or “driving on wrong side of road”.

Our results showed that young females driving with an infant passenger, probably most often mothers, are at an elevated risk of a fatal crash when they drive with an infant. According to our crash risk estimation young female drivers’ risk is higher compared to older females when driving with an infant. In addition, our results indicate that young females driving alone with an infant have higher crash risk than young female drivers without passengers. Also, our results showed that young female drivers’ probability to die in a crash is higher due to the lower use of safety seats, the infant being more often on front seat and use of older and smaller vehicles compared to older females with an infant.

Although our results showed that especially young females’ risk is elevated, female drivers with an infant, regardless their age, were more often fatigued or inattentive than similar aged drivers without passengers. Also, an adult passenger beside an infant lowered drivers’ risk regardless of drivers’ age. This indicates that an infant in the vehicle may distract driver, but when other adult passenger is also in the vehicle he or she may assist the driver by taking care of the infant and enabling the driver to focus on driving.

Future studies

The aim of our third study is to replicate results from our first study using more extensive database. Our first study was based on the Finnish fatal accident database which contains relatively few cases as the number of annual fatal crashes is around 200. Thus, data from the more extensive U.S. FARS database during 1996-2015 will be used in our third study.

In the third study the amount and risk of crashes will be examined for male and female drivers with a small 0–9 year old child passenger either with or without an adult passenger. Only 23–46 year old drivers will include to analysis representing the typical age of drivers with 0–9 year old child passengers in FARS database (the mean age +/- 1 SD).

Drivers’ risk of crashes will be estimated by the ratio of at-fault to not at-fault drivers in two types of crashes: intersection related crashes and front-to-front non-junction crashes as our preliminary results indicated that drivers with a child passenger have different crash risk in these traffic environments. In addition, our preliminary results indicate that presence of an adult passenger beside of a child passenger lowers drivers’ risk of crashes regardless drivers’ gender but that the effect is clearer in non-junction crashes. Also, our preliminary results indicate that female drivers with a child passenger have a higher crash risk than male drivers especially in intersection crashes. Possible explanations behind results from the study three will be discussed when the final results will be completed.

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Can we explain attention-related errors while driving?

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Keywords: ARDES; BYNDS; Young driver; Ergonomics; Inattention; Mobile phones

EXTENDED ABSTRACT

Driver inattention is one of the main causes of road crashes. Factors that result in drivers' attention-related errors, especially from the perspective of driver characteristics, have not been systematically investigated. This study conducted a questionnaire survey and investigated the inter-relationship between driver characteristics and their attention-related errors. Results indicated that (a) driving experience decreases attention-related errors while driving; (b) a higher frequency of driving violations, high disinhibition, and high susceptibility to involuntary distraction are associated with frequent attention-related errors. The findings shed light on the direction of countermeasures to reduce distracted driving and attention-related errors.

Background

Driving is an attention demanding task that requires continuous interactions between humans, vehicles and road infrastructure. However, with the proliferation of mobile phones and other nomadic devices, drivers often engage in secondary tasks such as texting or listening to music while driving. Secondary tasks potentially interrupt the driving process and this interference could result in road crashes. For example, in Australia, it has been reported that drivers who use a mobile phone for up to 10 minutes are more likely to have a crash [1]. Nonetheless, there are still many unknown factors regarding crash causation in mobile phone distracted driving [2].

Educational campaigns, legislation and enforcement have been frequently implemented to stop distracted driving, however their success has been insufficient. In Australia, the high prevalence of mobile phone use confirms that there are a large number of distracted drivers on the roads [3, 4] and the need to explore new approaches to prevent attention-related errors is imperative. Therefore, the aim of this research is to characterize the inter-relationship between a group of driver characteristics (e.g. age, gender, driving experience, sensation seeking, and distracted driving susceptibility) and attention-related errors.

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Materials and methods

A cross-sectional design was selected. A total of 466 participants (65% females) completed a 30-min questionnaire. Participants have an average age of 29 years and reported holding a valid driving license for 11 years on average. Other personal characteristics of the participants are reported in Table A1.

The scales utilized in this study are showed in Table 1. Reliability of the scales was studied using Cronbach's alpha coefficient. A value of 0.70 or greater was considered adequate. Additionally, a correlation analysis was conducted to determine any relationships among the variables tested.

Table 1 – *Scales included in the Questionnaire*

Scale	Definition	Subscales	Responses	Author
Sensation Seeking (SS)	Sensation seeki ng is explained as the need for novelty and complexity of stimulation	(a) Experience seeking, (b) Boredom susceptibility, (c) Thrill and adventure seeking, and (d) Disinhibition	(1) "Strongly disagree" – (5) "Strongly Agree"	Hoyle et al. [5]
Condensed Behaviour of Young Novice Drivers Scale (BYNDS)	Inventory of risky driving behaviours in Australia	(a) Transient violations (risky driving behaviours that can change throughout the journey, such as speeding), and (b) fixed violations (risky driving behaviours that are not transient in nature, such as not wearing seatbelt)	(1) "Never" – (5) "Nearly all the time"	Scott-Parker et al., [6]
Crash-involvement Scale	Prior involvement in crashes (at least one in the last three years)	N/A	(1) "No" – (2) "Yes"	N/A
Susceptibility to Driver Distraction Questionnaire	Involuntary and voluntary distraction involvement	(a) Distraction engagement, (b) Attitudes and Beliefs about Voluntary Distraction, and (c) Susceptibility to Involuntary	(1) "Strongly disagree" – (5) "Strongly Agree"	Feng et al., [7]
Attention-Related Driving Errors Scale (ARDES)	Inventory of driving errors resulting from failures of attention	N/A	(1) "Never or almost never"- (5) "always or almost always"	Ledesma et al. [8]

Results and Conclusion

The correlations are reported in Table A1. Some of the findings include:

Years with a valid driving license was negatively correlated to attention-related errors. Experience driving serves as a protective factor against attention-related errors. A focus on novice drivers safety is essential.

Attention-related errors are positively correlated with transient and fixed driving violations. Tackling distraction would potentially benefit other risky driving behaviors. This also supports a systematic approach for driver safety, and it is not efficient to just target one behavior. Further research is necessary to study causality relations. Based on the literature we know that distracted drivers change their driving performance [9].

Disinhibition was positively correlated to attention-related errors and presented as the largest correlation among the SS subscales. In addition, disinhibition has been consistently linked with mobile phone use while driving and multitasking. This personality trait seems to be characteristic of distracted drivers who present frequent attention-related errors.

Distraction engagement was not correlated directly with attention-related errors. A potential explanation is that disinhibition regulates the distraction-error relationship. Particularly, highly disinhibited drivers could be more invested in mobile phone tasks. This is also a promising line of research.

Susceptibility to involuntary distraction is positively correlated to attention-related errors. A potential explanation for this phenomenon is that drivers are not able to activate timely self-regulation behaviours such as selective engagement or workload management [8]. Efforts to prevent involuntary distraction could reduce the number of inattention errors.

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Table A1 – ***Participants' characteristics, responses to scales, and correlation analysis***

Variables	M	SD	Driver Characteristics				Sensation Seeking (SS)				Risky Driving (BYNDS & Crash involvement)			Susceptibility to Driver Distraction Questionnaire			Attention-Related Driving Errors Scale (ARDES)
			S	A	YDL	DW	EX	BO	TA	DI	TR	FI	CI	DE	AB	SID	
Sex (S)	0.35[a]	N/A	1	-.1	-.07	-.06	-.08	-.05	-.17**	-.14**	-.09*	-.15**	.04	.06	-.01	-.00	-.04
Age (A)	29	11		1	.95**	.08	-.03	-.24**	-.20**	-.30**	-.22**	-.03	-.43**	-.2**	-.21**	.08	-.06
Years with a valid driving license (YDL)	11.0	11.1			1	.07	.02	-.23**	-.18**	-.25**	-.17**	-.01	-.45**	-.2**	-.16**	.02	-.10*
Driving hours per week (DW)	2	1				1	.13**	.11*	.04	-.11*	.05	-.04	.01	.05	.02	-.08	-.09
Experience seeking (EX)	3.54	.99					1	.46**	.40**	.26**	.13**	.04	-.11*	.22**	.23**	-.14**	-.01
Boredom Susceptibility (BO)	3.07	.96						1	.34**	.36**	.15**	.11*	.01	.22**	.19**	-.07	.10*
Thrill and adventure (TA)	2.65	1.16							1	.44**	.23**	.19**	-.04	.20**	.19**	-.04	.11*
Disinhibition (DI)	2.49	1.12								1	.38**	.27**	.02	.33**	.27**	-.07	.17**
Transient Violations (TR)	2.16	.69									1	.44**	-.01	.48**	.37**	-.00	.33**
Fixed violations (TR)	1.20	.43										1	.02	.11*	.11*	.11*	.56**
Crash-involvement (CI)	0.5[b]	N/A											1	-.04	.00	.04	.01
Distraction Engagement (DE)	3.34	.63												1	.55**	-.07	.09
Attitudes and Beliefs (AB)	3.28	.48													1	-.25**	-.01
Susceptibility to Involuntary Distraction (SID)	2.78	.64														1	.29**
Attention-Related Driving Errors Scale (ARDES)	1.49	.46															1

[a] represents the percent of male drivers;
[b] represents the percent of drivers that are involved in crashes before;
* represents a significance level of 0.05;
** represents a significance level of 0.01.

What contextual and demographic factors predict drivers' decision to engage in secondary tasks?

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Keywords: Distracted driving; Self-regulation; Willingness to engage; Secondary task

INTRODUCTION

With the introduction of on-board and portable technology, drivers have to deal with an increasing plethora of distractions that divert their attention away from the driving task and compete for limited cognitive resources. The consequences of such distractions range from minor lapses in attention to catastrophic safety outcomes if attention is diverted at critical points during driving. Indeed, distraction is the main contributing factor in almost 16 percent of serious casualty road crashes resulting in hospital attendance in Australia [1] and in 10 percent of fatal and 15 percent of injury crashes in the United States [2].

Fortunately, humans are not passive receivers and processors of information and can actively adjust or regulate their attention and behavior when performing two tasks [3]. In relation to driving, a driver's ability to self-regulate their behavior is an important factor that can influence the impact of secondary task engagement on performance outcomes [4]. At the strategic level, for example, drivers can regulate their exposure to risk by deciding not to engage in potentially distracting activities while driving. Indeed, previous research has demonstrated that engagement in secondary tasks is not arbitrary and drivers use a range of different strategies or criteria when deciding whether to engage or not. In a survey study, drivers reported a range of conditions in which they do not engage in secondary tasks, including in heavy traffic, in poor weather, on winding roads or in school zones [5]. More recently, data from naturalistic driving studies (NDS) have supported these self-reported behaviors. Funkhouser and Sayer [6], for example, found that drivers were more likely to engage in phone tasks when stationary. Tivesten and Dozza [7] also found that visual-manual phone tasks were more likely to be initiated when the vehicle was stationary, at lower speeds, or when there were no passengers present. Drivers were also found to adjust the timing of their engagement in phone tasks until after completing a driving maneuver such as a sharp turn or overtaking.

Using data from the Australian Naturalistic Driving Study (ANDS) [8], this study examined the contextual factors and driver characteristics that influence drivers' decision to engage in secondary tasks while driving. This study extends previous findings by examining a wider range of secondary tasks and determining if, and what, demographic characteristics influence drivers' propensity to engage in secondary tasks.

METHOD

This study used data collected as part of ANDS. Three hundred and fifty-two privately owned vehicles (n = 191 from New South Wales; n = 161 from Victoria) were equipped with a data collection system and driven for a period of 4 months in real-world, everyday driving. The Data Acquisition System (DAS) equipped to each vehicle were supplied by the Virginia Tech Transportation Institute (VTTI) and comprised sensors and data-loggers, allowing the continuous recording of vehicle data and video while the vehicle ignition was on. Variables captured included: acceleration in multiple axes, gyroscopic motion, indicator status, speed and GPS position. A continuous multi–

camera video recording system captured the driver's face, forward- and rear views, and a view of driver interaction with the dashboard and other systems.
Approximately 50tb of data were collected during the study. The data used in this paper comprises randomly selected trips from the first wave of data collection. Two analysts viewed entire trips and coded sections where drivers were observed engaging in at least one secondary task. A range of variables were coded for each secondary task event, including: secondary task type, passenger presence, driving context and conditions, self-regulatory behavior and any incidents that occurred while the driver was engaged in the secondary task. Driving context variables were coded at the time of secondary task initiation. More information about the driving context and secondary task variables coded are in Table 2. Trips were not coded if they lasted less than 1 minute, longer than 1 hour or if a camera view was missing.
At the time of writing, a preliminary dataset of 34 trips had been coded, equating to 776 minutes of driving time. Analysis of a greater number of trips and the driver demographic data will be presented in the full paper.

RESULTS

A total of 465 secondary task events were identified from the coded trips. On average, drivers engaged in a secondary task every 1.7 minutes of driving. Table 1 displays an overview of driver engagement in secondary tasks. Many commonly performed tasks involved short, discrete presses of steering wheel and center stack controls. Manipulating a hand-held phone was the most common *phone* activity performed followed by talking hands-free. Interestingly, 7.1% of secondary tasks involved drivers reaching for an object or phone, a task that has been associated with an 8.8 times greater odds of being involved in a crash or near crash [8].

The percentage of secondary task events that fall into each driving context category is provided in Table 2. Results reveal that drivers most frequently decided to engage in a secondary task when there were no passengers present and they were driving during the day, in clear weather, at their previous speed and while not performing a driving manoeuver (e.g. overtaking). Drivers also chose to engage more frequently in secondary tasks when the surrounding traffic volume was light or medium, when travelling mid-block (between intersections) and on residential streets.

Table 1 Number and percentage of all secondary tasks in each coding category

Secondary Task	**n**	**%**	**Secondary Task**	**n**	**%**
Adjusting/Monitoring other devices integral to vehicle	114	24.5	Drinking	11	2.4
Adjusting/Monitoring center stack controls	62	13.3	Manipulating Object (other than phone)	9	1.9
Interacting with front passenger (adult)	57	12.3	Talking/listening phone (hands-free)	5	1.1
Looking at an object/event OUTSIDE the vehicle	43	9.2	Eating	4	0.9
Adjusting steering wheel buttons	35	7.5	Mobile phone, holding	4	0.9
Reaching for object (includes moving object)	31	6.7	Manipulating phone (hands-free)	2	0.4
Talking/Singing to self	24	5.2	Reaching for phone (includes moving phone)	2	0.4
Holding object (other than phone)	16	3.4	Talking/listening phone (hand-held)	1	0.2
Personal Hygiene	16	3.4	Inserting/retrieving CD (or similar)	1	0.2
Manipulating phone (hand-held)	12	2.6	Other	4	0.9
Looking at or for object INSIDE vehicle (not reaching or touching it)	12	2.6			

Table 2 Percentage of all secondary tasks in each driving context category

Driving Context	**%**		**%**
		Weather conditions	
Front passengers		Sunshine	58.3
Yes	33.3	Cloudy	13.8
No	66.7	Rain	1.5
		Unknown (dark)	26.5
Driving manoeuvre		**Road type**	
Driving in own lane	88.2	Residential	43.4

	0.6	Suburban	10.3
Changing lanes	4.3	Car park	9.5
Pulling in/out of parked position		Freeway/motorway	7.7
Reversing	0.9	Rural Rd/highway	28.9
Other	6.0	School zone	0.2
Speed		**Road section**	
Travelling at previous speed	63.2	Mid-block	68.6
Slowing down to stop	11.4	Intersection	28.0
Slowing down to turn	1.7	Other	3.4
Stationary	23.7		
Traffic density		**Road surface**	
Heavy	3.7	Dry	89.9
Medium	22.6	Wet	2.4
Light	54.2	Gravel/dirt	1.5
No traffic	19.6	Unknown (dark)	6.2
Light conditions			
Daylight	67.1		
Dusk/dawn	25.8		
Darkness	7.1		

CONCLUSIONS

The ANDS data revealed some interesting findings regarding driver engagement in secondary tasks and the driving context in which they chose to engage. First, the results indicate that driver engagement in secondary tasks is frequent, with drivers engaging in a secondary task once every 1.7 minutes, on average. However, the most common secondary tasks tended to involve short, discrete button presses or interactions with vehicle controls. Surprisingly, over 60% of the secondary tasks were initiated when drivers were travelling at their previous speed, with less than one quarter of tasks initiated while the vehicle was stationary. This finding is not consistent with the results of previous work, which found that drivers were more likely to engage in secondary tasks when stationary [6, 7]. Drivers also engaged more frequently in secondary tasks when travelling on residential streets compared with other road types, perhaps because they felt more confident engaging when at lower speeds. Further analysis of the ANDS data set will be presented in the full paper, along with an analysis of the driver demographic data.

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Pre-Crash Driving Behavior of Individuals with and without ADHD

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Keywords: ADHD; Crashes; Inattention; Medication; Road safety

EXTENDED ABSTRACT

Motor vehicle crashes are the leading cause of death among young adults [1]. Young adult drivers diagnosed with attention-deficit/hyperactivity disorder (ADHD) are more likely to be involved in motor vehicle crashes than non-ADHD drivers [2,3,4]. Characteristics of ADHD individuals include inattention, impulsive behaviors, and unfocused motor activities [5]. One study found that the driving performance of ADHD individuals was compatible to the driving performance of non-ADHD intoxicated drivers [6]. Weafer et al. (2008) suggest that the poor performance exhibited by ADHD drivers is due, in part, to deficits in cognitive functioning such as, difficulties attending to more than one object, poor speed management, and impulsivity [6]. Moreover, a recent study found that approximately 22% of motor vehicle crashes committed by ADHD drivers could have been prevented if they were medicated [2], suggesting that the cognitive deficits, which negatively impact ADHD drivers performance may be mitigated through medication.

Given the high prevalence of ADHD (4.40% of young adults in the US) [7] and of preventable crashes among this population, it is important to further understand ADHD drivers' performance in relation to motor vehicle crashes. Specifically, the aim of this study was to evaluate performance differences between ADHD (when medicated and not medicated) and non-ADHD drivers prior to a crash to reveal which unsafe behaviors led to a crash. These results may also shed light on whether ADHD drivers are inherently unsafe drivers or if such detrimental behaviors can be remediated by medication. Therefore, the study's hypothesis was that medicated ADHD individuals would have similar driving performance prior to a crash as individuals without ADHD.

Method

Participants

Forty-four young drivers (17 without ADHD, 27 with ADHD) participated in the study. Participants were recruited from George Mason University and local communities. All participants were between the ages of 18 and 24 (M = 20.82, SD = 1.79), held a valid US driver's license, had normal or corrected-to-normal vision and hearing, and were either clinically diagnosed with ADHD (verified via the Conners' Adult ADHD Rating Scales (CAARS) [8] and an ADHD Symptoms Survey) and took stimulant ADHD medication (Federal Drug Administration-approved), or were not clinically diagnosed with ADHD (verified via CAARS scores) nor did these individuals take ADHD medication. Twenty-eight participants met the eligibility requirements. However, given that the goal of this study was to evaluate driver behavior prior to a crash, only participants who were involved in an at-fault crash during the experiment were included. Data from 18 participants (5 men, 3 women without ADHD; 7 men, 3 women with ADHD) were included in the present study. Participants were compensated at a rate of $30 per hour.

Materials

Participants completed a series of surveys online via Qualtrics, the CAARS [8] online via Multi Health Systems (MHS Inc.) Assessments, and responded orally to the Simulator Sickness Screening [9]. Individuals with ADHD also completed the Conners' Adult ADHD Diagnostic Interview for DSM-IV [10] orally, and an ADHD Symptoms Survey via Qualtrics. Additionally, the ADHD participants identified someone close to them (referred to as observers) to complete two surveys (ADHD Symptoms Survey, CAARS) concerning the participants' ADHD symptoms.

The experiment took place at George Mason University in a half-cab Realtime Technologies, Inc. motion-based high-fidelity driving simulator. The driving scenarios were programmed using Javascript, the driving environment was developed in SimVista and run using SimCreator. Participants completed a practice drive and four experimental drives each lasting between 7-15 minutes. The drives contained ambient traffic and consisted of one or two-lane roads in rural and urban environments.

Procedure

The study procedures were approved by the George Mason University IRB and all participants signed an informed consent form. Participants first completed a number of self-report surveys, then completed the simulator drives, and finally completed another set of self-report measures. Participants were instructed to drive as they normally would, remain in the right lane, and follow the traffic and speed limit signs, and navigation instructions.

A number of safety measures were in place: medication intake was monitored, ADHD participants were dropped off and picked up by a friend or family member, and participant safety was actively monitored during simulator driving. The ADHD participants completed the study across two days. In the non-medicated condition, participants did not take their ADHD medication the day of participation whereas, in the medicated condition, participants took their ADHD medication under supervision and waited one hour for the medication to take effect prior to completing the study. The order of the medication conditions (ADHD participants) and drives were counterbalanced across participants. Participants without ADHD (control condition) completed a shorter list of self-report measures and the same simulator drives in one study visit.

Results

Driving data were recorded at 60 Hz. Among the variables recorded, this study evaluated velocity (m/s), brake force (Newton's), steering angle (absolute value in degrees), and lane offset (absolute value in meters from lane center). MATLAB was used for data reduction and all statistical analyses were performing using R. Pre-crash data were defined as five seconds (binned into five 1-second blocks) prior to each crash sample. A crash was defined as occurring when the participants was less than or equal to two meters from another vehicle. Table 1 lists the means and standard deviations of pre-crash and crash data across conditions.

Condition	Sample	Velocity	Steering	Brake force	Lane offset
Control	Pre-crash	15.13 (6.04)	53.32 (8.89)	18.34 (16.01)	0.32 (0.23)
	Crash	10.27 (5.71)	53.24 (9.11)	113.26 (79.91)	0.42 (0.56)

ADHD medicated	Pre-crash	14.86 (5.41)	54.16 (11.58)	24.59 (16.07)	0.34 (0.23)
	Crash	8.75 (7.35)	54.10 (11.56)	102.25 (71.65)	0.43 (0.25)
ADHD non-medicated	Pre-Crash	13.63 (7.54)	43.60 (15.31)	31.12 (36.39)	0.51 (0.31)
	Crash	8.90 (6.18)	42.89 (15.57)	79.82 (65.90)	0.53 (0.37)

Table 1. Means and standard deviations of pre-crash and crash data across conditions (control, ADHD-medicated, ADHD-non-medicated).

On average, individuals with ADHD were involved in 2.40 (*SD* = 1.58, range: 1-5) crashes and those without ADHD were involved in 1.38 (*SD* = 1.06, range: 1-4) crashes, $t(16)$, = 1.57, $p = .14$. Linear mixed effects models with a random intercept of subject type (ADHD, non-ADHD) nested within subject were performed to evaluate the effects of experimental condition (non-medicated, medicated, control) and pre-crash block on velocity, brake force, steering, and lane offset. There was a significant effect of condition on velocity, β = 2.52, *SE* = .15, $p < .001$. Specifically, velocity was significantly lower prior to a crash in the non-medicated condition compared to the medicated (β = -2.63, *SE* = .08, $p < .001$) and control (β = -3.57, *SE* = .21, $p = .043$) conditions. There was no significant difference in velocity pre-crash between the medicated and control conditions, $p = .56$. There were also no significant differences in brake force between conditions, *p*s > .05.

Steering movement was significantly different between conditions, β = 9.48, *SE* = .16, $p < .001$. The non-medicated condition had significantly reduced steering movement prior to a crash compared to the medicated (β = -9.75, *SE* = .09, $p < .001$) and control (β = -13.28, *SE* = .17, $p = .002$) conditions. Steering did not significantly differ pre-crash between the medicated and control conditions, $p = .34$. Finally, there was a significant effect of condition on lane offset, β = -.12, *SE* = .14, $p < .001$: the non-medicated condition had significantly greater lane offset than the medicated condition, β = .13, *SE* = .08, $p < .001$. Lane offset did not significantly differ between ADHD and non-ADHD drivers, *p*s > .05. Additionally, there were no significant interactions between condition and pre-crash time block, *p*s > .05.

Conclusion

The current research, contrary to some prior simulator studies [3, 4, 6] revealed that ADHD drivers were just as likely as non-ADHD drivers to be involved in a simulated crash. Additionally, medicated ADHD drivers exhibited behaviors (velocity, steering, lane offset) similar to those of non-ADHD drivers. However, these individuals compared to non-medicated ADHD drivers had higher magnitude of steering movement prior to a crash, which may suggest that they were aware of an upcoming crash and took actions in attempt to avoid a crash. Conversely, the non-medicated ADHD drivers significantly reduced their steering movement, which could suggest that they either underestimated the likelihood of a crash or overestimated their ability in preventing a crash. In support of the latter, research suggests that ADHD drivers exhibit strong beliefs of self-efficacy [4, 6]. Oftentimes, such beliefs coupled with the inherent impulsive behaviors characterized by ADHD, leads these individuals to terminate medication and treatment [6]. Assistive in-vehicle technologies could be used to determine when individuals have not taken their medicine or when their medicine has worn off by assessing real-time changes in driving behavior.

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Young people use their smartphone all the time – also while crossing the street?

6th International Conference on Driver Distraction and Inattention (DDI2018)

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Keywords: Observation study, pedestrian distraction, young pedestrians

Aim and scope of the study:

The effect of distraction by smartphone use has been extensively examined for car and truck drivers. However, a study in the US has shown that distraction may also become a major health problem for pedestrians in traffic (Nasar & Troyer, 2013). The authors especially found a higher frequency of injuries of young pedestrians which were related to mobile phone use. Thus, talking on the phone or texting can be dangerous when done while walking. However, corresponding data from other countries, especially from Germany, are still rare.

The aim of the study was to examine the frequency of mobile phone use in pedestrians and to examine whether this leads to dangerous behavior or even safety-critical situations. As young people seem to be especially prone to use mobile phones and are frequently actively participating in traffic as pedestrians, the study focused on young pedestrians on their way to and from school. Their behavior was observed at zebra crossing with and without traffic light in the vicinity of four major high schools in the middle-sized city of Braunschweig, Germany. The observers recorded basic characteristics of the pedestrians like age and sex, their activities before and while crossing the street (including mobile phone use). They also rated the crossing behavior with regard to safety while crossing (e.g. checking the road for cars before crossing). Overall, 1386 pupils were observed.

Materials and methods:

The four high schools in Braunschweig were selected as having zebra crossings with a traffic light very near school where a lot of pupils crossed the street. Additionally, there were also supposed to be locations without a zebra crossing but a high frequency of pedestrians crossing the street anyway. The observations were done from November 2016 to January of 2017. A trained observer (Christin Nicolai from the authors) used a tablet including a freely configurable software (Observer, freely available from https://www.tu-braunschweig.de/psychologie/abt/ingenieur/software) to record the behavior of the selected pupils. Before the observation, a second observer was used to examine interrater reliability in a pre-test. All variables were observed with a correlation larger than 0.97. Thus, the observations could be done with a very high reliability. In order to keep the observations as unobtrusive as possible, the main study then used only one observer. This observer positioned herself near the crossing. Recording the observations on the tablet gave outsiders the impression that she was involved in something on her tablet and thus should not have influenced the behavior of the pupils.

The observations were done either in the morning on the way to school or at noon when coming from school. Each observation was done for about 15 minutes and recorded date from about 70 pupils. Overall, 1386 pupils were observed.

At the beginning of each observation, the time of day (morning / noon), the high school, the characteristics of the crossing (zebra crossing with traffic light, free crossing) and the weather conditions (sun, clouds, rain) were recorded.

For each pupil, age (young: 10-14 years, older: 15-19 years) and sex was estimated. Distraction was coded as follows (multiple selections were possible):

- None
- Mobile phone in hand, but not used
- Looking at mobile phone
- Typing on the mobile phone
- Listening to music with earphones
- Other

Additionally, it was observed whether the pupil was alone or with others (either quiet or talking to them). With regard to the behavior while crossing at free crossing, the observer watched whether the pupil had looked to the right and left before beginning to cross and if he had shortly stopped to do so. At the crossings with traffic lights it was added whether the pupil went at red light or did not move although it was green. Moreover, an overall evaluation of whether the crossing had been safe was added (yes/no). Finally, the absence of presence of oncoming traffic was recorded (non, cars, bicycles).

The observations were automatically stored on the hard-drive as text files and then imported to SPSS 24 using a routine included with the program.

Results:

Table 1 (left) gives an overview of the sample. There were about 900 observations in the morning and about 500 at noon. This was due to the fact that school begins at the same time for all classes, but ends at different times. The number of observations at traffic lights and free crossing was each about 700. In the right part of the table one can see that somewhat more females than males were observes (about 777 to 609), and somewhat more young pedestrians (737 young as compared to 649 older ones).

Table 1: Overview about the sample (% of total, N; left) and about the age and sex of the observed (% of total, N; right)

	Traffic Light	Free Crossing	N
Morning	33.4	31.0	893
Noon	14.3	21.3	493
N	661	725	1386

	Male	Female	N
Young (10-14)	24.8	28.4	737
Older (15-19)	19.1	27.7	649
N	609	777	1386

For the analysis of the distraction, Figure 1 gives the percentages of the different categories. 76.8% of the pedestrians were not distracted while crossing the street which corresponds to nearly 25% of distracted persons. The most frequent distractions was listening to music (10%), followed by typing of the mobile phone with 8.8%. An additional 1.7% watched something on the mobile phone. Other distractions accounted for 2.3%. Thus, about 20% of the young pedestrians were involved with their mobile phone even when crossing the street.

In order to examine influencing factors, a logistic regression (stepwise backward, Wald criterion) was computed using age, sex, time of day and presence/absence of traffic light as predictors. Watching something and typing on the mobile were combined as these seemed the most dangerous kinds of distraction. In this analysis, only time of day was significant (Wald 21.8, $p < 0.001$, OR 2.3 noon vs morning). In the morning, 7.6% of the pedestrians were using their mobile as compared to 5.6% at noon. Interestingly, neither age nor sex changed the percentages. Even more important, the pedestrians did not change their distracted behavior when crossing without a traffic light.

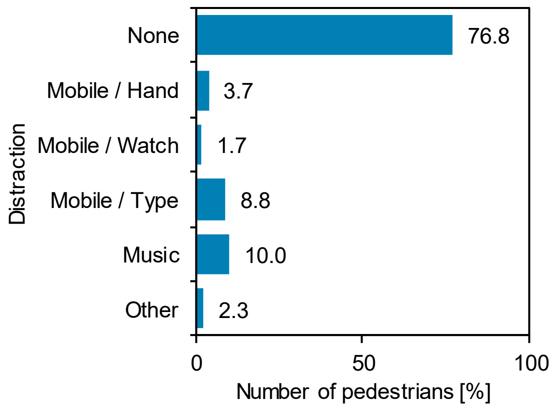

Figure 1: Overall percentage of the different types of distraction while crossing the street.

With regard to the safety relevant aspects of behavior, at traffic lights 12.7% of the pedestrians looked to the left and right before crossing the street. 6.5% went at red light and 2.4% stood although it was green. Looking to the left or right was done somewhat less often when pupils were involved in their mobile phone (9.7% with as compared to 13.1% without distraction). However, this was not significant (Fisher exact test $p = 0.463$). Even against expectations, when pupils looked at their mobile or typed, they went less frequently when red (0.3% as compared to 6.2%). However, they much more frequently did not notice when it had become green again (11.1% as compared to 1.4%, Fisher exact test $p < 0.001$).

At free crossings, 75.7% of the pupils using their mobile (watch or type) did not stop and look to the left and right as compared to 56.5% of the other pupils (Fisher exact test $p = 0.004$).

Fortunately, there were only 0.4% of the observations were the observer judged it was dangerous and 1.4% where is was risky. There was no difference with regard to distraction (Fisher exact test 0.268).

Conclusions:

For pupils in high school in Germany, using their mobile phone to type or watch media while walking concerns a large percentage of the pupils observed (about 20%), even when crossing a street. At traffic lights, the major consequence of distraction is missing a green light which may be annoying but not safety critical. However, at places without a traffic light, mobile phone use leads to a larger frequency of crossing the street without watching for oncoming traffic. While this did not lead to risky situations in the present study, the large percentage rises concerns about this behavior. Thus, young pedestrians should be focused for prevention measures, perhaps most effectively in school.

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Who is responsible for driver distraction and inattention? A systems analysis of contributory factors

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Keywords: driver distraction; driver inattention; safe systems; systems thinking

EXTENDED ABSTRACT

Driver inattention refers to situations in which a driver fails to allocate sufficient attention to the driving task [1]. This includes instances of driver distraction, in which the driver actively diverts attention to a secondary task, such as using a telephone [1]. In-depth crash analyses have implicated distraction and inattention as a contributing factor in up to two-thirds of serious crashes [2]. For this reason, distraction/inattention is counted among the "fatal five" crash contributory factors (alongside fatigue, intoxication, speeding, and failing to wear a seatbelt), and is commonly targeted in road safety intervention and awareness campaigns.

Because definitions of inattention and distraction focus on the driver (i.e., their failure to allocate attention adequately), inattention is often considered as being largely within the individual's control. Examples of this can be seen in media stories blaming inattention-related crashes on "lazy" drivers. However, road transport is a complex sociotechnical system and the prevailing "safe system" view emphasises shared responsibility among all actors within the system, including vehicle and road designers and engineers, not just road users [3]. We conducted two studies to explore systemic issues that could potentially contribute to or prevent driver inattention and distraction: a community survey, followed by an expert workshop.

Study 1: Community Survey

We conducted an online survey of 316 adult drivers in Queensland, Australia, to elicit participants' experiences and opinions of the "fatal five" crash contributory factors.

Participants. Of the full sample, 276 drivers (131 female) provided full data for the inattention and distraction questions. Nearly all participants (92%) held an open (full and unrestricted) driver's licence, and most participants were aged 41-70 years (70%).

Methods. Data were collected online using the online survey platform SurveyMonkey®. For each of the fatal five behaviours, participants were asked to indicate whether they had ever engaged in the behaviour and their opinion of why they and others engaged in this behaviour. Finally, they were asked to suggest solutions that could prevent each behaviour. All questions were open-ended, except for the questions about whether they had engaged in the behaviour, which had three options: yes, no, and prefer not to say.

Data analysis. This paper presents only the data regarding the distraction/inattention questions (see Salmon et al. [4] for full details.) Suggested causes and solutions for driver inattention and distraction were mapped onto a hierarchical control structure model of the road transport system [3]. The control structure describes the actors that influence road safety across five system levels, as well as the control and feedback relationships between them. The five levels were: 1) *Parliament and legislatures*; 2) *Government agencies, industry associations, user groups, courts, and universities* (e.g., road authorities, standards agencies); 3) *Operational delivery and management providers* (e.g., employers, hire car companies, hospitals, media); 4) *Local management and supervision providers* (e.g., traffic controllers, inspectors, police officers, driving instructors); and 5) *Immediate operating process and environment* (e.g., driver, vehicle and in-vehicle devices, road infrastructure/environment). The full dataset was coded by one analyst, with a second analyst coding 20% of the data to ensure consistency and reliability.

Results and Discussion. Over three-quarters of respondents indicated that they had driven while distracted or inattentive (76% yes, 22% no, 2% prefer not to say).

The top reasons for engaging in distracted driving were: using a mobile phone (55%); interacting with children (31%); general passenger interaction (26%); general lack of attention (18%); using the radio or stereo (17%); emotions and stress (16%); complacency or optimism bias (12%); and other road users' behaviour (11%).

Table 1 summarises the contributory factors, as mapped on to the hierarchical control model. Here it can be seen that most factors were mapped onto lower levels of the hierarchical system, predominantly Level 5, which comprises the driver and their immediate operating environment.

Broader context: Australian society & culture • Social expectations (expect immediate response to call/text) • Time-poor lifestyles	**Level 1: Parliament & legislatures** • Laws too lenient
	Level 2: Government agencies, industry, user groups, courts, universities • Licensing requirements too low
	Level 3: Operational delivery & management • Work requirements/pressure • Technology design – e.g. Bluetooth connectivity, complexity of dashboard and in-vehicle information systems, poor integration of tech in vehicles
	Level 4: Local management & supervision • Family/relationship problems, expectations and social pressure • Peer pressure & social norms • Poor driver education & training
	Level 5: Operating process & environment • In-vehicle distractions – technology (phones, GPS, music), children (fighting, crying, removing restraints), passengers, animals, insects • External distractions – billboards, other road users, weather, etc. • Emotions – attachment to phone/social media, bored, stressed • Personality – complacency, indifference, selfishness, laziness, arrogance • Ignorance – unfamiliar with road, fail to appreciate risks • Physical impairment – intoxication, fatigue, hunger, sneezing, coughing

Table 1. Results from Study 1 – Community Survey.

Study 2: Expert Workshop

Following the community survey, a two-day expert workshop was held. The aim of the workshop was to discuss the survey findings and devise additional solutions and interventions.

Participants. The participants were six road safety experts who each had a PhD and worked in academic research positions. All had published extensively in the area of transport safety and had expertise relevant to the "fatal five" behaviours.

Methods. Workshop participants reviewed the findings from the community survey, with the reasons for distraction and inattention mapped on the hierarchical control structure. They then discussed these and added further contributory factors and identified additional solutions and interventions.

Results and Discussion. The additional contributory factors identified through the expert workshop are summarised in Table 2. Here it can be seen that, although many of the perceived causes of distraction and inattention were at Level 5, there were a larger number of contributory factors identified at higher levels of the hierarchical control system compared with Study 1.

<table>
<tr><td rowspan="5">Broader context: Australian society & culture
• Ubiquity of mobile phones
• Social norms
• Social acceptance of behaviours
• Social environment encourages behaviours (e.g. connectivity)</td><td>Level 1: Parliament & legislatures
• Lack of clarity around whose responsibility it is
• Financial constraints around enforcement → priorities</td></tr>
<tr><td>Level 2: Government agencies, industry, user groups, courts, universities
• Vehicle design standards (including lack of human factors integration)
• Rules & regulations around work-related driving
• Vague / unclear rules
• Poor urban planning → car reliance, increased driving time</td></tr>
<tr><td>Level 3: Operational delivery & management
• Rapid technological advancement outpaces regulation
• Job design
• App/technology design: poor human-machine interface, requires lengthy interaction to select songs, etc.
• Manufacturers focused on increasing in-vehicle tech/integration</td></tr>
<tr><td>Level 4: Local management & supervision
• Inadequate enforcement
• Lack of education</td></tr>
<tr><td>Level 5: Operating process & environment
• Drivers' risk perception (i.e., "I can multi-task")
• Vehicle/technology design (allows phone use)
• Poor availability & affordability of public transport</td></tr>
</table>

Table 2. Results from Study 2 – Expert Workshop.

The experts also identified several potential strategies for reducing distraction and inattention. Notably, many of these strategies were at a higher level than the perceived immediate cause. For example:

- Legislate to place responsibility for mitigating distractions on tech developers (L 1)
- Increase availability of roadside stopping areas to allow regular phone use (L 2)
- Increase availability/accessibility of public transport to allow multi-tasking (L 2)
- Telematics linked to insurance discounts, to encourage desirable behaviour (L 2)
- Vehicle manufacturers develop apps for phone integration with vehicle systems, including ability selectively disable functions (L 3)
- Better integration of human factors principles in vehicle/device/app design (L 3)
- Policy initiatives focused on employers, to better manage job expectations (L 3)
- Social media campaigns to encourage public transport use (L 3)
- Community education, such as teaching children to be safe passengers (L 4)

Summary and Conclusions

Overall the findings suggest that the causes of driver inattention and distraction are complex, with contributory factors residing across many levels of the system. Moreover, the potential solutions often exist at a higher "level" of the system to the perceived cause; for instance, preventing drivers from using their phones while driving may require working with telematics providers to limit phone functionality in vehicles, or with employers to eliminate the expectation that employees will be "on-call" while driving. Therefore, road safety stakeholders should focus on high level leverage points such as legislation, design processes and standards to make sustainable gains in mitigating driver distraction and inattention. Further, the observed differences between community and expert indicate that although "safe system" principles are widely endorsed by road safety stakeholders, this message has not yet been effectively translated to the general community.

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Distracted cycling among university students in Braunschweig, Germany

6th International Conference on Driver Distraction and Inattention (DDI2018)

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Keywords: Bicycle, Distracted cycling, Headphones, Mobile phone use, Observational study, Safety

Aim and scope of the study:

As with distracted car driving, the performance of a secondary task while bicycling may be unsafe for the person engaging in the behavior as well as for other people around them [1,2]. For car drivers, it has been found, that the engagement in distracting activities depends on the environmental situation [3]. This has not yet been examined for cyclists, for whom environmental influences are much more direct than for car drivers. In other observations [4], we have found cyclists who engage in one unsafe behavior to also be more likely to engage in another one. Therefore the aims of the present study were:

(1) To estimate the frequency of different distracting activities while cycling in Braunschweig, Germany.
(2) To examine whether cyclists adapt their behavior to the traffic situation and to what extent the behavior depends on environmental and cyclists' characteristics.
(3) To examine whether and how cyclists' secondary task engagement is related to other safety-related behavior.

Materials and methods:

Observations were made between October 17, 2017 and November 17, 2017 at eight locations within the city of Braunschweig, Germany. All locations are located along a prominent cycle path used by students of the Technische Universität Braunschweig to get from a dormitory to the university`s campus and back. In the morning (07:15-11:00), the way into the city (and to the campus) was observed, and in the afternoon / evening (15:00-18:45) the way out (to the dormitory). Each location was observed once on a weekday between Tuesday and Thursday and once on a Friday to control for differing traffic situations.

A trained observer (Selvi Gerceck from the authors) used a tablet including configurable software (Observer, available for free from https://www.tu-braunschweig.de/psychologie/abt/ingenieur/software) to record the behavior of the cyclists. She rated the age (young: about 18–24 years old, middle aged about 25–64, and old drivers from 65 years onwards) and the sex of the cyclist. As studies on cars drivers [4] have shown that the engagement in secondary tasks highly depends on the presence of others, it was also observed if cyclists were cycling in a group or not. Weather, lighting conditions, cycling path surface conditions, and traffic density on the cycling path were also recorded for each observational period to analyze their potential influences on secondary task engagement. The following distractions could be observed and were recorded (multiple selections were possible):

- Handheld phoning: Cyclists held in their phone in their hand.
- Hands-free phoning: Cyclists were talking on their phone not held in hand.
- Using the smartphone: Cyclists were operating (typing on) their mobile phone.

- Headphones: Cyclists were observed to wear headphones.
- Interaction with others: Cyclists were talking to someone else with whom they were cycling in a group.
- Eating/drinking/smoking: These activities were recorded separately.
- Other: non-cycling activities that do not fall into any of the above categories.

Additionally, other safety-related behavior was recorded in order to examine it's relation to secondary task engagement. These behaviors were:

- wearing a helmet,
- wearing light-colored or reflective clothing,
- having the bike properly lightened,
- having both hands on the handlebars.

The observations were automatically stored on the hard-drive as text files and then imported to SPSS 24 using a routine included with the program.

Results:

Within 32 hrs., 2178 cyclists (1209 female, 969 male) were observed. 1208 of them were young (18-24 yrs.), 879 middle-aged (25-64 yrs.) and 91 older (>65 yrs.). 1994 (91.6%) were cycling alone, 171 in a group (8.4%) and 13 of them with children (0.6% of all observed cyclists). 1684 cyclists (77.3%) were found not to be engaged in any secondary task, 464 (21.3%) were observed to do one of the recorded activities, 28 (1.3%) two of them (therein 19 holding a phone in their hand and another activity), and two cyclists were observed to have their phone in one of their hands, typing on it and also wearing headphones. The most common distraction found was "wearing headphones" which was done by 2845 (13.1%) of cyclists, followed by interaction with others (n=152 of 184 cyclists that were observed while cycling in groups; 7.0% of all and 82.6% of them in groups). All mobile phone related activities were found rather seldom, in only 44 cyclists (2.0%). An overview of the activities is shown in Figure 1.

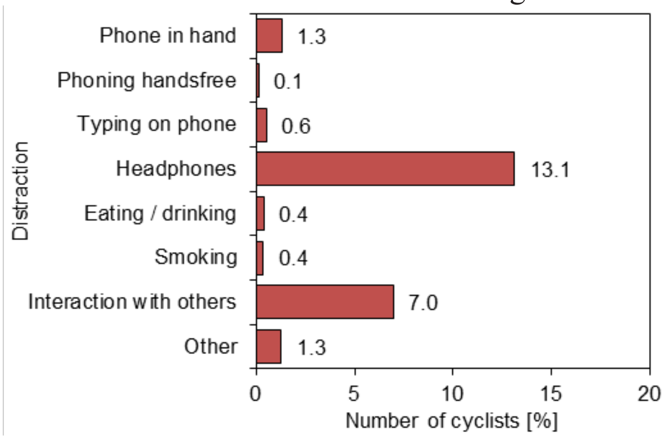

Figure 1: **Overall percentage of the different types of distraction while cyling.**

In order to examine influencing factors, a logistic regression (stepwise backward, Wald criterion) was computed using age, sex, location and time of observation, weather and lighting conditions as well as surface conditions as predictors and the presence of any distracting activity as criterion. Table 1 gives the results of the last logistic regression model (Chi^2=542.07, df=5, p<.001, Nagelkerke R^2=.335). Age, gender, and cycling in a group vs. alone were found as significant predictors. For age, middle aged cyclists had an OR of 27.7 as compared to younger cyclists and older cyclists had an odds ratio (OR) of

5.1 as compared to the youngest age group. The OR of males compared to females was 1.4. The OR of cycling in a group as compared to cycling alone was 22.6.

Table 1: Results of the logitic regression for any distracting activity.

Any Distraction				Confidence Interval	
Predictor	Wald	p	OR	lower	upper
Male vs. Female	7.6	0.006	1.4	1.1	1.8
Age	144.9	<0.001			
Medium vs. Young	19.3	<0.001	27.7	6.3	122.3
Older vs. Young	4.6	0.032	5.1	1.2	23.1
Group vs. Alone	198.0	<0.001	22.6	14.7	34.9

For examining the relationship between distracting activities and other safety-related behavior, Chi²-tests were conducted for each type of distraction and the four recorded safety-related behaviors. Tests show, that those who engage in any type of distraction are less likely to wear light-colored clothing ($Chi^2=7.895$, df=1, $p<.005$) or a helmet ($Chi^2=68.581$, df=1, $p<.001$). They were less often found to have both or even one hands on the handlebars ($Chi^2=92{,}997$, df=3, $p<.001$). More specifically, cyclists who were wearing headphones were also less often wearing a helmet ($Chi^2=43.863$, df=1, $p<.001$) or having their hands on the handlebars ($Chi^2=28.117$, df=3, $p<.001$). No other dependencies were found.

Conclusions:

In this observational study on mostly young and middle-aged cyclists on a connecting cycle route, about one fifth of cyclists were found to be distracted in any way. Most of these were wearing headphones which have been shown to severely disrupt audio-perception [5]. The demographics of those most found to be distracted differ from the results found in car driving [4], as in this sample the middle-aged and older group was more often found to be distracted. No influences of environmental conditions on distracting activities were found. Additionally, those cyclists found to be engaged in those activities were less likely to show other safety related behaviors, such as wearing a helmet. To promote safer cycling for these behaviors as well as for secondary tasks, an educative approach seems to be the most promising, showing cyclists the effects on unsafe behaviors and teaching them how to prevent those negative consequences.

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To text or not to text - Drivers' interpretation of traffic situations as the basis for their decision to (not) engage in text messaging

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Keywords: Adaptation; Complexity; Context; Interview; Predictability

EXTENDED ABSTRACT

Texting, with its strong visual component, is task that obviously has the potential to interfere with the primary task of driving. Not surprisingly, various studies have reported negative effects of texting on driving performance [1]. One shortcoming of most of these investigations, however, is the fact that participants usually did not get the chance to decide for themselves whether to text or not. Instead, as most of these studies were experimental in nature (e.g., in a driving simulator environment), participants were confronted with different traffic situations, and required to text at a predefined moment (e.g., after the passage of a certain waypoint). While such an approach is fully reasonable when considering the need for standardization and control in experimental studies, it neglects the possibility that a driver, although in general willing to text, might decide against the engagement in a secondary task in the specific traffic situation in which he or she is put experimentally.

Indeed, there are clear indications that drivers adapt their general secondary task engagement, and also their texting behaviour in particular, to the driving context (e.g., [2]). Most of these findings, however, are based on observations of behaviour (in experiments or real world driving), and therefore cannot give insight into the drivers' reasoning. One notable exception is the study of Hancox and colleagues [3], who presented participants with video clips of traffic situations of varying complexity, asked them to indicate their willingness to engage in different secondary tasks (texting among them), and allowed them to freely provide information with regard to their thought processes ("think aloud"). Unfortunately, the findings of the "think aloud" portion of the study were only reported anecdotally, to offer "insight as to why the [...] results [regarding the (un)willingness to text] were observed" (p. 219).

The aim of this study was to get a better understanding of the drivers' reasoning when deciding to (not) text, focussing on their interpretation of the traffic context regarding its suitability for texting. In our video based interview study, we, to some degree, followed the approach of Hancox et al., however, put a stronger focus on the participants' explanations for their decision to (not) text, both in the design of the study and the analysis of the data.

Method

Participants: Fourty-one drivers (19 female, 22 male) were selected for participation. They had a minimum of 12,000 km of annual mileage (mean 30,146 km), and were in possession of driving license for 14.5 years on average. All participants had expressed a general willingness to text while driving in a screening questionnaire.

Material: We collected a wide range of traffic situations from a driver's point of view, using a camera (1920x1080 px, 25 fps) mounted on the windshield inside a vehicle. Out of that collection, we selected a total 43 situations for our study. The selection was based on road type (motorway, rural, urban) and complexity of the situation. Following the classification scheme of Fastenmeier [4], nine of our situations were considered of low complexity, nine of medium complexity, and eight of high complexity. The remaining 17 situations were added to the selection because they depicted situations known to be safety relevant and of frequent occurrence, but did not fit into the scheme proposed by Fastenmeier (e.g., driving through a tunnel, overtaking a cyclist). The final cuts of the videos were between 6 and 18 s in length, and showed the current driving speed at the bottom left of the video (see Figure 1).

Figure 1. Screenshot of one of the traffic situations (urban road, medium complexity).

Procedure: Following a general introduction, participants were instructed to view the videos (order counterbalanced across participants) from a driver's perspective. They were supposed to state whether they would be willing to write a text message under the depicted circumstances. In addition, they were asked to specify what situational characteristics had an influence on their judgement. Participants also estimated how crash risk would change in this situation as a result of texting. All responses were audio recorded. (In addition, participants were asked to clarify what would need to be different in the respective traffic situation in order for them to revise their judgment. They also provided general information about their texting behaviour. These results are not reported in this abstract.)

Data analysis: We collected about 3,000 min of audio recordings. All recorded responses were transcribed verbatim. In total, we transcribed 1,996 arguments for texting in the different situations, and 2,648 arguments against texting. The method of qualitative content analysis was used to classify the arguments, through multiple steps, into different categories. These argument categories were then analysed with regard to their frequency of occurrence.

Results

On average, our participants indicated a willingness to text in 18.5 out of our 43 situations (about 43 %, $SD = 6.5$). The most cautious participant considered only 6 situations suitable for texting, while the two most willing participants judged 34 situations as appropriate. Complexity as defined through the Fastenmeier scheme clearly played a role for the participants' judgment, as the situations that were categorized as highly complex went with an indicated texting rate of 22.3%, the ones of medium complexity with a rate of 39.0%, and the low complexity situations with a rate of 61.8%. Not surprisingly, we found a very strong relationship between participants' stated (un)willingness to text in a specific situation, and their estimation of the increase in crash risk as a result of texting in that situation, with a significant correlation of $r = -.884$, $p < .001$.

In Figure 2, the different categories of arguments in situations participants considered suitable for texting are presented (the arguments provided against texting mostly mirror them, and are therefore not reported in this abstract). One frequently provided argument was the absence of other road users, or the fact that their behaviour would be highly predictable. Others included the idea that there was a lot of "empty" space ahead and around the vehicle, or that lighting and the environment provided a clear view of what was to occur ahead. A perceived moderate or low level of speed, just as the vehicle being stopped completely, also appear to increase the willingness to text.

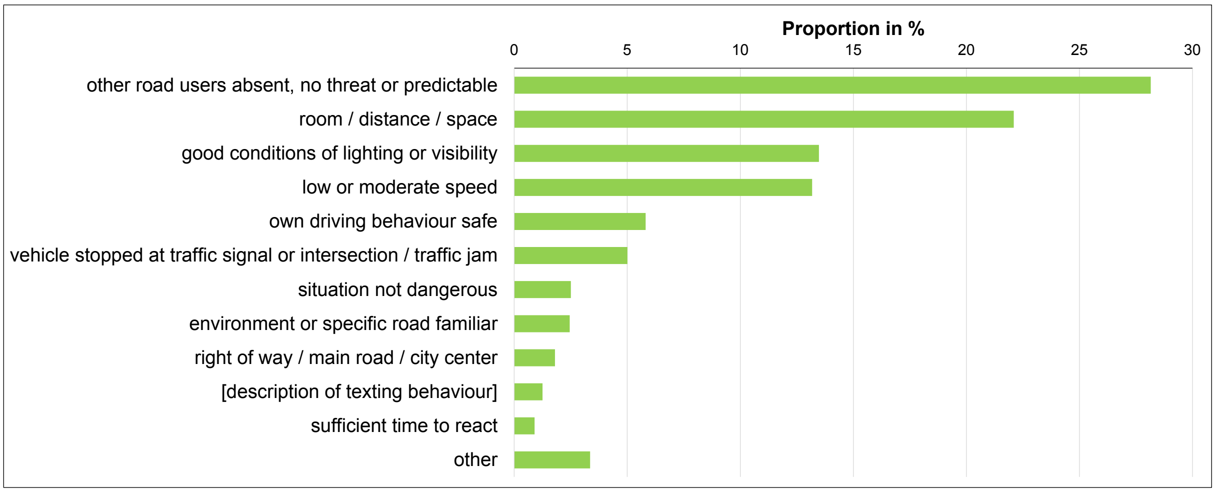

Figure 2. Categories for arguments provided by participants as explanations for why they would be willing to text in a certain traffic situation.

Conclusions

The findings of our study clearly indicate that the complexity of the traffic situation plays a role in drivers' willingness to text, which is in line with the results of Hancox et al. [3]. More importantly, however, the analysis of drivers' explanations of why they deemed a certain situation suitable for texting provided insight into what aspects of such situations they consider when making the decision to text. The most frequent arguments (being able to foresee the behaviour of other road users, having lots of space ahead, having a clear view and driving at low speed) are all aspects that indicate that, subjectively, there is no imminent threat, and that any threat that might occur could be easily dealt with, as there would be sufficient time to respond to it (because of low speed, or because the threat would be easily detected). To what degree this subjective assessment of the traffic situation is appropriate, however, has to be subject of further investigation.

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Validation Study of Driver's Attention Level during Actual Driving Using fNIRS

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Abstract: As an evaluation method for traffic safety measures, the self-reflection reports of drivers by means of questionnaires and the macro traffic accidents analysis have conventionally been used. However, there are some problems, such as the former method cannot avoid the occurrence of a variety of biases, and the latter method cannot strictly evaluate the vary effect of traffic safety measures. In this study, based on the measurement of brain activity using fNIRS and the driver's behaviour using automobile CAN data, we tried to grasp the driver's attention level while driving for traffic safety facilities. As a result, we confirmed that PAC and PFA activated in the case of driving with recognition and judgment for the information which a driver collected from the environment while driving. Then it was suggested that it was needed to expand PAC in order to measure the brain activity. Furthermore, it was suggested that both on and off throttle stroke were connected with the activity of PFA. In other words, it was suggested that it was confirmed the driver's attention level at every steps, such as "recognition", "judgment", "behaviour", by means of being approached from a neuroscience using fNIRS.

1. Introduction

As an evaluation method for traffic safety measures, the self-reflection reports of drivers by means of questionnaires and the macro traffic accidents analysis have conventionally been used. However, there are some problems, such as the former method cannot avoid the occurrence of a variety of biases, and the latter method cannot strictly evaluate the vary effect of traffic safety measures [1]. Then we are trying to grasp the driver's attention level by measuring the brain activity using functional Near Infra-Red Spectroscopy (fNIRS) at sighting Variable Message Sign (VMS) on expressway. And we are also trying to grasp the driver's attention and behavior measuring both the driver's activity and the change of car acceleration and deceleration [2-4]. As a result, we showed that when the driver, who intended to reduce speed, noticed the speed reduction and stop the speed reduction at an ascent straight road section following the Okitsu sag on New Toumei Expressway, the activity of parietal association cortex (PAC) and prefrontal area (PFA) activated, and then the driver took action to press on the accelerator [5]. Then we could hypothesize that the linked activity between PAC and PFA were involved in the process of "recognition", "judgment" and "behavior" in order to take action to drive as a result of driver's noticing the situation change or condition change during driving. Moreover, according to preceding study at Shirosato test center of Japan Automobile Research Institute (JARI), we qualitatively confirmed the rise of PAC, and also confirmed the reduction of driver's acceleration behavior, caused by the installation of attention attracting sign as a traffic safety measures. [6]

Then we considered that we could grasp the driver's attention level, and later driver's behavior (such as recognition, judgment and behavior) with checking the change of brain activity using fNIRS and with getting the driver's behavior from Controller Area Network (CAN) data. So we tried to grasp the driver's attention level and behavior at recognizing the information on VMS, by means of statistically analyzing examinee's driving behavior and brain activity on passing by VMS.

2. Experiment

2.1. Examinee

A total of 12 healthy, right-handed adults (men: 5, women: 7, mean age: 31.3±6.8 years) participated in the experiment. The mean period of time for which examinees had had a license was 11.3 ± 6.8 years. When conducting the test, the aim of the test was explained in writing and orally in accordance with the document and procedure approved by a research ethics committee of University of Tokyo, thus obtaining agreement to participate in the test and to report the test results from the examinees.

2.2. Test course of actual driving

The experiment was conducted in Okasaki-higashi segment of Shin-Tomei Expressway, while it was under construction. In the test course, there was a speed bump at 506m from a start point, the first sign at 674m point, VMS at 772m point, and the second sign at 932m point. The test vehicle was a passenger car (Estima Hybrid, Toyota, Japan). It was a 2WD 5-speed automatic. A multi-channel fNIRS brain activity measuring device (FOIRE-3000, Shimadzu Corporation, Japan) was installed behind a driver's seat. (Fig. 1-2)

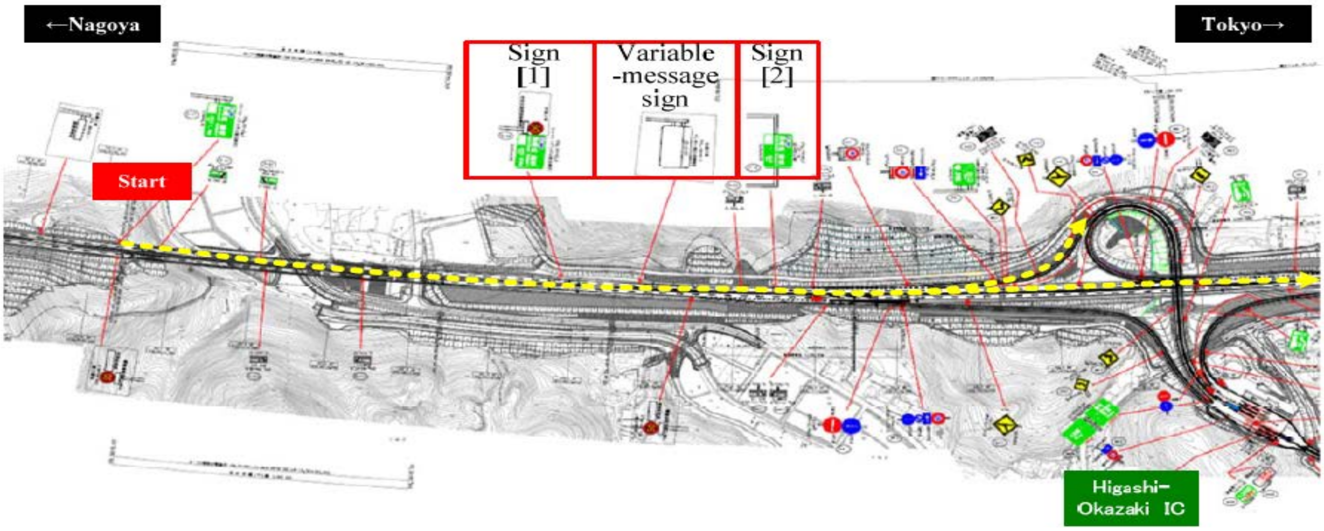


Fig. 1. *Over view of test course, New Tomei Expressway before opening*

Fig. 2. Test vehicle and mounted fNIRS (A) Side, (B) Back

2.3. How to get the data

The fNIRS used for the brain activity measurement is equipped with a light emitting probe that irradiates the skull with near infrared waves from 700 to 900nm and a light receiving probe that condenses light that is absorbed and dispersed by the cerebral cortex, clarifying brain activity (Fig.3-7), [7].

Brain activity consumes oxygen in the brain's neurons. This means that neuron activity is accompanied by hemoglobin containing oxygen that flows from the arteries in capillaries (oxygenated hemoglobin: oxyHb) changing into hemoglobin without oxygen (deoxygenated hemoglobin: deoxyHb). But when there is no neural activity, even if the oxyHb increases, dexoyHb does not increase. fNIRS can measure the concentration change of oxyHb and deoxyHb that occurs in these capillaries (Fig. 3b). This measurement was done by sampling 70ms of oxyHb and deoxyHb [2] [4] [7].

ΔCOE was calculated from equation (1) [7].

$$\Delta COE = \frac{\Delta DeoxyHb - \Delta OxyHb}{\sqrt{2}} \qquad (1)$$

Increased COE indicates that oxygenation in blood vessels is low, whereas decreased COE indicates higher oxygenation in blood vessels. ΔCOE is a more accurate physiological indicator of localized brain activity than the conventionally used ΔOxyHb or cerebral blood volume changes [6].

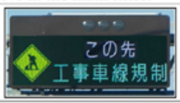
We obtained the driving behaviour data from a controller area network (CAN) included steering degree (steering to left = plus, steering to right = minus), accelerator divergence (%), speed (km/h), accelerator and brake pedal stroke, acceleration of movement direction (m/s^2), and a car position by GPS.

In order to synchronize fNIRS data and CAN data, we input the value by measuring a laser displacement meter mounted on the car to fNIRS device and CAN analyzer. And

GPS data and CAN data were synchronized by the car velocity.

According to the visual axis data analysis, we checked the visual axis to VMS or not at every image by shooting the eye-trucker, and recorded a visual axis on to "1 or 2", and off to "-". Then a visual axis on "1" was a bulb of eye moved from other point to VMS, and "2" was a bulb of eye did not move in the case of VMS's being imaged in eye-trucker image area.

Table 1. Tasks

Task 1	Task 2	Task 3
No event	Congestion	Construction
VMS displaying "Blank (No event ahead)" Examinee's challenge was to drive on the main lanes.	On condition that a car stopped ahead. VMS displaying "Congestion ahead". Examinee's challenge was to drive on the main lanes.	On condition that the construction lane regulation ahead. VMS displaying "Construction ahead". Examinee's challenge was to drive in the main lines.
		

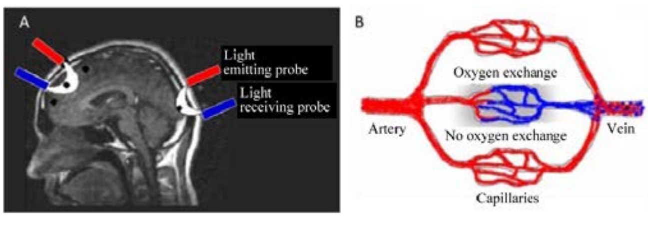


Fig. 3. *fNIRS measurement principle*

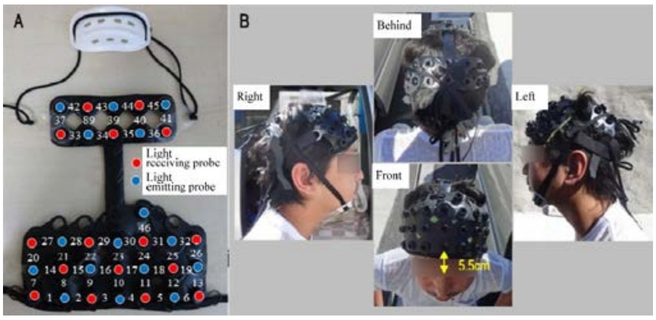


Fig. 4. *View of examinee wearing head attachment*
(a) Probe channel number, total 46 channels. Red: Emitter, Blue: Detector
(b) Wearing a head attachment

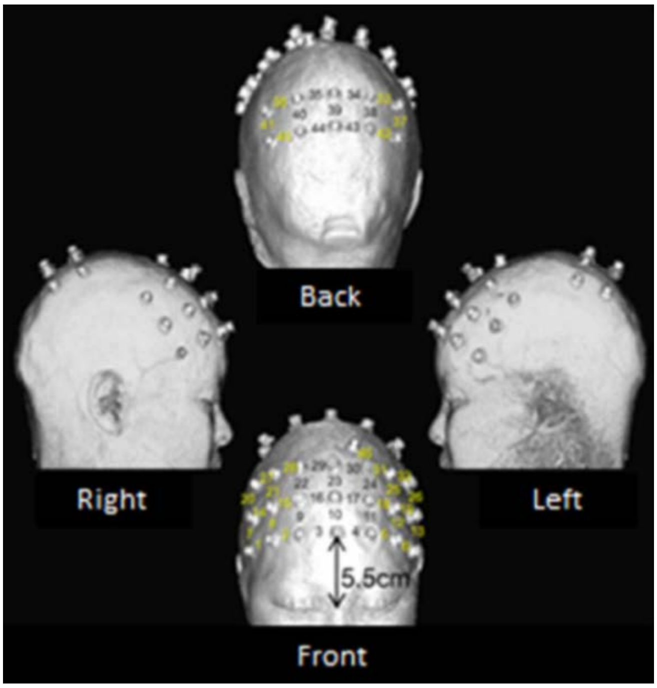


Fig. 5. *Layout of fNIRS probe*

Fig. 6. *fNIRS probe and Brodmann's areas*

Fig. 7. *Examinee wearing fNIRS in car*

2.4. Task

One examinee drove 3 test runs with different 3 tasks. We instructed examinees to drive 80km/h on left lane with obeying the traffic regulation, and to run and stop safely on their own advices except the special indication. Table 1 shows 3 tasks.

2.5. Data analysis

The changes in DeoxyHb (ΔD) and OxyHb (ΔO) data were subjected to low-pass filter in gat 0.1Hz to remove any high frequency components. Then the change in cerebral oxygen exchange (ΔCOE), which indicated the oxygen change in a capillary vessel, were calculated for each of these two indicators (ΔD, ΔO). A positive value for ΔCOE indicates hypoxic change from ΔCOE=0, and this means that Deoxygenation is occurred in capillary vessel because of a nerve cell's spending oxygen. A negative value for ΔCOE indicates hyperoxia change in capillary vessel, and this means that red blood corpuscle containing much oxygen is provided from an artery. ΔCOE is a more accurate physiological indicator of localized brain activity than the conventionally used ΔOxyHb or cerebral blood volume changes [1] [3] [6]. ΔCOE was calculated from equation (1) [6].

2.6. Data normalization

In order to evaluate and to analyze every examinee's brain data, driving behavior data and glance data with same criterion, we normalized these data by a travel distance. Therefore, these data were linearly interpolated using GPS coordinates with respect to the locus on the road at every meter. The travel start point was set to zero (0-m point) for the COE value of average land-series data.

3. Result

3.1. Brain activity task1 and task 2

Analysing all examinees' data (n=12), there was a significant difference between Task 1 (No sign) and Task 2 (Congestion ahead) in ΔCOE before VMS (772m) at left PFA (BA9: channel 18) and right PAC (BA7: channel 38). (Table 2, Fig.9)

Fig. 9 shows a brain data, and the change of acceleration to the forward direction. A black dot line shows Task 1 (No warning) mean wave profile. A black solid line shows Task 2 (Congestion ahead) mean wave profile. Light brawn belt shows the significantly different area.

At left PFA, ΔCOE at 754m and 727-759m in the case of Task 2 indicated significantly higher value than ΔCOE in the case of Task1. ΔCOE indicated plus values in the case of Task 2, and ΔCOE indicated minus values in the case of Task 2 at every point. (Task 1<Task 2: $p<0.05$) At right PAC, there was a significant difference between both ΔCOE at 727-728m and 732m in the case of Task 1 and Task 2. (Task<Task 2: $p<0.05$) ΔCOE indicated plus values at every point in the case of Task 2, and ΔCOE indicated minus values at every point in the case of Task 1.

The increase ratio of ΔCOE at left PFA was a slower than that of ΔCOE at right PAC, and then ΔCOE at left PFA kept increasing in spite of ΔCOE at right PFA decreasing at 736m. So we considered that there was the specific pattern to accentuate the right PFA activity after the left PAC activity.

We also confirmed that the acceleration reduced after PAC activated in the case of acceleration change to the forward direction. In other words, it suggested that there was a strong possibility for brain activity to affect the behaviour data.

Table 2. Brain part of ΔCOE significant difference between Task 1 and Task 2

Area Channel	Significantly different point	Start point of ΔCOE increase	Distance from VMS (772m)
Right PFA Channel 38	727-728m, 732m	664m	107m
Left PAC Channel 18	754m 757-759m	665m	106m

Fig. 8. A view of from 664m point (We can see VSM in VTR image at the start point of a brain activating.)

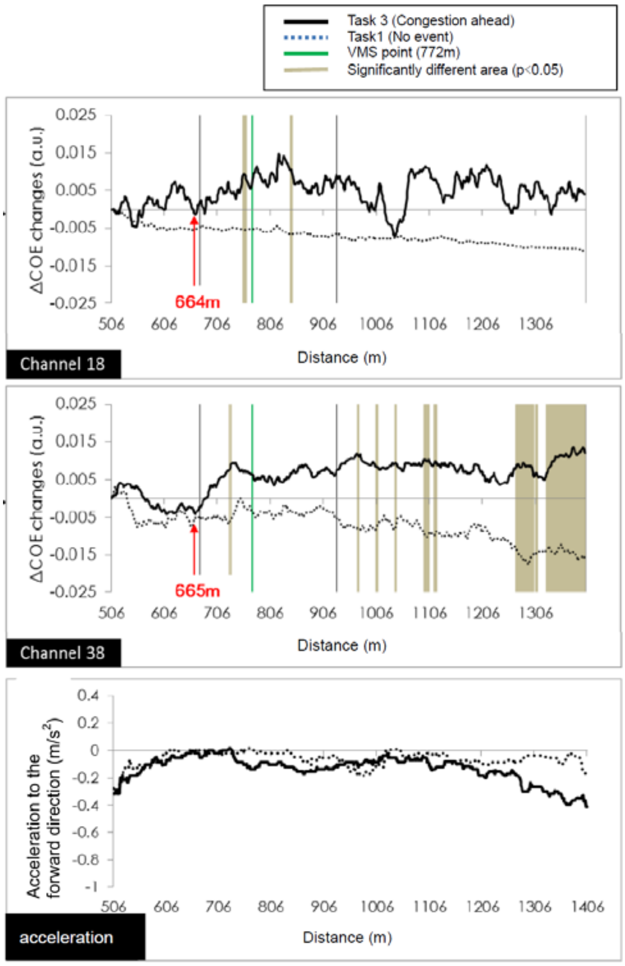


Fig. 9. Comparison of brain activity between Task 1 and Task 2 after 506m

3.2. Brain activity task1 and task 3

We compared between Task 1 (No sign) and Task 3 (Under Construction) in ΔCOE regarding all examinees' data. As a result, only the ΔCOE increased area in Task 3 than that in Task 1 was left PAC (BA7:channel 44) on this side of VMS (772m) significantly. (Table 2, Fig.10)
Regarding left PAC, we recognized between both groups (Task 1<Task 3: $p<0.05$) at 760-766m. Then ΔCOE in Task 3 showed a plus value, and ΔCOE in Task 1 showed a minus value at this point. ΔCOE at left PAC increased gradually till showing a significantly difference and ΔCOE changing point of increase was 639m. (However, at once, ΔCOE decreased passing at the sign 1, and increased 714m point again.) The acceleration to the forward direction tended to increase slightly. (Table 3, Fig. 10.)

Table 3. Brain part of ΔCOE significant difference between Task 1 and Task 3

Area Channel	Significantly Different point	Start point Of ΔCOE increase	Distance From VMS (772m)
Left PAC Channel 44	760-766m	639m	133m

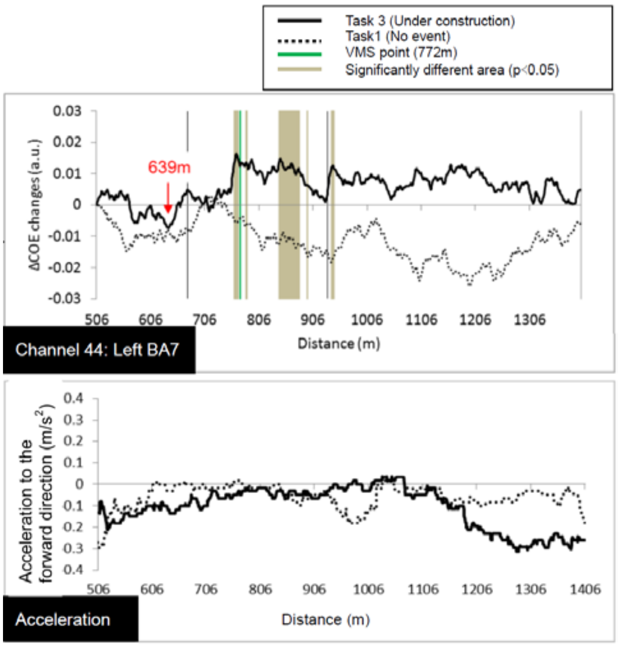


Fig. 10. Comparison of brain activity between Task 1 and Task 3 after 506m

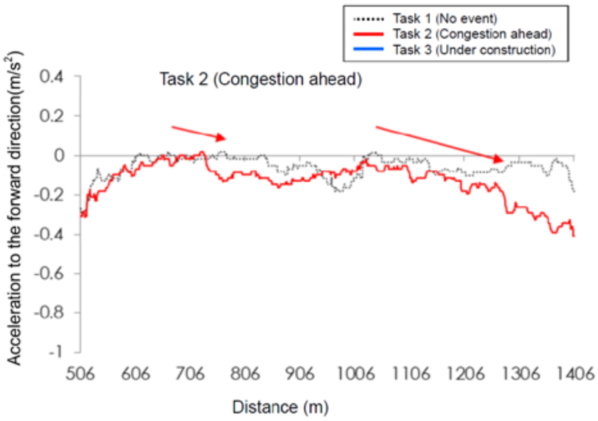


Fig. 11. Mean wave profile of acceleration in Task 2

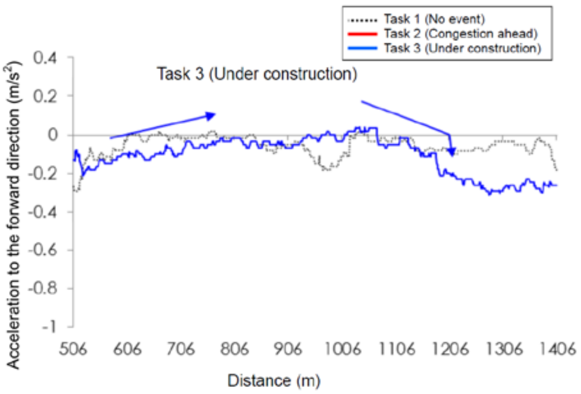


Fig. 12. Mean wave profile of acceleration in Task 3

3.3. Driver's behaviour

We analysed the change of acceleration to the forward direction by reason of the display content on VMS (Fig.11-12). As a result, on this side of VMS, the acceleration tended to decrease in the case of "Congestion ahead". On the other hand, the acceleration tended to increase in the case of "Under construction". At the phenomenon of "Congestion ahead" and "Under construction", we could recognize that the acceleration at "Congestion ahead" rapidly decreased than that at "Under construction".

3.4. Difference by information

In the case of "Congestion ahead", from a visible point, PFA activity began gradually to increase, after PAC activity gradually increased. Then PFA activity kept increasing, after PAC activity changed to a decrease from an increase. Especially, right PAC activated. And the acceleration to the forward direction decreased before passing VMS. Moreover PAC activity activated from 664m point, and ΔCOE of PFA began to increase from 665m point which was 1m delay.

In the case of "Congestion ahead", there was some typical pattern which PAC activity significantly activated. To be specific, we grasped the reaction of beginning to activate in PAC from a visible point of VMS. The acceleration to the forward direction was a tendency to increase with VMS point.

The active area of PAC was a left hemisphere. And the activity of PAC activated from 636m point.

4. Brain reaction for visual perception

Compared between the brain activity with and without information on VMS, we found that the brain activity at PAC and PFA activated more with information than without information. Then we also suggested that the gradually increasing activation rose about 100m point on this side of VMS.
However, at that time, we could not support that that the brain activation of gradually increase caused by the visual perceptive information. Then we tried to detect the activating brain part in the process of starting action by visible perception based on driver's gaze data in this test.

4.1. Experiment

4.1.1: Examinee We selected 10 examinees that were judged to keep the accuracy of gaze data calibration.

4.1.2: Experiment method We experienced this test using Driving Simulator (DS) in order to confirm the brain activity caused by visible information, because of measuring driver's gaze data accurately.

The DS with 6 degrees of freedom is made by Mitsubishi Precision Company Limited in Japan (Fig.15-16). This DS was equipped with a bonnet, roof, and a post etc. in order to reproduce the field of vision on riding in an actual car. And this DS test reproduced with the actual sound condition. The scenario of the running DS was the reproduced test course of the 2km actual Expressway to the greatest possible degree based on New Tomei Expressway (around Okazaki-Higashi IC) construction plans and the moving pictures and the photos taken during driving. Each examinee sat in the driver's seat of the DS, then he adjusted the seat position, so the examinees could fully operate the accelerator pedal and brake pedal. Each examinee practiced until he was accustomed to the feeling of driving DS. Then the examinee was instructed to drive about 80km/h at this test.

4.1.3: Analysis The examinees checked a speed meter to keep the car speed 80km/h many times, through the gaze data at DS test. Then examinees controlled an accelerator while watching a speed meter. So we recognized that the driver conducted the series of process, such as visual perception, recognition, judgement, and behaviour, without any time lag. Therefor we defined that the section where a driver watches a speed meter, was an analysing section.

We detected the section of watching a speed meter by checking frame by frame playback of the gazing data on VTR. And we normalized this data by a travel distance, like brain data. We used ΔCOE as brain data, and the change of accelerator angle as driver's behaviour data. We calculated the mean changing volume of ΔCOE and accelerator data at whole analysing section, with offsetting 1m from the analysing section defined by the gaze data (Fig. 13).

We classified the getting 262 data into 3 groups according to the change of accelerator angle, such as a constant group (n=10), an increase group (n=107), and a decrease group (n=145). We searched the point in common and difference between an increase group and a decrease group, because the driver in a constant group did not press on the accelerator pedal at all.

We defined "a common point" as a channel in which ΔCOE increased in two groups, and "a different point" as a channel in which ΔCOE showed different trend in two groups (t-test). We set that the significant level was 5% (Fig. 14).

4.2. Experiment result

4.2.1. Common parts of brain activity: Figure 32 shows ΔCOE mean change volume (±SEM: Standard Error of the Mean) at every channel in the acceleration angle increase group (to press an accelerator pedal) and decrease group (to loosen an accelerator pedal). The red ✓ shows ΔCOE is +. The red belt shows the section which ΔCOE increase at both two groups.

There were 11 channels out of 46 channels which showed +ΔCOE in both two groups. 11channels were BA46, BA6, BA8 in PFA, and BA7, BA40 in PAC (Fig. 17).

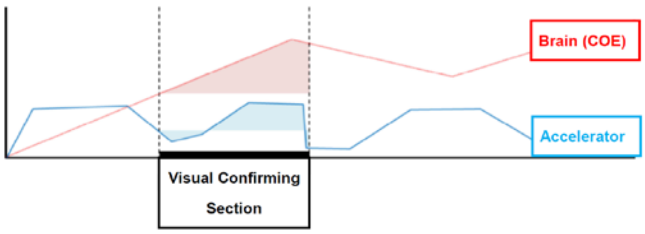


Fig. 13. *Image of data analysing*

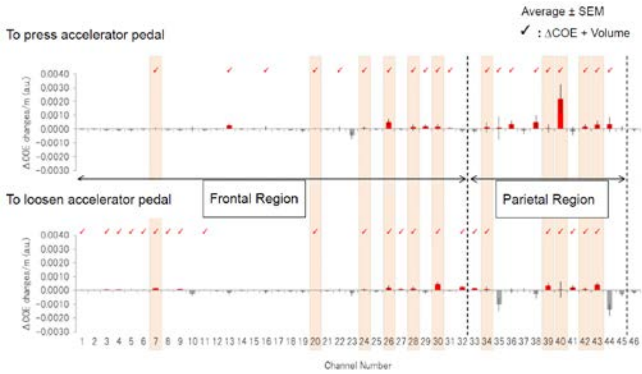


Fig. 14. *ΔCOE Mean change volume*
Red band shows ΔCOE increase channel in both 2 groups

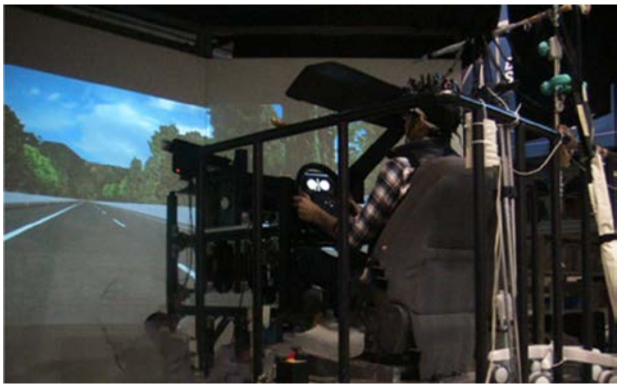


Fig. 15. *Scene of DS test*

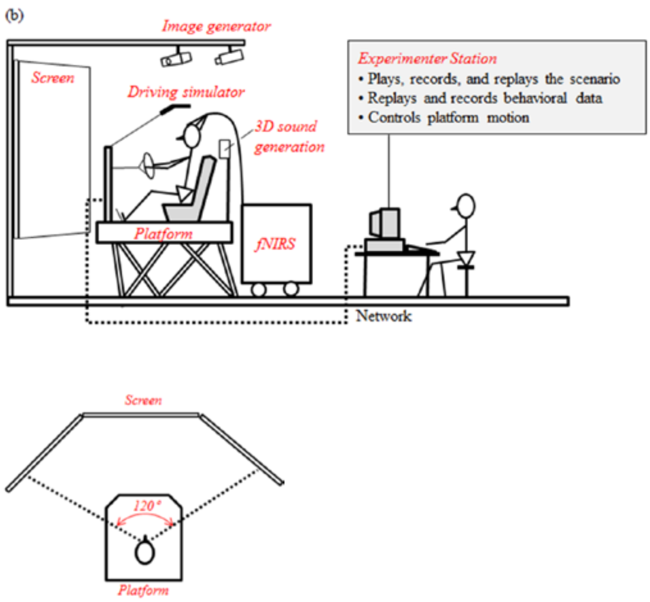


Fig. 16. *Structure of DS*

Table 4. Channel No. and Brodmann's area

Channel No.	Brodmann area (BA)	
7	Right	BA46
20	Right	BA6
26	Left	
24	Left	BA8
30		
28	Right	
34	Right	BA7
39	Middle	
40	Left	
43	Right	
42	Right	BA40

4.2.2. Different part of brain activity: Compered with ΔCOE by t-test in two groups, we found the difference in 3channels out of 46 channels (Fig.18-19).

The right and left PFA (BA9; left channel 5, p=0.032; right: Channel 8, 51, p=0.022) in an accelerator decrease group were significantly activated in brain activity, compared in an accelerator increase group. And the left PAC (BA7; Channel 44, p=0.045) in an accelerator increase group was significantly activated in brain activity compared in an accelerator decrease group.

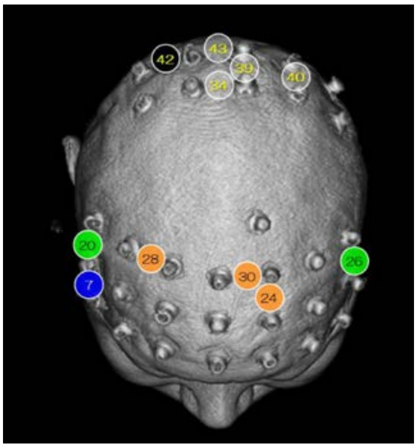


Fig. 17. *+ΔCOE showing area in both 2 groups*

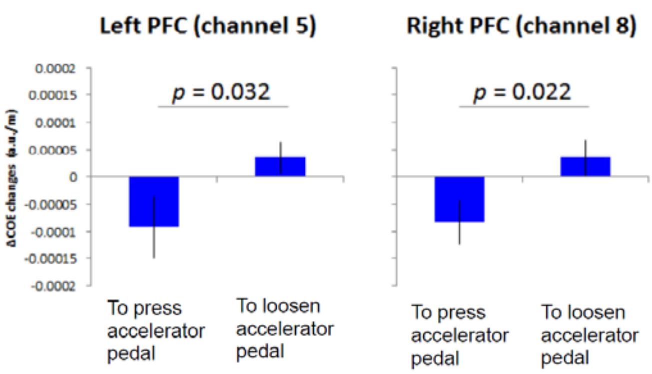


Fig. 18-1. *ΔCOE different 3 channel's volume between 2 groups*

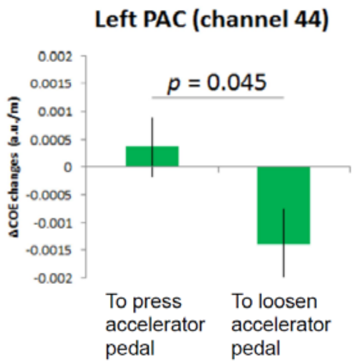


Fig. 18-2. *ΔCOE different 3 channel's volume between 2 groups*

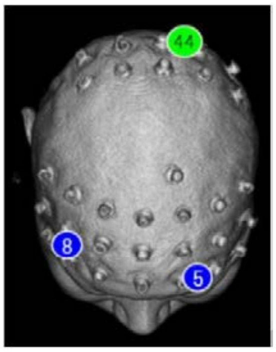


Fig. 19. *3 channels being different ΔCOE between 2 groups*

4.3. Discussion

In this test, it was suggested that PFA (BA46, BA6, and BA8) and PAC (BA7, BA40) activated at the time to start the driving action with observing visually, whether to press on the accelerator or to loosen the accelerator. BA46 takes part in a working memory, then we considered that BA46 activated with multitasking, like operating while watching [8]. And we could confirm the activation of BA6 related to the planning of motion, and BA8 related to an ocular motility, which was regarded as important for driving, and it was confirmed in a previous study. In addition, we confirmed that the activation of BA7, and BA40, which were connected the visual space information processing and the caution function. So we confirmed the activation of necessity brain parts for driving again, that were measuring until now [9] [10].

In this DS study, we found that to start a restrained action, like an action to loosen an accelerator pedal, activated PFA (back outside part) compared with brain activity by different accelerator pedal operations. And we also found that to start an accelerant action, like a activate PAC.

4.4. Summery

In this DS study, we confirmed that different activities activated different parts of brain, like when I watched (ocular motility), when recognized (PAC), when judging (PFA), and when to start action (CAN data). Therefor owing to get the visual information, we confirmed that the corresponding brain region was activated by the

7

reaction target. That is, because DS test was reproduced actual road test in detail, it was suggested that the cause of ΔCOE increase in actual road test, was the reaction occurred by the visual information according to measurement result of the visual axis movement.

5. Discussion

5.1. Importance of PAC and PFA activity for driving

We inspected the brain activity interlocking between PAC and PFA for "Congestion ahead" on VMS in actual car driving. This brain activity interlocking between PAC and PFA was same as former study.[4] Orino et al. indicated that PFA activated after PAC activating in the process of recovering a car speed on driver's perceiving a speed reduction because of an upward slope passing through a sag.

We confirmed again that PAC and PFA activated in the case of a driver's recognizing and judging for getting information during driving from an environment, though the contents of task was different between a sag environment and a warning on VMS. Till now, the car driving evaluation area using fNIRS was PFA as a measuring subject [11] [12]. However we suggested that the measuring subject needed to expand both PFA and PAC. From now on, we considered that it was needed to measure the both PFA and PAC for the evaluation of car driving.

5.2. PAC activity for driving

The activity at PAC was detected to both the warning of "Congestion ahead" and "Under construction". The function of PAC was known as the attention of visual space [13]. And it was indicated that the hypo-function of PAC was related to the attention deficit / hyperactivity disorder (AD/HD) [14], the parietal region function was related to activate an attention.

In this test, we considered that the PAC activation was caused by the activation of visual attention. The right PAC activity was significantly observed at the warning "Congestion ahead" on VMS in actual car driving test. It was reported that the right PAC had a role of sustaining an attention for space [15], and then it was considered that there was a possibility for VMS to contribute the activation of an attentive sensibility.

5.3. PFA activity for driving

In this test, the common brain activity for both a warning "Congestion ahead" and Orino et al [5] report was the activation of PAC and PFA. But drivers' behaviours were different between two. In this test, in the case of a warning "Congestion ahead", drivers were tended to reduce an acceleration to forward direction (To lose an accelerator pedal). On the other hand, in the Orino et al. report, drivers pressed on an accelerator pedal (To change from the reducing a speed to the keeping a constant speed). Based on these results, both the increase and decrease throttle angle were connected with PFA activity.

The car driving behaves 3 processes, such as recognition, judgment and action. Considering that drivers behave the suitable accelerator work for driving condition at every time, we consider that PFA activation is connected with the activity of judging by a recognition, such as "To change driving behaviour".

In this experiment, PAC activated and PFA did not activate, and then it was shown the increase of throttle angle (press on an accelerator pedal) in the case of "Under construction". On the other hand, in the case of "Congestion ahead", PFA activated and then it was shown the decrease of throttle angle (release an accelerator pedal). In the case of "Congestion ahead", we considered that a driver needed to stop, and that a driver changed the action from pressing on an accelerator pedal to releasing an acceleration pedal, then PFA activated. On the other hand, in the case of "under construction", we considered that a driver needed not to release an acceleration pedal, and that a driver did not change the action, then PFA did not activate.

PFA has the function related a behaviour depression, and PAC has the function related behaviour acceleration [16]. Then above-mentioned hypothesis is favoured.

We considered the hypothesis that the activity of PFA for the display on VMS activated while the action to depress the behaviour to press an accelerator pedal. So, it was suggested that there was a possibility to judge an occasion of driving behaviour by a display on VMS with or without PFA activation while a driving evaluation.

In other words, a driver need to stop in the case of congestion, and a driver need not to stop in the case of under construction because of keeping one lane. Then the difference of brain reaction for the display on VMS was considered the possibility related the experience of driving. Therefore, we confirmed that owing to get the content of information, the brain reacting region was different, and its attention level was also different.

6. Conclusion

In this study, according to actual car driving on the actual expressway, based on brain activity measuring using firs, we tried to grasp the interaction between a driver's reaction on sighting VMS, and a driver's behaviour, such as the change of car speed and acceleration, measured by CAN data after that.

As the result, we confirmed that PAC and PFA activated in the case of a driver's driving with recognition and judgment using the collecting information from an environment. Therefore it was suggested that it needs to expand the measuring area to PAC.

Also, it was suggested that PFA activity was connected with both increase and decrease throttle angles. Then we confirmed that the action to watch, to recognize, to judge, and to act activated different parts of brain respectively through the action of driving.

So it was considered that it was possible to grasp driver's attention level by measuring the brain activity. And according to the neuroscience approach, we could suggest that it was effective to confirm the driver's reaction at every step, such as "recognition", "judgment", and "behaviour".

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Physiological indicators for detecting a driver falling asleep during highly automated driving

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Keywords: Driver state monitoring; Heart Rate; Highly automated driving; Muscle tension; Sleep; Skin Conductance Level

EXTENDED ABSTRACT

Introduction: Adverse driver states such as distraction and fatigue increase the crash risk by three to six times [1]. Highly automated driving (HAD) might have the potential to reduce the adverse effects of these driver states by relieving the driver of a great deal of her/his driving tasks. Many HAD concepts are even designed in such a way that drivers are allowed to be distracted or inattentive [2]. However, driving with automation can be the cause of adverse driver states on the other hand. Driver drowsiness was found to increase in situations of low situational demand [1] and especially during automated driving compared to manual driving [3]. A new dimension of adverse driver state is likely to emerge in automated driving: Drivers might fall asleep and sleep for a longer period during the drive. N=8 out of 30 drivers fell asleep while driving a highly automated vehicle on a test track even though they were told that they were required to intervene occasionally in a study by Omae, Hashimoto, Sugamoto and Shimizu (2005, cited by [4]). Also drivers indicate that they want to use automation to sleep while driving [5]. Anyway, even though it will not be legal to sleep during automated driving (see national traffic laws like e.g. the German traffic law) and driver availability to retake vehicle control after waking up is not investigated yet, the risk of drivers falling asleep during highly automated driving has to be considered and dealt with.
A study by WIVW GmbH and Takata AG will be presented in which driver state monitoring is used in order to assess whether the driver is still in a cognitive state where s/he is capable of performing the driving task. A great deal of driver state monitoring systems uses either driving behavior indicators such as steering behavior data or eye tracking data such as glance pattern, glance duration, blink frequency, pupil diameter etc. [2]. However, these metrics cannot be used in driving with an automation level that doesn't require the driver to steer and that allows her/him to close the eyes e.g. to relax without falling asleep. Several physiological indicators such as heart rate parameters, skin conductance or muscle tension parameters seem promising to discriminate between wake and different sleep depths [6]. The aim of the study is to investigate the potential of various physiological measures to differentiate between a wake state and sleep of drivers during an automated drive.
Method: N=21 subjects (11 male, 10 female; age 34.7, sd= 13.0) completed a drive in the high-fidelity moving base driving simulator of the WIVW GmbH. In a within-subjects study design several physiological indicators were compared to differentiate between wake state and different sleep stages.
The participants were allowed a maximum of 4 hours of sleep the night before the drive. Then they arrived at the WIVW by taxi at 6 a.m. After being equipped with the physiological measuring devices they were instructed that they could use a two-hour simulator drive with the highly automated system to sleep. The drive was performed in highly automated mode on a two-lane highway at a constant speed of 120 km/h and took up to two hours. The system carried out the longitudinal and lateral guidance and overtook slower vehicles.
During the drives several physiological measures were taken such as Electroencephalography (EEG) and Electrooculography (EOG) as a ground truth to distinguish between sleep stages. The sleep stages were assigned according to the AASM standard [7]. It was differentiated between the stages:

- *Stage W*: Wakefulness (ranging from full alertness to early stages of drowsiness)

- *Stage N1*: light sleep
- *Stage N2*: stable sleep
- *Stage N3*: deep sleep
- *Stage R*: REM-sleep (Rapid Eye Movement sleep).

In our study no participant reached sleep stage R due to the limited time period of two hours. Sleep stage N3 was apparent for three subjects. Since drivers will most probably be wakened by a driver monitoring system before sleeping that deeply, only sleep stages W, N1 and N2 were considered relevant and included in the analyses.
Electrocardiography (ECG), Electromyography (EMG), Electrodermal Activity (EDA), Respiration and Eyeblink parameters were measured in order to investigate their discriminative power to distinguish between wake and different sleep stages.
Results: Several physiological indicators showed a great potential to differentiate between wake and sleep and even to differentiate the depth of sleep.
A global ANOVA including those subjects who reached at least sleep stage N2 revealed a significant effect of driver state (factor levels W, N1 and N2) on muscle activity (EMGmean: $F(2, 1552)=3.9674$, $p=.019$). The effects on electrodermal activity (SCL: $F(2, 1552)=10.413$, $p=.000$) and heart rate (hrmean: $F(2, 1632)=66.608$, $p=.000$) were significant as well. Only for the respiratory rate no significant state effect was found (RRmean: $F(2, 1264)=1.3356$, $p=.263$). It has to be noted that the hardware for measuring respiratory parameters turned out not to be very reliable which might be an explanation for the poor results of these measures.
Since physical reactions can vary among persons, all parameters were considered on the level of individual subjects as well. The heart rate seemed to be the most promising indicator to differentiate between sleep stages W, N1 and N2. For 17 out of 19 subjects with available data for all 3 sleep stages a significant state effect was found on the mean heart rate.
Conclusions: The advancing automation of the driving task and the successive relief of the driver of her/his driving and even monitoring tasks raises questions about driver states such as sleep. Conventional driver monitoring measures use driving parameters such as steering wheel movements or eye/blink measures. These measures are not available anymore in automated vehicles since there is no steering input from the driver and s/he might be allowed to close her/his eyes to relax but might not be allowed to sleep. Alternative physiological indicators of sleep were tested with regard to their discriminative potential. A relaxation of the neck muscle was apparent after falling asleep and continued during the transition to stable sleep. The skin conductance level reflecting the sweat gland activity decreased during the transition from wake to sleep and sleep phase N2. The strongest effect was found in the decrease in heart rate after falling asleep and after the transition to sleep phase N2. Standard methods for heart rate measurement such as electrocardiogram (ECG) and photoplethysmography (PPG) will not be applicable for driver state detection because of their intrusive nature. Currently developed technologies such as imaging photoplethysmography (iPPG) allow a non-intrusive video-based measurement of heart rate parameters (e.g. [8]).
Several physiological measures showed to be considerable indicators for detecting a driver falling asleep in highly automated driving. These measures should be investigated further especially regarding their technical feasibility.

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Investigating the Mechanisms Underlying Lane Keeping Improvement during Cognitive Load: Testing the Predictions of Existing Hypotheses

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Keywords: Cognitive load; Lane keeping improvement; Physiological arousal; Gaze concentration; Multilevel regression

EXTENDED ABSTRACT

Driver distraction is one of the main causes of motor-vehicle crashes. However, the impact on traffic safety of tasks that impose cognitive (non-visual) distraction remains debated. One particularly intriguing finding is that cognitive distraction seems to improve lane keeping performance, most often quantified as reduced standard deviation of lateral position (SDLP)[1]. Cognitive load has also been found to lead to increased micro-steering activity [2], higher gaze concentration towards the forward road center [3], and higher levels of physiological arousal [4].

Different hypotheses have been put forward to explain this set of observations during cognitively loading tasks. According to Engström et al. (2017) [5], the current understanding in this area is that cognitive load affects lane keeping performance via a mediating factor of either arousal, gaze concentration towards the road center, or both, with different predictions made by the three competing hypotheses, as shown in Figure 1. This study presents the first direct test of these predictions, investigating the causal relationship suggested by the three hypotheses.

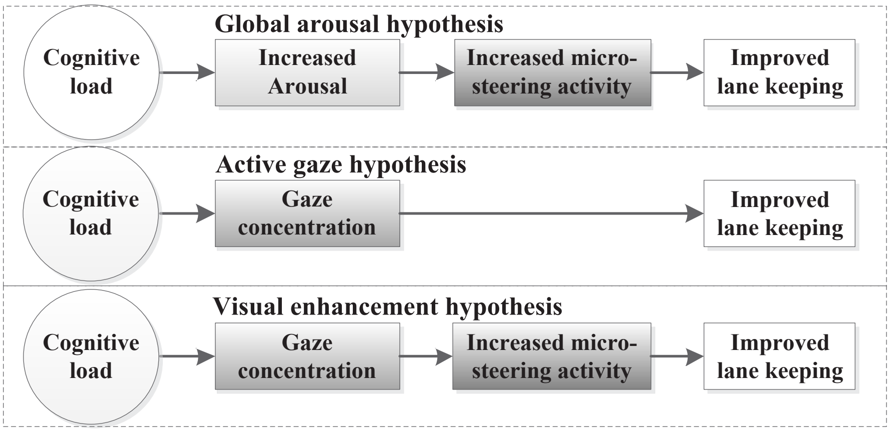

Figure 1. The main hypotheses used to explain the improved lane keeping performance observed during cognitive load. All boxes are measurable metrics, and the arrows represent predictions. For example, the global arousal hypothesis predicts that increased physiological arousal is associated with increased micro-steering activity, which in turn improves lane keeping performance.

This study of cognitive load is based on data collected for a previous study [6] that focused exclusively on lane keep performance data. The simulator experiment involved 35 participants driving on a straight city road section whilst completing a cognitive task at three different levels of difficulty, with data collected from a driving simulator, SensoMotoric Instruments (SMI) eye tracking glasses, and BIOPAC (for skin conductance/arousal).The hypothesized relationships between driving performance measures (lane keeping performance, micro-steering activity) and the possible mediators (physiological arousal and gaze concentration) were analyzed.

Lane keeping performance, micro-steering activity, arousal, and gaze concentration were measured and analyzed in the present study. Where, lane keeping performance was measured by SDLP, while micro-steering activity was measured using steering reversal rate (SRR) with a relatively low threshold of 0.5° [2], whilst driver physiological arousal was measured by skin conductance [4], using a sliding-window to measure the standard deviation of skin conductance (SDSCL), and then getting the mean value of SDSCL in the distracted task phase (MSDSCL). Gaze concentration towards the road center was measured by standard deviation of horizontal gaze position (SDGAZE)[3].

The results showed that, in line with previous studies, cognitive load led to increased physical arousal, higher gaze concentration towards the road center, and higher levels of micro-steering activity, accompanied by improved lane keeping performance.

To further test the predictions of the hypothesized mechanisms above, we therefore firstly constructed three multivariate models of micro-steering activity: (1) Model 1, suggested by the global arousal hypothesis[5], with only physiological arousal as the explanatory variable, (2) Model 2, suggested by the visual enhancement hypothesis[7, 8], with only gaze concentration as the explanatory variable, and (3) Model 3, based on the hypothesis that both mechanisms are simultaneously active.

Four main multilevel models of SDLP were then constructed: (1) Model 1, suggested by both the global arousal and visual enhancement hypotheses, with only micro-steering activity as explanatory variable. (2) Model 2, suggested by the active gaze hypothesis [9, 10], with only gaze concentration as the explanatory variable. (3) Model 3, suggested by the possibility of all three causal pathways being simultaneously active, with both micro-steering activity and gaze concentration as the explanatory variables. To test whether physiological arousal contributes to explaining the variability of SDLP due to some other unknown mechanisms, we also tested (4) Model 4, with micro-steering activity, physiological arousal, and gaze concentration as explanatory variables.

To determine the best model for lane keeping improvement, a model comparison method was used, with Akaike Information Criterion (AIC) as index, where model with lower AIC can be regarded significantly better, when AIC difference between two models is over 2 [11]. Here, results showed that for micro-steering activity, Model 3 was preferable to Models 1 and 2, suggesting two separate causation pathways between cognitive load and micro-steering activity, one involving arousal but not gaze concentration (suggested by cognitive control hypothesis), and one involving gaze concentration but not arousal (suggested by visual enhancement hypothesis). For lane keeping performance, Model 3 was preferable to Models 1 and 2, but Model 4 was not preferable to Model 3, which means Model 3, with the least necessary explanatory variables, is preferable for explaining the variability of SDLP, i.e., that both increased micro-steering activity (suggested by both the cognitive control hypothesis and visual enhancement hypothesis) and gaze concentration (suggested by active gaze hypothesis) contributed to the reduction in SDLP, but without a direct link between arousal and reduction in SDLP.

In conclusion, our results suggest that all of the mechanisms proposed by existing hypotheses could be simultaneously involved. In other words, it is suggested that cognitive load leads to: (i) an increase in arousal, causing increased micro-steering activity, which in turn improves lane keeping performance, and (ii) an increase in gaze concentration, causing lane keeping improvement through both (a) further increased micro-steering activity and (b) a tendency to steer toward the gaze target – this is summarized in Figure 2.

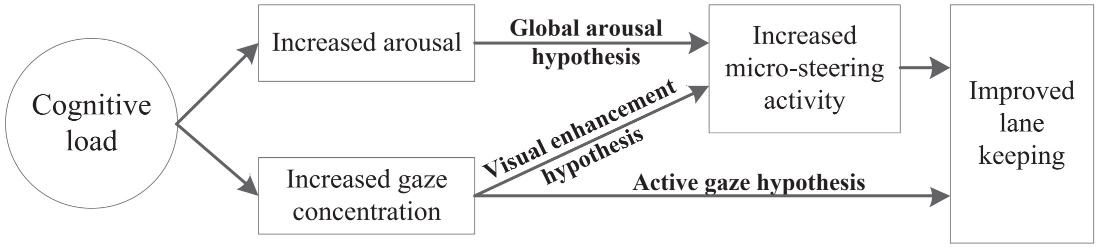

Figure 2. Structure of causation of lane keeping improvement during cognitive load

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Using real time driver monitoring to examine visual time-sharing in naturalistic driving

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Keywords: Distraction; driver behaviour; driver engagement; driver monitoring; naturalistic driving; visual time-sharing.

BACKGROUND

Long-duration glances away from the forward roadway have been widely reported to be associated with increases in crash risk [1,2]. The factors that contribute to drivers making these types of glances (as well as the overall occurrence of long-duration glances) however, are subject to a wide variety of confounds, including road environment, driver experience, and both the nature and type of secondary behaviours that drivers may be engaging in when these long-duration glances occur [3]. There is a need to consider (or otherwise account for) these additional factors to not only gain a better understanding of distraction but so that this understanding can then be applied in the broader context of monitoring engagement to the driving task.

One approach that may better account for these factors is to consider driver glance behaviour in the context of visual time-sharing (VTS) sequences. A VTS sequence is defined as the series of alternating glances between an area of interest and the forward roadway undertaken by a driver in the course of gathering information from the area of interest while driving [4,5]. VTS metrics have previously been reported to reflect a multitude of factors including time pressure for task-completion, resumption cost, and glance efficiency [4,5]. By clustering several discrete glances to a given region as one semantically-related sequence, the focus is shifted away from analyses of low-level glance metrics toward higher-level monitoring of driver engagement.

This paper describes an exploratory analysis of VTS in a naturalistic driving study involving shift-workers. Participants' glance strategies away from the forward roadway and toward the driver lap and centre console regions were examined across time. Using an automotive-grade driver monitoring system (DMS), driver state data was captured in a way that was highly ecologically-valid and objective. Real-time driver monitoring presents significant advantages in this context in terms of supporting the collecting of a wider range of driver features and with greater accuracy while also removing the need for extensive manual annotation.

METHOD

Dataset

The dataset used in the current analysis was previously reported by Kuo et al. [6]. In brief, the dataset comprised naturalistic DMS data from N=20 shift-workers (320 trips, 167.7 hours) during their commutes to and from work over alternating periods of day and night shifts. Participants were recruited on the basis of having sufficient commuting time to and from work and, as part of the broader project, working shifts likely to promote high levels of sleepiness.

Participants drove a study vehicle (Honda Jazz) instrumented with Seeing Machines' DMS. DMS is an automotive-grade driver monitoring research platform comprising a driver-facing camera running real-time computer vision algorithms for tracking features including head pose, eyelid opening, and gaze. Participants were not required to complete any form of system calibration (other than adjusting seat position for visibility/comfort), and were free to use eyewear for vision correction or sun protection.

Analysis

VTS sequences for lap and centre console glances were calculated using a method based on that recently proposed by Ahlstrom and Kircher [7]. A VTS sequence was defined as a series of glances to an area of interest (in this case, to either the lap or centre console regions) in which glances away from the area of interest do not exceed 4s duration. The 4s threshold was determined by analyses of probability density functions from on-road glance data, in which 70% of VTS sequences could be bounded by the 4s threshold. Consistent with the system used by Ahlstrom and Kircher [7], driver attention regions were determined by valid intersection points between a tracked gaze vector and predefined scene items in a 3D world model of the vehicle interior. For lap and centre console VTS sequences per trip, frequency and duration metrics were then derived.

Based on previously reported findings [6] of differences in driver gaze behaviour between drowsy and non-drowsy trips, this grouping variable was also retained for the current analysis. Trips were classified as drowsy or non-drowsy on the basis of max PERCLOS levels exceeding a threshold of 0.15. PERCLOS is an extensively used metric of drowsiness based on the proportion of time a participant's eyelids are more than 80% closed over a 20-minute window [8,9]. PERCLOS values were automatically generated by DMS.

General linear models with participant as random factor were specified to investigate differences in the frequency and duration of VTS sequences between drowsy and non-drowsy trips ($\alpha = 0.01$). To account for positive skew in frequency and duration data, a Poisson distribution was fitted and a log transform was applied, respectively.

RESULTS

Preliminary results are presented for driver lap VTS sequences. Compared to non-drowsy trips, driver lap VTS sequences on drowsy trips were performed significantly less frequently but with longer overall duration ($F(1, 308)=7.05$, $\beta=-0.32$, $p=0.007$; $F(1, 289)=8.88$, $\beta=0.33$, $p=0.003$, respectively. See Figure 1).

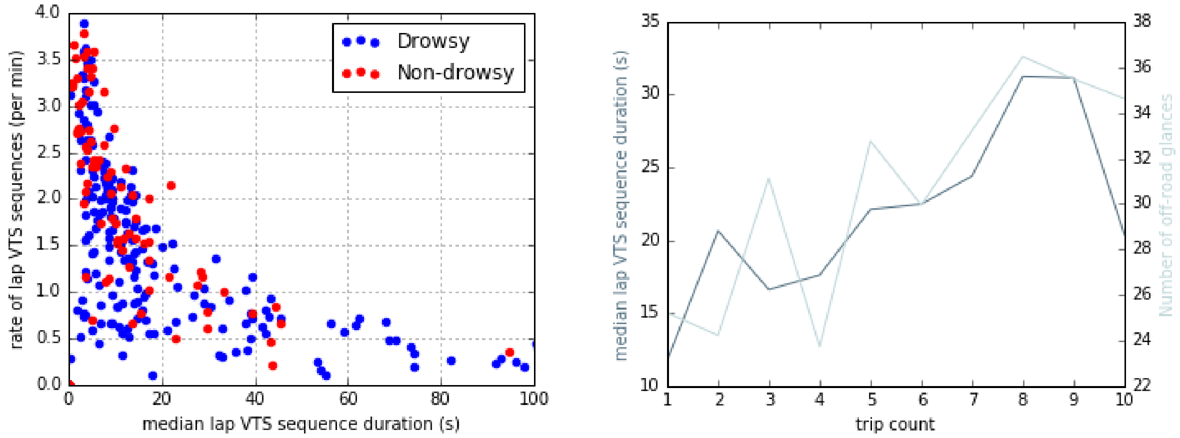

Figure 1. (Left) Frequency (count per minute) by median duration (s) for lap VTS sequences. (Right) Lap VTS sequence duration (s) by number of off-road glances across consecutive trips for all participants. Trip count 1-10 corresponds approximately to first 5 days of data per participant.

Timeseries over the first 10 trips for lap VTS duration by number of off-road glances for all participants is presented in Figure 1. A positive linear trend between VTS duration and off-road glance count can be observed, with both metrics increasing over time. Subsequent efforts will extend the current analyses to centre console VTS sequences, as well as quantitatively examine these metrics over time.

DISCUSSION

There is a critical need to monitor driver state not only for the purposes of understanding driver behaviour and detecting distraction but, as the role of the driver continues to shift with increasing automation, more broadly for assessing drivers' engagement (or disengagement) to the driving task. The current analysis extended our previous work in which real-time driver monitoring was applied in a naturalistic driving study to continuously monitor the behavioural and physiological signals associated with distracted driving in the real world. By further clustering driver off-road glances into visual time-sharing sequences, a more semantically-meaningful metric was generated and analysed in the current study.

The preliminary findings showed that real-time DMS could be applied to analyse semantically-related VTS glance sequences. We observed significant differences across drowsy and non-drowsy trips in the frequency and duration of these sequences, highlighting the interaction effects of different driver states and the utility of real-time DMS. These findings demonstrate the potential for metrics such as VTS (which capture both spatial and temporal components of driver glance behaviour) to not only capture drivers' engagement with the driving task, but to do so in a way that implicitly accounts for factors that may otherwise confound lower-level glance metrics. Further work will be undertaken to extend these analyses to other attention regions within the vehicle, as well as with consideration of behavioural adaptation over the course of participation in the study.

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Driver distraction, engagement and drowsiness: Initial outcomes from a multi-method program to enhance driver monitoring technology

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Keywords: Distraction; Driver monitoring; Drowsiness; Technology development

Background

A wide range of conditions can impact drivers' attentiveness or engagement in driving to a sufficient level to maintain safety. Drowsiness and distraction are two driver states that are known to degrade performance and safety and for which there is extensive literature documenting these impacts.

There are significant efforts worldwide devoted to establishing methods to measure these driver states and to manage the associated risks in real-time. These approaches broadly fall into three categories. The first approach uses exterior forward-facing sensing to detect safety-critical events. These typically use Advanced Driver Assistance Signals (ADAS) related to headway and lane departure warnings. While these are important safety events to manage, they are indirect or surrogate measures of the behaviours linked to rear-end crashes in the case of distraction and lane departure crashes in the case of drowsiness. The second approach uses driver inputs to identify potential risks. For example, most telematics systems will measure hard braking and steering events, while human factors research continues to examine the potential for vehicle measures to be good predictors of state and risk [1-2]. The challenge with vehicle-based metrics alone is that changes in these metrics can be related to any number of forms of impairment, therefore achieving good sensitivity for a specific driver state can be problematic. The third category uses driver states and, in particular, measures related to head pose, gaze and eyelid behaviour. The latter class are typically referred to as driver monitoring systems (DMS). A potential advantage of the latter class, DMS, relates to specificity. Recent research has shown that such feedback from such technology is an effective means of changing risky driver behaviours related to drowsiness [3-4].

This paper describes the first phase in a multi-year program aimed at enhancing driver monitoring technology. The paper presents an exploratory analysis of extensive drive state data captured in a driving simulator using a sensing suite that included an automotive-grade DMS.

Method

Participants: 80 car drivers are being recruited from the Monash University Accident Research Centre (MUARC) simulator driver database. At the time of writing this submission, 40 participants have completed at least one of the three test sessions. By March 2018 all 80 drivers would have been tested in time to report formal analysis in the final abstract (if accepted).

Materials: Data collection is being conducted using the MUARC Advanced Car Simulator which consists of a Holden Calais cab on a 4-DoF motion platform with a half-cylinder forward screen and flat rear screen. The programmed simulator scenario comprised a monotonous drive in a rural setting at between 80-100 km/h. Ambient traffic was present but infrequent, with light levels kept at a low, constant level.

Data collection technologies: Seeing Machines' DMS is a proprietary driver monitoring system, comprising a driver-facing infrared camera with a pair of pulsed infrared lights on either side. Additional sensors fitted into the driving simulator included a time of flight camera, thermal camera, webcam and EEG.

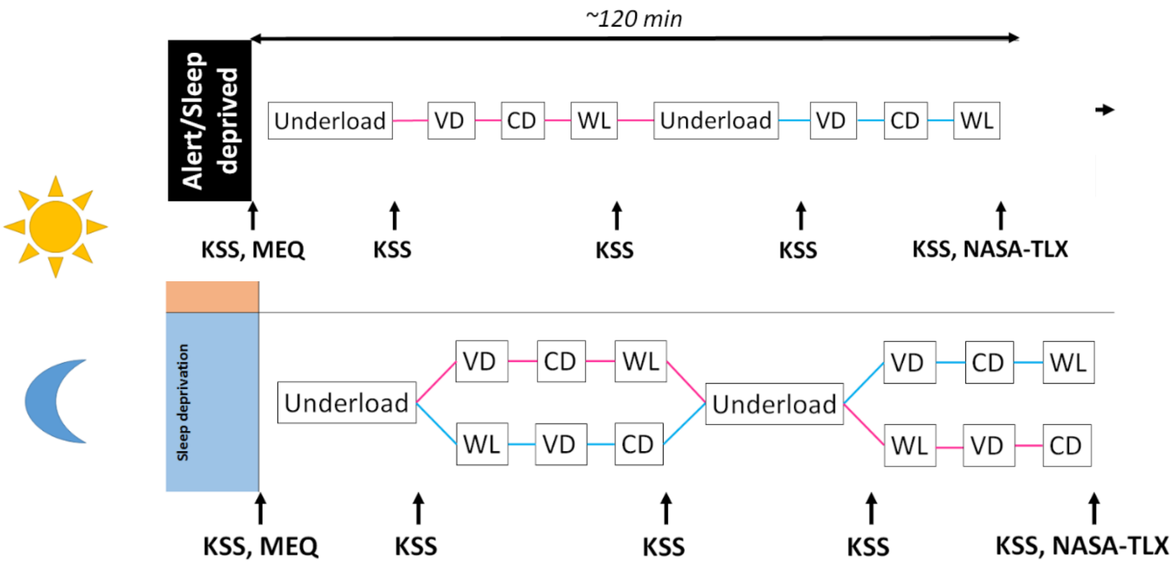

Figure 1. Schematic of the experimental design (VD = Visual distraction task; CD = Cognitive distraction task; WL = workload task [VD + CD]).

Design: An overview of the design is presented in Figure 1. In brief, each participant attended one alert and sleep deprivation condition (the latter occurred following one night without sleep). Each session involved driving in the simulator for approximately two hours while completing additional tasks through the drive that aimed to introduce visual and cognitive distractions alone and in combination. Subjective surveys used collected data for drowsiness (KSS) and workload (NASA-TLX).

Results (preliminary)

Drowsiness manipulation: Measurements of percentage eye closure (i.e. 'PERCLOS', an extensively validated ocular metric of drowsiness) highlight the efficacy of the prolonged wakefulness protocol. Preliminary data show mean PERCLOS levels increased from 0.030 (SD=0.025) during the alert condition to 0.091 (SD=0.076) after sleep deprivation. While there were 6 periods (>5 mins) within the drive where PERCLOS was above 0.10, for two of these the PERCLOS value exceeded 0.15 which is regarded as the benchmark to classify a driver as drowsy.

Impact on gaze behavior: Comparing driver gaze position across the sessions for forward roadway and centre console glances, a greater degree of gaze clustering can be seen in the bottom left corner of the drowsy data (see Fig 2, right), indicative of decreased scanning of the roadway and increased duration of distraction when engaging with the centre console task.

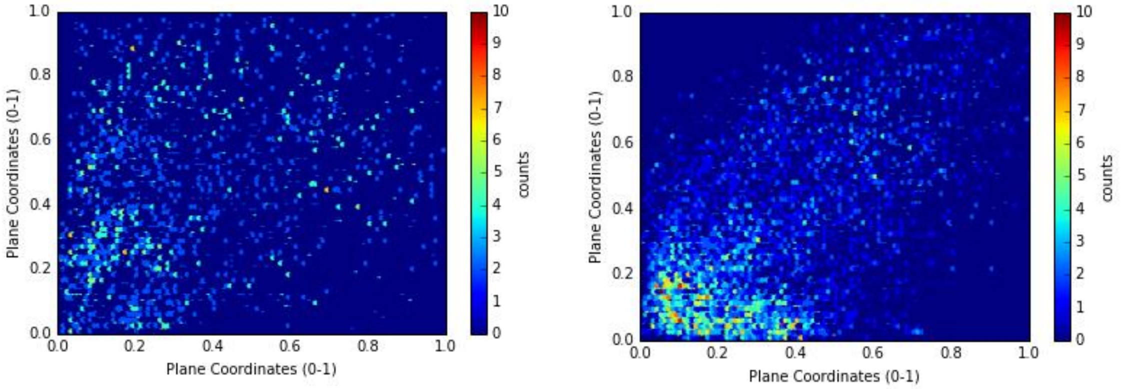

Figure 2. Alert (left) and drowsy (right) heatmap of gaze position to centre console. Glances to the centre console are indicated by gaze coordinates in the bottom left corner of the figures

Discussion

This paper outlines the early stages of a significant research effort to develop enhanced technology to measure and predict driver state in real-time, using Seeing Machines' driver monitoring technology as the core sensing. It represents a whole-of-industry approach to tackle driver drowsiness and distractions with involvement from an OEM, a truck operator, a driver monitoring technology provider and supported by strong university research partners. The car simulator study described in this paper has captured some data from 40 drivers at the time of submitting this paper. Data from all 80 car drivers, with appropriate statistical analyses, will be available by March 2018 and will be provided in the paper review process. Preliminary data confirm research suggesting that drowsy drivers engage in more distraction behaviours compared to alert drivers [5].

The title of the paper refers to a multi-method program. Extensive data are being collecting using a driving simulator and will be analysed in time for paper submission. Additional studies using truck simulators are also being conducted (not described here). Combined, these will represent one of the largest and most in-depth drowsiness datasets available when compared to recently published research (Lenne & Jacobs, 2016). The second phase being launched in February 2018 is Australia's first naturalistic truck study, and the first worldwide to our knowledge to use driver monitoring technology. Ten trucks will be instrumented with the sensing platform described later for up to 6 months. This is estimated to generate over 30,000 hours of real-world data that is critical for technology development. The third and final phase will use a mixed-method approach to develop new Human Machine Interface concepts for driver distraction, drowsiness and workload and subsequent iterative design and evaluation of these.

The end goal of this program is to develop a new driver monitoring concept that can be built into future product. In essence, we are looking here to develop the core intelligence of our future technology.

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Smartphone Logging – A New Way to Gain Insight About Smartphone Usage in Traffic

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Keywords: Mobile phone; Phone logging; Prevalence

EXTENDED ABSTRACT

The prevalence of mobile phone usage in traffic has been studied by road-side counting [1-6], naturalistic driving data [7-9], and subjective estimates via surveys [10-13]. Here we present an alternative solution based on a custom-made mobile phone application. The developed application logs start and end times of all phone interactions (mobile phone applications, incoming/outgoing phone calls and text messages, audio output, and screen activations). In addition, all movements (GPS positions) are logged via a secondary application called Moves, which automatically classifies all trips into transport, cycling, walking, running or stationary (where stationary means that the phone is not moving, but excluding inactive periods larger than 6h, if at least four of these hours occurred between 22:00 – 08:00, i.e. presumed sleep).

Using the mobile phone itself as a logging device to gain insight about smartphone usage in traffic is a rather recent invention. Kujala and Mäkelä [14] used a system in which an additional mobile phone was installed in the participant's car, acting as a hotspot. The participant's phone then connected to the hotspot, and a custom-made application, installed on the participant's phone, tracked screen touches and logged the foreground application. The collected data also contained the current position, road type and driving speed, logged via GPS with a frequency of 1 Hz. The company ProtextMe® (Ra'anana, Israel) developed another solution, which is based on an application installed on the participant's telephone [15]. This application also monitors touches and the foreground application, along with position and speed, when the GPS is turned on. Driving is detected by analysing the GPS signal, by the activation of navigation applications (like Waze® or Google Maps®), or by connection to a near-field sensor or beacon mounted in the car.

The aim of this study was to develop an alternative method of mobile phone logging which allows phone usage monitoring around the clock. The logged phone usage data is complemented with road type and speed limit via a post/processing stage. Together, this provides increased knowledge about the prevalence of application usage both when stationary (outside the vehicle) and in various modes of transportation. Data from a pilot study in Sweden with 143 participants (33946 hours of phone usage data) are presented as initial proof of the proposed method, and to identify areas for improvement.

Smartphone logging solution

The so-called Apparat-VTI application is running in the background and stores interactions with the phone (Figure 1). Only the names of the applications are stored, not the internal state or the content. This means that webpages that the participants visit, text that is entered, etc., are not stored. To be able to monitor user interactions with the phone, the Apparat-VTI application uses a series of watch services, where separate services are used to monitor application activity, call activity, connection activity, screen activity, text message activity and music activity. Each service continuously stores information about the activities in an internal data format that is called an "Event". All events are sent to, managed, and stored locally on the device by an "Observing Meta Service".

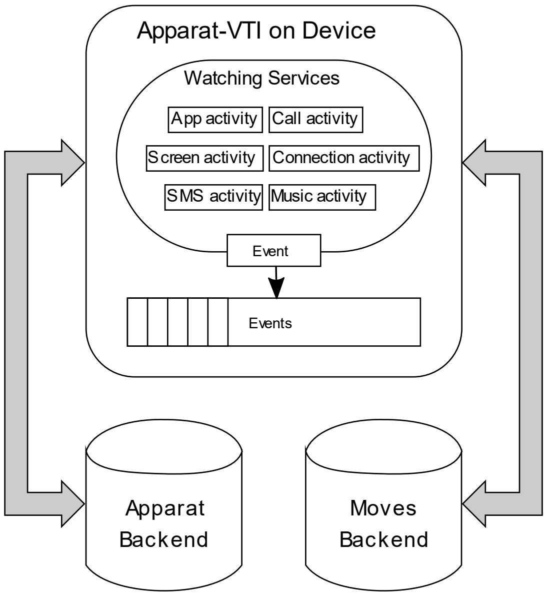

Figure 1. Schematic illustration of the data flow in the Apparat-VTI app. Activities that are detected by the watching services are stored in an internal data structure called an Event. All events are queued up and sent to the Apparat backend three times a day. Data from the Moves application are synchronized via the Moves Backend, which the Apparat-VTI application has access to.

In order to link phone usage behaviour to GPS positions, Apparat-VTI is linked to the Moves application. Data are synchronized between the two applications via the Moves backend (Figure 1). The Moves application stores the user's GPS coordinates together with timestamps. Based on these data, Moves clusters coordinates into trips and classifies the trips as transportation, cycling, running, walking or stationary. A drawback with Moves is that GPS data are stored irregularly and with low sample rate to reduce battery consumption, limiting the range of possible analyses.

Apparat-VTI includes the possibility to ask the phone owner for off-line annotations of trips, like indicating whether one had been driver or passenger, and which type of motor vehicle had been used. It is also possible to send push-messages with information or questionnaires if desired.

Proof of concept evaluation

A pilot study was conducted with 143 participants from December 2016 to February 2017. Given the diversity of when and how a phone can be used, this should be considered a small dataset. The smartphone usage data were complemented with annotations by the phone owners (driver or participant) and with road type and speed limit data from OpenStreetMap®.

Figure 2 shows the prevalence of phone usage per transportation mode. Drivers interact with their phone about 12 % of the time, which is not much less than while stationary (16 %). In general, it is much more common to use applications than to talk or send text messages. The percentage of trips during which users interacted with their phone at least once was 47.1 % while driving, 19.2 % while cycling and 22.0 % while walking.

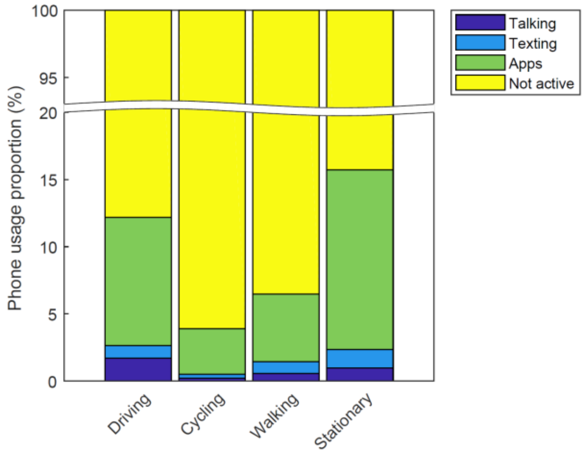

Figure 2. Proportion of time the phone was used per transportation mode. In “stationary”, the category Not active was removed if it had a duration >6h, of which >4h occurred between 22:00 – 08:00 (presumed sleep).

Talking: Car drivers were called at least once in 3.8 % of the trips, whereas they made outgoing calls in 8.4 % of the trips. On average, the users talked on their phone every 35th minute while driving. The median duration of incoming phone calls was 2.4 minutes, and 1.7 minutes for outgoing phone calls.

Texting (including most common messaging apps): The car drivers sent or received text messages in 8.4 % of the trips. There were twice as many incoming as outgoing text messages while driving. The median duration of a text messaging session was 36 seconds. The probability of sending a text message increased if it was preceded by an incoming message and vice versa.

Apps: The most common application category while driving consists of transportation applications, followed by talking. The categories social media, games, browsing and media sum up to about 40 % of the time during which drivers use their phone while driving.

Conclusions and future work

Phone logging is a complementary alternative to measure prevalence. Advantages include information about which applications are used and where the applications are used, split into transportation modality and road type, all at a relatively low cost. Much needed improvements to the developed phone logging solution include higher sample rate of location data, as well as information about whether the phone was used in hands-free or handheld mode.

A combination of NDS and phone-based logging would be an interesting way forward, where video from NDS can be used for contextual information, and data from phone logging can be used as event markers as well as for more detailed information about what the phone is used for.

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Prevalence Evaluation and Self-Regulation of Drivers' Secondary Task Engagement at Intersections Using Naturalistic Driving Data

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Keywords: Driver behaviour; Driver distraction; Intersections; Naturalistic driving studies; Self-regulation; Secondary task engagement.

Aims and scope:

The core idea that underpins this study is the in-depth analysis of driver's engagement in distracting activities (secondary tasks) whilst performing manoeuvres at intersections. The analysis was based on Naturalistic Driving (ND) data from the large-scale European ND project known as the 'e**U**ropean naturalistic **D**riving and **R**iding for **I**nfrastructure & **V**ehicle safety and **E**nvironment' (UDRIVE). The importance of the study lies in the combination of two key critical challenges to roadway safety, distractions and intersections. Although intersection- and distraction-related problems in traffic safety have been widely studied, little is known about the willingness of the drivers to engage in distracting activities as they pass through intersections during normal everyday driving. The focus of the current study was the determination of how drivers self-regulate and manage secondary activities as they drive through intersections but not the estimation of the risk presented by secondary task engagement.

Correspondingly, the study aimed to examine the types of secondary tasks (e.g. mobile phone using, smoking, eating, etc.) that drivers typically engage in as they pass through intersections and explore the prevalence of such conduct. Moreover, the study aimed to investigate whether engagement in secondary tasks at intersections is influenced by driver-related personal characteristics, such as age and gender, and some situational variables, specifically those related to the complexity of the driving environment, including intersection control, intersection priority, intersection locality (urban or rural), vehicle status (moving or stationary) and turning direction. The study also aimed to conduct a distraction-related comparison of the intersection approach phase (upstream functional area), the during-intersection phase (intersection physical area) and the beyond-intersection phase (downstream functional area) to explore how drivers manage secondary task engagement at intersections in accordance with changing roadways and demand situations.

Materials and methods:

ND studies are generally designed to provide insight into everyday driver's behaviours through the continuous recording of information on vehicle manoeuvres, driving behaviours and external conditions. Consequently, recording is carried out with unobtrusive instruments attached to a vehicle, and no form of experimental control (e.g. specific instructions or interventions) is allowed during observation [1].

The UDRIVE project dataset contains data across five European countries, namely, the UK, France, the Netherlands, Germany and Poland. The vehicles owned by the participating drivers were equipped with a data acquisition system (DAS) composed of (1) a combination of sensors that automatically provide continuous measurements (e.g. an accelerometer, a global positioning system and an internal controller area network intended to measure speed, brake pedalling, engine revolutions per minute, etc.); (2) a smart forward camera that detects and measures frontward distances from other road users; and (3) multiple other cameras for broad video coverage of the road environment and driver behaviour (8 cameras in total) [2]. The DAS remained in the vehicles for 18 months from mid-2015 to early 2017. The UDRIVE project yielded data on nearly 140,000 trips, with nearly 46,000 hours of ND data. Due to the excessive effort for data reduction and time limitation for the current study, the trips made by each driver within the dataset were randomly selected (10 trips per driver) an in-depth analysis was conducted on a total sample of 1630 intersection cases (each selected from unique trips in which no more than one intersection case was selected per trip). The intersection cases were distributed evenly between left turns, right turns and straight driving through intersection scenarios.

A scheme developed particularly for this study was used to code the selected sample to appropriately define different categories and subcategories related to distracting activities, drivers' personal characteristics (age and gender) and situational factors (intersection type, intersection control, intersection priority, intersection locality, vehicle status and turning direction). The reliability of the coded data was tested using inter-rater checks. The influence zones of each intersection (physical and functional areas) were identified through map matching (i.e. coordinate identification), after which they were annotated and used as bases for extracting the required variables. The intersection functional area was determined as a distance-based zone that extends both upstream and downstream beyond the boundaries of the physical intersection area. The major component considered in determining that distance zone was the Stopping Sight Distance (SSD). SSD, in turn, is produced by adding the distance travelled during perception–reaction time to the distance travelled whilst braking.

Finally, several descriptive and inferential analyses were carried out to examine the types and prevalence of secondary task engagement in relation to the selected situational and personal driver variables. The major metric selected to evaluate the prevalence of secondary task engagement was the proportion of intersection manoeuvring time accounted for by secondary tasks.

Results and conclusion:

As previously stated, this study investigates distractions from secondary task-related situations at intersections by adopting the ND technique. The data were extensively studied to establish patterns of interactions amongst task types and prevalence, situational factors and driver personal characteristics. This treatment is expected to enhance knowledge on distraction-related challenges and generate accurate descriptions of how drivers behave at intersections. Specifically, the research unravelled the secondary tasks that drivers choose to engage in, when they choose to engage in the tasks and whether they adjust engagement depending on different demand/complex situations.

The analysis of the coded data (the 1630 intersection cases) revealed that 50.9% of the intersection cases and 30.6% of the total intersection manoeuvring time were associated with at least one kind of secondary task engagement. In other words, nearly one-half of the intersection cases and one-third of the total intersection manoeuvring time included at least one sort of secondary task. The most frequently observed secondary task in terms of their proportion of total intersection time was conversation with a passenger (13.2%), followed by mobile phone using (6.6%) and navigation system (6.6%) related tasks. The proportion of time that the drivers allocated to secondary task engagement decreased with age; young drivers were more likely to engage in distracting activities than older ones (Figure 1). Another important observation was that the proportion of time allocated to secondary task engagement at the during-intersection phase was significantly lower than that at the upstream- and downstream-intersection phases. This makes sense since the drivers at the within-intersection phase are in the most demanding part of the intersection segment.

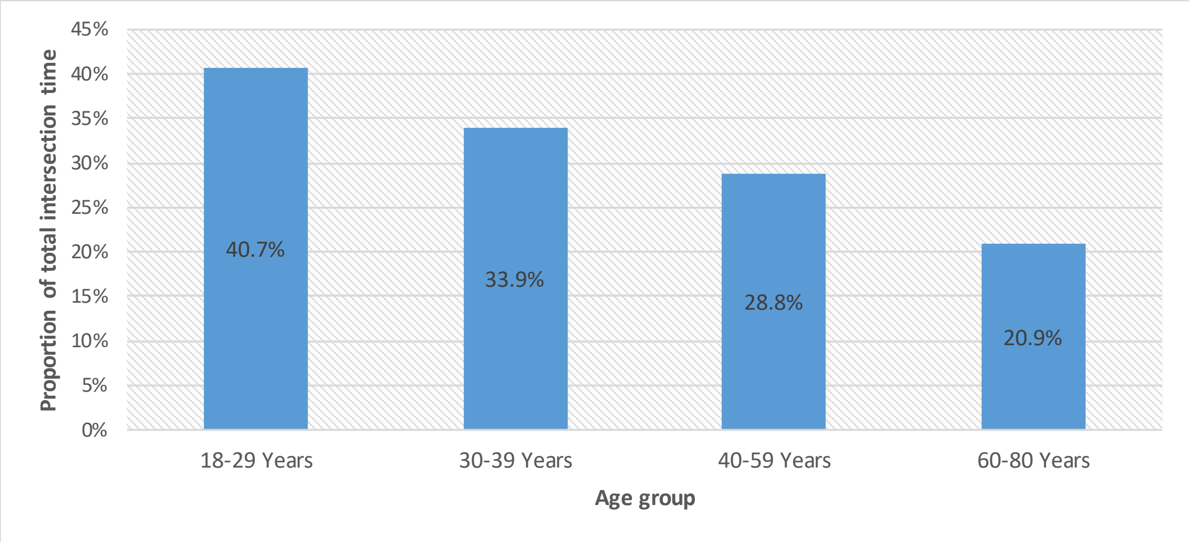

Figure 1. Proportion of total intersection time allocated to secondary tasks by age group

In addition, the drivers substantially increased the proportion of time devoted to secondary tasks when their vehicle was stopping beyond the levels observed when their vehicles were moving. Conversely, drivers decreased such proportion of time at intersections controlled by traffic signs (which required gap judgments) below the levels allocated at intersections that are fully controlled by traffic signals.

The analysis of the data indicated that drivers might engage selectively in secondary tasks in accordance with the dynamics that underlie driving and roadway situations. This expectation will support the notion that drivers self-regulate through a reduction of their engagement in secondary activities during more challenging driving conditions. The findings of this study can serve as guidelines for the development of safety measures intended for traffic systems. The recommendations encompass traffic regulations, driver awareness, road design, driver training and traffic enforcement. Apart from expanding the theoretical scope of driver distraction and road safety research, this study also offers practical implications for the development of safer traffic systems. This is done based on the resultant broadened understanding of who engages in secondary tasks at intersections, when these tasks are executed, what types and subtypes of tasks drivers implement and where such activities are implemented.

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Stress and sleepiness in city bus drivers – an explorative study on real roads within the ADAS&ME project

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Keywords: ADAS&ME, Bus drivers, Explorative study, Real road, Sleepiness, Stress.

Introduction

The goal of doubling travels with public transportation by 2020 requires more efficient operation, and already now working as a bus driver involves much more than just driving the bus. The responsibilities to control where to go, keep track of the timetable, make sure that the bus is on time, oversee and support ticketing, communicate with the operator and interact with the passengers can be overwhelming [1]. On top of that, the bus driver occupation is associated with negative physiological, physical and psychosocial factors related to driver's health [2]. Many of these factors are expected to become more severe in the future and lead to an even more stressful work environment. The high associated risk of obstructive sleep apnoea causes driver fatigue, a problem shown to be pronounced in the public transport sector among taxi drivers [3].

High levels of work related stress and disturbed sleep is a dangerous combination contributing towards diseases and poor workplace performance [4]. Driver fatigue has received increased attention during recent years and is now considered to be a major contributor to approximately 15 – 30% of all crashes [5-7]. The main cause of driver fatigue is sleepiness due to sleep loss, being awake for too long, and driving during the circadian low [8]. Also, work-related factors such as stress [9, 10] and shift work [11] contribute to driver fatigue. In addition, it is important to consider the type of task [12, 13], as both cognitive underload and overload contribute to demanding situations influencing the drivers. Measuring stress is traditionally done using individual physiological indicators like heart rate, heart rate variability, galvanic skin response or respiration rate [14]. To get a deeper understanding of bus driver stress, there is a need to consider multiple factors simultaneously, and not just multiple physiological indicators, but also external factors (environment, traffic complexity, route, scheduling, passengers etc.) as well as individual aspects (driver traits, health status, family situation etc.). Such research has been initiated to get a better picture of the causes of driver sleepiness [15] and stress [16], but mostly on a theoretical level, and not taking the operator's demands into account.

This study is part of the H2020 project ADAS&ME (Adaptive ADAS to support incapacitated drivers mitigate effectively risks through tailor made HMI under automation). ADAS&Me include seven use cases, one of them addressing bus drivers, with the aim to reduce stress and fatigue by automating the docking procedure at the bus stop. This particular scenario has been highlighted by bus drivers to be very stressful since they have to keep track of the passengers, watch out for vulnerable road users outside the bus, and manoeuvre the bus in a smooth and precise manner. The experiment described here is a pre-study with the goal to attain a better understanding of the stress and fatigue levels that we can expect in bus drivers' during an every-day working shift.

Method

Participants: In total 15 drivers (2 females/13 males, mean age 41±12 years, 11.6 ± 8.2 years of bus driving experience) were involved in the experiment. They had a BMI of 25.9 and 13 out of 15 drivers reported being satisfied with their working hours. They were recruited from Transdev, the local bus operator in the city of Linköping. The bus drivers received a compensation of 100 Euros. The study was approved by the regional Ethics committee in Linköping (Dnr 2017/278-31) and all drivers signed an informed consent.

Preparations: Sleep diaries and actigraphy (ActiGraph LLC, Pensacola, FL, US) was collected for three days before the experiment day to keep track of the drivers sleep/wake history. This was considered as important since stress and fatigue interacts. The Actigraph was sent to the drivers together with a background questionnaire and the sleep diaries one week before the experiment day.

Data collection: At arrival the drivers were equipped with disposable electrodes to record an electrooculogram (EOG) and an electrocardiogram (ECG). An observer accompanied the bus driver throughout the experiment, making notes of potentially stressful events that occurred along the route. The observer also asked the driver to rate his/her subjective sleepiness level on the Karolinska sleepiness scale (KSS) [17] and stress level on the Stockholm University stress scale (SUS) [18]. This was done every fifth minute. The bus was also equipped with an eye tracking system (Smart Eye Pro, SmartEye AB, Gothenburg, Sweden) and a data logger storing GPS and video of the forward view and of the driver (Video VBOX Pro, Racelogic, Buckingham, UK).

Design: The design of the experiment was exploratory, and no experimental manipulation of the stress or sleepiness levels of the driver was made. Instead, the drivers' normal fluctuations in stress and sleepiness levels were of interest. This means that except for the electrodes and the measurement equipment, there is no difference between the experiment and an ordinary day at work. The data collection was done during a part of the working day when driving a specific bus route with passengers. Data from two drivers were collected each day, during the morning shift and during the afternoon shift, respectively. After the shift, the measurement equipment and electrodes were removed, and the driver answered a final questionnaire about his/her experiences during the shift.

Analysis: Analyses were based on descriptive statics due to the exploratory nature of the study. Fatigue indicators were investigated as a function of time on task, and stress levels were investigated as a function of how delayed the bus was compared to the time table, and also near bus stops (mean value in the region ± 100 meters from the bus stop) versus in between bus stops. This was analysed with a mixed model analysis of variance (ANOVA) with the fixed factor bus stop versus driving, and the random factors participant and bus stop. Inattention, or rather glance behaviour, was analysed as glance frequencies and glance durations throughout the trip.

Result

On average the bus drivers reported low levels of stress and sleepiness while driving, see Table 1. There was a slight trend towards longer blink durations towards the end of the drive, indicting reduced alertness, and reduced heart rate variability (RMSSD) with larger delays compared to the time table, indicating increased stress. Eyes off road glances had a mean duration of 0.7 seconds and a 95th percentile duration of 2.3 seconds, which is comparable to what is typically found in car driving. Glance behaviour while approaching bus stops show tracking is lost for up to 70% of the time since the gaze direction is moved outside the coverage of the eye tracking cameras when the drivers gaze is shifted towards vulnerable road users outside the bus and towards the passengers who are lining up to get onboard. This has implications on driver distraction algorithms intended for bus drivers, were a "straight ahead road centre" based algorithm will not work well (which also holds true for city driving in general).

Table 1. KSS and SUS reporting. Each value is corresponding to the feeling the last 5 minutes.

Sleepiness rating			Stress rating		
KSS	Frequency	Percentage	SUS	Frequency	Percentage
1	60	38.0	1	59	39.9
2	39	24.7	2	54	34.0
3	41	25.9	3	14	8.8
4	13	8.2	4	12	7.5
5	5	3.2	5	8	5.0
6	0	0.0	6	8	5.0
7	0	0.0	7	3	1.9
8	0	0.0	8	1	0.6
9	0	0.0	9	0	0.0
Total	158	100	Total	159	100

Conclusions

In conclusion, the results show that even without manipulation there are epochs of sleepiness and stress in some individuals at a normal bus route during daytime. Countermeasures to make sure this is not the case is most truly helpful for the drivers.

The most interesting result is how important context is when analysing visual behaviour, especially in complex environments such as in the city. Available real-time driver distraction detection algorithms typically set up a fixed 'on-road'-region where the driver is supposed to look most of the time. When looking outside this region for too often or for too long, the driver is considered distracted. The 'on-road'-region must be dynamic, and in the bus use case, this region should adapt to include the bus stop and the vulnerable road users surrounding it rather than the road ahead.

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Bicyclists' adaptation strategies when receiving text messages in real traffic

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Keywords: Attention; Behavioural adaptation; Bicyclist; Mobile phone; Music; Text message

EXTENDED ABSTRACT

Introduction

Cyclists, similar to car drivers and pedestrians, often use their mobile phones in traffic. Much research has been dedicated to understanding the consequences of mobile phone interactions in car driving, showing deteriorated control of the vehicle (Caird et al. 2014; Caird et al. 2008; Collet et al. 2010; Horrey and Wickens 2006; Kircher et al. 2011; Nabatilan et al. 2012; Svenson and Patten 2005), but also driver adaptation strategies to counteract the consequences thereof (Funkhouser and Sayer 2012; Tivesten and Dozza 2015). Less research has been made on cyclists and their use of mobile phones. In Sweden for instance, the prevalence of mobile phone use while cycling was 19 % in 2012, with 17.1 % listening to music, 1.9 % calling and 0.6 % interacting with the phone (Adell et al. 2014). How cyclists adapt their behaviour while interacting with their mobile phones, has not been investigated to any large extent.

Results from controlled experiments have shown that overall, using a mobile phone while cycling is related to reduced speed, reduced lateral control, reduced peripheral vision performance, and to increased ratings of mental effort (de Waard et al. 2011; de Waard et al. 2014; de Waard et al. 2010). Listening to music through in-ear headphones while cycling has shown deteriorated auditory perception (de Waard et al. 2011; de Waard et al. 2014) but otherwise only limited effects on bicyclists' behaviour have been found (de Waard et al. 2011; de Waard et al. 2014; Kircher et al. 2015). A limitation concerning most of these studies is that the cyclists were not allowed to decide how to assimilate the mobile phone task with the cycling task.

Aim

The aims of this study are to explore how cyclists adapt when texting and listening to music in a complex urban environment, and if they compensate sufficiently to maintain a safe traffic behaviour with respect to themselves and other road users.

Method

Cyclists were recruited for the study via an on-line questionnaire. The inclusion criteria were that they should be at least 18 years old, experienced with cycling in the city centre of Linköping, willing and able to cycle for 6 km, provide own bike and smart phone, used to using the phone in traffic, and that they should have normal eyesight or eyesight that could be corrected with contact lenses or with extra dioptric lenses within ± 4 dioptres, which was a requirement to be able to use the eye tracking system. Normal bikes as well as e-bikes were allowed. The cyclists participated in a semi-controlled study (Kircher et al. 2017a), using their own bike and smartphone in real traffic. They were equipped with eye tracking glasses and rode the same route twice, once while listening to music and once without music.

The route chosen for cycling was situated in the city centre of Linköping, Sweden, and consisted of cycle tracks, mixed traffic as well as pedestrian streets without motorized traffic. It was divided into a total of six segments, three per lap, and on one of these segments on each lap, the participant was asked to think aloud about his or her attention allocation. Each participant also received three text messages along the route which they were instructed to deal with as they normally handle incoming text messages while cycling.

In the study, the minimum required attention (MiRA) theory (Kircher and Ahlstrom 2017) was used. The MiRA theory defines what a road user needs to be attentive to, as well as when, where and how often information needs to be sampled from these required targets. Only static MiRA requirements related to the infrastructure are used in this study. The requirements were divided into those that were necessary, for example checking the state of traffic lights, and those that were useful for own safety, such as checking side roads when entering an intersection where other traffic should yield.

Results

Forty-one participants (37.4 ± 11.1 years old, 46 % women) participated in the study. The results show that listening to music while cycling did not affect workload, speed, SMS interaction or attention. Seven different adaptation behaviours were identified when the cyclists dealt with received text messages. One fourth of the text messages were replied to while cycling and half of the participants read a text message while cycling at least once. In general, the cyclists manage to integrate SMS interactions with their cycling behaviour. Three of the intersections were coded according to the MiRA theory and for these requirements, there was no significant difference between the music condition (82 % of the necessary MiRA requirements attended to) and the condition without music (86 %). However, there were two occasions when basic attention criteria were violated while texting. They both occurred in connection to a traffic light. In one case, the cyclist was not observed to notice the red light for cyclists and had to negotiate with a car turning right. In another case the cyclist was not observed to pay attention to an intersecting cycle path to the left nor to the right, when approaching a traffic light. The cyclist slowed down and picked up the phone on approach to the cycle path, and started texting while standing still at the red traffic light. For the attention requirements that were categorized as useful for own safety, but not totally necessary, about half were attended to and half were not. This was true both in the baseline and in the texting condition.

Conclusions

In conclusion, cyclist behaviour was not affected by music, neither in terms of subjective workload, attention, speed nor SMS interaction. No adaptation in terms of increased visual scanning could be found, but there were also no signs of decreased information intake when listening to music. For text messaging, seven different adaptation behaviours were found, from ignoring the text message, stopping the bike while reading, postponing the interaction with the phone, to instantly replying to the message. One third of the text messages were dealt with while cycling. The overall impression was that the cyclists managed to integrate their mobile phone use into their cycling behaviour. However, there were two occasions when basic attention criteria were violated while texting, which motivate further studies with larger study populations.

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Intra-individual difference in sleepiness and the effect on driving performance – a three-times repeated driving simulator study

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Keywords: Intra-individual differences, Sleepiness, Simulator experiment, Young males

Background

There are major differences between individuals in *how* they are affected by sleepiness and by *how much* they are affected [1-3]. The susceptibility to sleep loss has been found to be systematic and trait-like. Sustained attention performance, cognitive processing capability, and self-evaluation of fatigue and mood are three factors that have been found to be predictive of how sensitive an individual is to sleep loss [4]. These differences remain also when taking known risk groups into account [5, 6]. On top of the inter-individual variability, there may also be intra-individual differences. However, intra-individual differences are not well researched, and a recent review article even stated that literature on the topic is unsystematic and post hoc [7]. Up to now, most studies have taken for granted that a driver performing a test represent himself/herself as if there are no differences within this individual from time to time. Whether this is a correct assumption needs further investigation.

Aim

The aim of this study was to study if drivers' sleepiness levels and behaviour in supposedly alert versus sleep deprived conditions varies from time to time when the same experimental procedure is repeated three times. The hypothesis is that there are significant differences within an individual from time to time, both during day (expected alert) and night (expected sleepy) conditions.

Method

In total 26 young male drivers participated in a high-fidelity moving-base driving simulator experiment. The study had a within-subject design with 3 identical repetitions. Each driver made 6 separate visits, three during day-time and three during night-time. Day-time and night-time driving was used to manipulate sleepiness. The day-time sessions were scheduled between 12.30h and 21.15h and the night-time sessions between 22.00h and 06.15h. All participants were prepared in the same way. They were instructed to sleep for at least 7 h during the three days before the trials, to go to bed no later than 24.00 h, and to get up no later than 09.00 h. A homogenous group was sought to minimise inter-individual effects and better isolate intra-individual effects. To minimize confounding by menstrual cycles or contraceptives only males were selected. In addition, individuals with relatively normal sleep patterns were included, that is, individuals without any sleep disorder, with day work, and with normal BMI < 30 (to reduce the risk of sleepiness due to obstructive sleep disorders). Distinctive morning types were excluded to avoid high levels of sleepiness in the daytime condition which stretched into the evening hours. Inclusion also required normal sensitivity to stressful situations, normal range extraversion/introversion and lack of proneness to kinetosis to avoid simulator sickness. These latter criteria were included to reduce first encounter effects, to reduce the risk of drop outs, and to increase the likelihood that the participants have the same ambition throughout the experiment series. Before arrival, the participants were

requested to avoid alcohol for 72 h and to avoid nicotine and caffeine for 3h. During their stay at the laboratory, the participants were offered snacks and non-caffeinated drinks.
On each visit a participant drove 3 times in succession, two times on a rural road with a speed limit of 80 km/h and once on suburban road with a speed limit of 60 km/h. Each road stretch lasted for 30 minutes, and there were 2h of rest between each drive. The exact same procedure was used at each visit.
Differences in the development of self-reported sleepiness (KSS) and number of line crossings were investigated. An ANOVA was used with a model including factors for time of day (day/night), time on task (1-6 corresponding to minutes 5-10-15-20-25-30), visit (1-2-3) and succession (1-2-3). Participant was included as a random factor.

Result

There was a significant difference between the three repetitions of the experiment; visit 1(mean KSS 6.0), visit 2 (mean KSS 6.2) and visit 3 (mean KSS 6.3), $F_{(df\ 2,2643)}=8.635$; $p<0.01$. As expected, there was also a difference in KSS ratings between day-time driving (mean KSS 5.0) and night-time driving (mean KSS 7.3), $F_{(df\ 1,2641)}=2324$;$p<0.01$. Significant effects were also found for time on task and trial order. There was a significant interaction for time of the day and visit ($F_{(df\ 2,2642)}=16185$; $p<0.01$).
Considering driving performance, here defined as the number of line crossings (#), there was a difference between the repetition of the experiment; visit 1 (# 0.39), visit 2 (# 0.43) and visit 3 (# 0.51), $F_{(df\ 2,2632)}=59.9$; $p<0.01$. There was also a significant difference between the total number of line crossings during day-time (mean # 0.38) and night-time (mean # 0.56), $F_{(df\ 1,2641)}=191.3$; $p<0.01$. As usual there was a significant effect of time of task, but in this case not for trial order. There were no significant interactions between visits and the other factors.

Conclusions

There is reason to believe that there are differences within an individual in sleepiness levels (KSS) and behaviour in terms of line crossings from time to time even under identical experimental settings. In particular, there was a large first encounter effect. This finding is important when trying to understand the generalizability and validity of results from studies using only one expectedly alert and one sleep deprived condition. Future studies on intra-individual differences should use actigraphy during the days before the trials to see if prior sleep quality can account for the observed differences.

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Speedometer monitoring before and after speed warnings and speed zone transitions

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Keywords: Distraction; Eye Movements; ISA; IVIS; Warning

EXTENDED ABSTRACT

Introduction

Speeding increases crash risk and severity of consequences of a crash [1, 2]. Intelligent Speed Adaptation (ISA) systems have been developed to reduce speeding [3, 4]. Such systems either directly slow down the vehicle or they give a warning when the set speed limit is exceeded. ISAs have been demonstrated to decrease speeding even when implemented as voluntary speed warning systems [5, 6].

Speed warning systems are nowadays widely available both as a smart phone application or as a built-in feature in a car. Most of such systems use visual and/or auditory modality to deliver their warning, even though haptic feedback has also been used [7]. A system with a visual display may attract drivers' attention and hence pose as a distractor. For example, the constant updating of visual information regarding eco-driving has been shown to attract a significant portion of drivers' visual attention [8]. Speed warning systems, in contrast, are likely to draw attention only when a warning is issued or input is needed.

This eye tracking study investigated speedometer monitoring before and after speed warnings and speed zone transitions. Speed warnings were expected to trigger glances towards the speedometer as drivers adapted their speed. In contrast, speeding events were expected to be preceded by a lack of speedometer glances. In addition, speed limit transitions were expected to trigger glances to the speedometer, both before and after the transition point, because drivers can see the speed limit sign before the transition point and start adapting their speed accordingly.

Methods

Three groups of drivers participated in the study[1]. Two groups drove with a speed advisory system, implemented as an app in a smartphone, which gave audio-visual (AV) speed warnings (flashing and beeping). For the passive group (n = 6) the warnings were automatically based on the current speed limit. The active group (n = 6) used a similar system, but they were required to set the speed limit manually each time the posted speed limit changed. The control group (n = 7) was aware that the study investigated speed warning systems, but the speed warning system

[1] This eye tracking study was part of a larger study, which is presented in an extended abstract "The Effects of an ISA on Speed Compliance and Distraction" by Charlton et al.

was not activated. All participants held a valid driver's license and had been driving in New Zealand regularly.

Participants drove a simulated rural road which had 60 km/h, 80 km/h and 100 km/h speed zones, as well as a work zone with 30 km/h. The speed warming system was implemented as an application on a smartphone attached to the dashboard to the left of the driver.

Gaze was tracked with Tobii Pro Glasses 2, a binocular head-mounted eye tracker which could be worn like sun glasses. The eye tracker was calibrated using the manufacturer's one point calibration method, where the participant was asked to look at a marker placed on the windscreen wipers (the marker was removed before the drive). Calibration accuracy was tested qualitatively before and after a drive by asking the driver to look at designated points in the car (smartphone, speedometer, side and rear mirrors, four markers places on the windscreen). Two participants, one from active and one from control groups, were excluded from the analysis due to inadequate eye tracking quality.

Fixations were detected with Tobii Pro Lab 1.58 using IV-T algorithm with parameters which classified a single glance to the speed app or the speedometer as one fixation. The speed app and speedometer areas of interests were defined for each participant. A fixation was categorized as a speedometer or speed app fixation if most of the gaze data points were within the area of interest.

Speed app and speedometer glance rates were calculated for each drive. In addition, glances were also calculated 30 s before and after each speed warning and speed transition, and the respective glance rates were calculated.

Results

Drivers constantly monitored the speedometer with short glances, but seldom looked at the speed app. Speedometer glance rate was higher (p = .037) in the 60 km/h zone (0.41 glances/s) than in 80 or 100 km/h zones (0.31 and 0.28 glances/s), but there was no difference between conditions. The control group often exceeded the speed limit, especially when driving in 60 km/h zones. Having a speed advisory system reduced proportion of time spent speeding at 60 km/h zone (p = .040, control M=70 %, active M=19 %; passive M=12%).

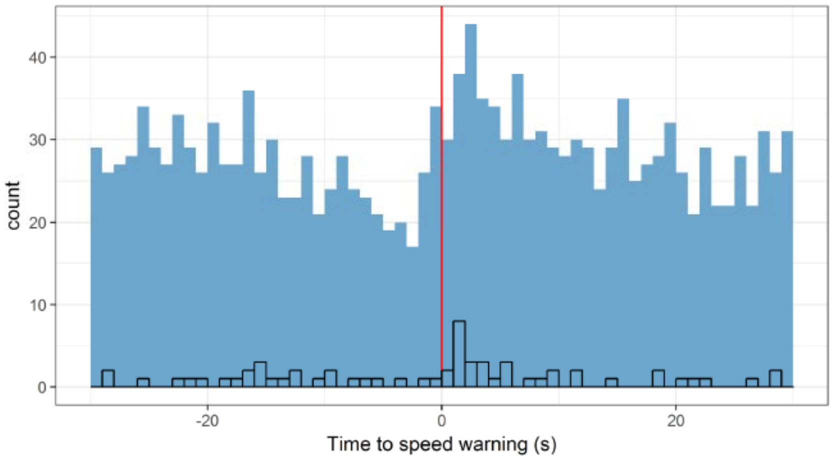

Figure 1. The total number of speedometer (the upper bars) and speed app (lower bars) glances before and after the speed warnings. Data pooled over all participants and speed warnings.

Speed warnings increased speedometer monitoring for the 10 seconds following a warning [Fig. 1]. There was no statistically significant decrease in speedometer glance rate before a speed warning. In contrast, glances to the speedometer appeared to increase some seconds before a warning was triggered, suggesting that drivers may have noticed that they were speeding before the warning.

In speed transition zones, speedometer monitoring decreased before a transition and increased after a transition [Fig. 2]. Similar to the speed warnings, glances to the speedometer increased some seconds before a transition point.

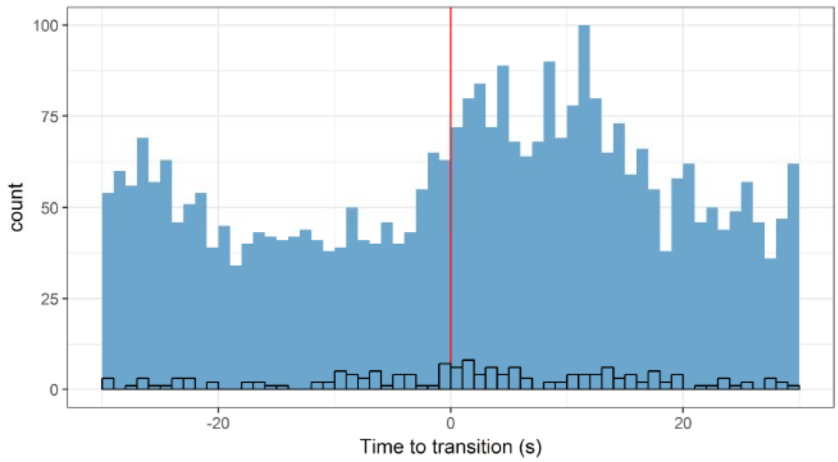

Figure 2. The total number of speedometer (the upper bars) and speed app (lower bars) glances relative to the speed zone transitions. Data pooled over all participants and transitions.

Conclusion

The analysis of speedometer glances in relation to the speed warnings and speed zone transitions suggests that warnings and transitions trigger drivers to monitor the speedometer. Statistical analysis of the speedometer glance rate before speed warnings did not confirm that speed warnings were related to momentary inattention regarding speed, in fact, glances towards the speedometer actually increased some seconds prior to a warning. This suggests that drivers sometimes realize they are going over the speed limit before the actual warning is triggered.

Surprisingly, speedometer monitoring decreased prior to speed limit transitions. This suggests that drivers first focus on identifying the new speed limit, and only then started to adjust their speed accordingly.

Higher speedometer glance rate can be interpreted as reflecting the increased cognitive control over the speed. Drivers' speedometer glance rate was higher also in the 60 km/h zone compared to 80 km/h and 100 km/h zones. In the experiment, the 60 km/h segment had a similar road geometry to 100 km/h and 80 km/h segments, so the drivers had to exert control to drive slower than they would in such roads.

Overall, the results suggest that speed warnings increase momentarily drivers' engagement to the speed control, like speed limit changes do: When a warning occurs, they do not just release the gas pedal and wait the warning go off.

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Extended Abstract for the 6th International Conference on Driver Distraction and Inattention (DDI2018)

The role of cognitive distraction and characteristics of situation elements on anticipation while driving

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Keywords: anticipation, cognitive distraction, cognitive process, n-back, situation comprehension, traffic psychology

Introduction

Anticipatory driving is the premise for safety and comfort in traffic. It is known as a high level-cognitive competence and based on identifying stereotypical traffic situations by perceiving characteristic cues [1]. This leads to an activation of pre-knowledge from long-term memory [2] which provokes selective and focused sensory processing, and provides a reduced number of options in the behavioral repertoire [3]. Consequently, anticipation enhances driving performance by increasing time and space for action [4], [5] and enabling effective positioning in traffic [1]. But people are not always able to anticipate adequately which might be a consequence of internal (e.g. cognitive distraction) and external factors (e.g. characteristics of situational elements). This study aims to focus on the impact of cognitive distraction on processing anticipatory cues in driving.

Anticipation is strongly related to the concept of situation awareness proposed by Endsley [6]. The perception and comprehension of situational elements provide the prerequisite for the generation of assumptions of their future behavior which refer to anticipation of dynamic situations. A series of studies investigated the probable largest influencing factors on situation awareness in traffic: driver distraction. Visual manual distraction did not have an impact on the structure of driver's situation awareness but on environmental information they sampled [7]. But especially cognitive distraction resulted in a decreased ability to anticipate the upcoming events, even though relevant situational elements had been perceived before [8], [9]. Baumann and colleagues [8] induced cognitive distraction by secondary tasks that loaded on different functions ascribed to the central executive of Baddeley's working memory model [10] and found that tasks interfering with the updating of working memory contents severely impaired the processing of cues indicating upcoming events. Consequently, they assummed that central executive functions controlling the working memory content are highly involved in anticipatory processes. However, the influence of situational elements on predicting upcoming events has hardly been investigated so far. We propose an anticipatory cue taxonomy that states situational requirements for anticipation and categorizes cues which support anticipatory performance. For this purpose, we differentiate between behavior and attention related cues. In line with the framework of action selection by Norman and Shallice [11] and the cognitive model of situation comprehension by Baumann and Krems [2] behavior related cues are environmental elements that directly trigger the upcoming action (schema) of the perceived traffic participant. For instance, the perception of an indicator is strongly linked to lane change behavior in a certain direction on a straight multilane street. Whereas attention related cues just attract attention to a specific event, but do not directly provide indication of the other's behavior (e.g. like a construction site traffic sign). Consequently, the presence of behavior compared to attention related cues should improve anticipation in dynamic traffic.

The aim is to investigate the effect of low and high working memory demand on anticipating another vehicle's lane change behavior based on different types of cues in dynamic urban traffic scenarios. Furthermore, we introduce a new methodological approach of gaining insights in the dynamic process of anticipation in traffic.

Method

We conducted a video-based laboratory experiment with 42 highly educated participants (81% female) who held a valid driving license. Participants watched dynamic urban traffic scenarios from a driver's perspective and should indicate the initial supposition of another's car entering the own lane (low certainty of anticipation) and the reliable prediction of that event (high certainty of anticipation). The experiment made use of a within - subjects design by varying cognitive distraction (high vs. low load) and cue characteristics (no additional cues, behavior related cues, attention related cues, combined cues). While watching the 48 urban traffic scenarios participants had to perform an acoustic 0-back (low demand) and 2-back (high demand) working memory task. Each secondary task was presented in a blocked design combined with 24 randomized videos. After completing a block, the subjective workload rating NASA – Task load index [12] was queried. Half of the trials contained distractor videos (in 50% combined with a behavior or attention related cue) to test the impact of different cues and reduce expectancy effects. In addition, the rating of certainty (scale from 0 to 100) and the reason of their anticipation reaction were gathered in every trial.

Results

Anticipation reaction. Participants had to state low and high certainty of anticipation. The percentage proportion of reactions and standardized reaction times were analyzed for both measurements. Behavior related cues triggered a higher rate of high certainty anticipatory reactions compared to no additional and attentional cues [post hoc analyses using Bonferroni corrections $p<.05$, $F(2.02,82.77) = 13.35$, $p < .001$]. The combination of behavior and attention related cues did not outperform single behavior related cues. Furthermore, subjective certainty ratings showed that participants were more certain about their choice when a behavior related/ combined cue was visible compared to no or attention related cue [post hoc analyses using Bonferroni corrections $p<.05$, $F(2.39,93.31) = 6.90$, $p < .001$].

As assumed, high compared to low cognitive demand resulted in decreased high certainty anticipatory reactions [$F(2,41) = 5.85$, $p < .05$]. There is also a tendency for this effect for low certainty anticipatory reactions [$F(2,41) = 3.43$, $p < .1$]. However, people did not react slower due to higher workload in the high certainty anticipation measurement. But there was a difference of cognitive demand on low certainty anticipation showing faster reactions with low cognitive load [$F(1,38)=13.49$, $p<.001$].

Working memory task. Secondary task performance (percentage of correct responses) was observed to be about one third better in the low ($M = 93\%$) compared to high ($M = 61\%$) cognitive demand condition [$F(1,41) = 241{,}80$, $p<.001$]. Subjective workload ratings confirmed this result by indicating higher ratings for the high demanding condition (M_{low} =8.37, M_{high} = 10.77, $t(41)$=10.42, p<.05).

With regard to cue conditions differences could predominantly be observed for high not for low cognitive load. There was a tendential increase of performance of combined compared to no and attentional cues [$F(3,123) = 2.34$, p<.1].

Discussion

Within this study we investigated the effect of different cue characteristics and cognitive workload on anticipation in urban dynamic traffic situations. Results showed decrement of anticipatory performance with increased working memory load which verifies the results of previous researchers (e.g. [8]). Furthermore, the relevance of differentiating between different types of cues that affect anticipation was shown. Behavior related cues are highly connected with specific behavior leading to increased anticipatory performance.

The assumption of an anticipatory interval ranging from low to high certainty anticipation seems promising for investigating the underlying cognitive process as we observed differences between these anticipatory reactions. Further insights and an enhancement of this methodological approach could be facilitated by using eye tracking and physiological measures in future studies.

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Do individual differences explain crash involvement in highly-reliable Supervised Autonomous Driving?

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Keywords: Automation, Individual Differences, Trust, Expectation, Irony-of-Automation,

EXTENDED ABSTRACT

Aim and scope

Supervised autonomous driving (Supervised AD) systems involve sustained automation of part of the driving task (e.g. headway control with or without some degree of steering assistance, i.e. SAE Levels 1 & 2 are both supervised). The human is still required to participate in the dynamic driving task by monitoring, and providing fallback by intervening with steering, braking, and accelerating at sensing or actuation limits [1].

As automation performance becomes more reliable and the operational design domain expands (e.g. more situations, speeds, and road types), human factors issues become more significant [2]. For example, operators' tend to reduce their monitoring because of the system's ability to function properly for an extended period of time [3], and *irony of automation* – the better the automation, the less attention drivers will pay to traffic and the system, and the less capable they will be to resume control [4] – becomes a concern. Further, operators can have gaps and misconceptions in their *mental models* of automated systems [5][6], and are often surprised and uncertain of what the automation is doing and will do next [6]. This results in a *first failure effect* – a very poor response to the automation when it initially fails after a period of highly reliable or perfect performance [7].

In three test track studies (the same studies as reported here), Victor et al (in prep) studied driver response to conflicts after highly reliable but supervised AD driving. The test vehicle followed a lead vehicle, keeping precise headway and lane position. After 30 min, a conflict occurred wherein the lead-vehicle cut out of lane to reveal a conflict object in the form of either a stationary balloon car or a garbage bag. Some drivers also previously had experienced an unexpected lane drift event. On average, 28% (21/76 drivers) crashed with the conflict object. These crashes occurred regardless of whether drivers were prompted to maintain eyes on road and hands on wheel, and despite explicit supervision instructions. This illustrates the important role of expectations and mental models, showing that a key component of driver-in-the-loop is cognitive (understanding in the brain the need for action), rather than visual (looking at the threat), or having hands-on-wheel.

The purpose of the present research is to study whether individual differences can explain crash involvement in these experiments.

Material and Methods

The three experiments shared the same general methodology. With highly-reliable, near-perfect driving performance, the test vehicle precisely followed the road and kept a constant headway behind a robot controlled lead vehicle (LV) on the AstaZero test track. For experimental conditions, see Table 1. After 30 minutes, the TV encountered a conflict object placed in the driving lane: either the ADAC Advanced Emergency Braking System Stationary Target (balloon car event) or a stuffed garbage bag (obstacle event). The conflict object was positioned so that participants were able to see it when going over the curve just prior to the event, before it became obscured by the LV when the road straightened out. About 20 meters from the conflict object, the LV did an evasive steering maneuver around the object, revealing it in full to the participants. In experiment 2 an additional drift out of lane (drift event) took place after 15 min. In all experiments, with varying degrees of instruction, drivers were required to supervise (pay attention to driving). In experiment 1 the test vehicle braked and avoided the conflict, in experiment 2 and 3 drivers needed to intervene to avoid the conflict (the vehicle did not brake or steer to avoid). Post-drive, the participants filled in a questionnaire which also served as the basis for a semi-structured interview.

Table 1. An overview of key methodological differences between experiments and conditions.

Experiment	N	HMI	Conflict scenario(s)	Test vehicle response to conflict	Reminder type	Details of instructions
1a	15	Production (Driver support Active/inactive)	Balloon Car fully in lane	Autonomous brake intervention	None	Low
1b	15	Production (Driver support Active/inactive)	Balloon Car partially in lane	Autonomous brake intervention	None	Low
2	16	Static AD HMI + attention reminders in DIM	Drift out of lane & Bag in lane	None	Eyes	Medium
3a	15	Static AD HMI + attention reminders in DIM & sound	Balloon Car partially in lane	None	Eyes	High
3b	15	Static AD HMI + attention reminders in DIM & sound	Bag in lane	None	Eyes	High
3c	15	Static AD HMI + attention reminders in DIM & sound	Bag in lane	None	Eyes & Hands	High
3d	15	Static AD HMI + attention reminders in DIM & sound	Balloon Car partially in lane	None	Eyes & Hands	High

Results and conclusions

Driver background variables and crash involvement. The participants tended to be more likely to crash in the conflict situation with increasing age ($p>0.05$) and years with driving license ($p<0.05$). There were however no clear differences in crash involvement due to gender or yearly mileage.

Subjective rating and crash involvement. The participants that rated high trust in the car resolving the conflict were much more likely to crash during the conflict in Experiment 2-3 ($p<0.001$). In fact, all participants who crashed reported at levels 5-7 on the trust scale (high or complete trust in the car to handle the situation), while the participants that did not crash were quite evenly distributed across the scale (values 1-7). The drivers who mid-drive reported being more calm/relaxed (as opposed to exited/stressed) were also more likely to crash ($p<0.05$). There were, however, no clear correlation between the reported level of feeling secure during the drive and crash involvement.

Glance data. There were large individual differences in the distributions of off-road glances as shown in figure 1. All drivers who crashed in experiment 2 had glance distributions shifted towards longer off road glances than the average distribution (see star marked curves compared to solid black line in figure 1b). Note that drivers in experiment 1 exhibit more extreme glances than in experiment 2, however there were no crashes as the vehicle avoided the crash by auto-braking.

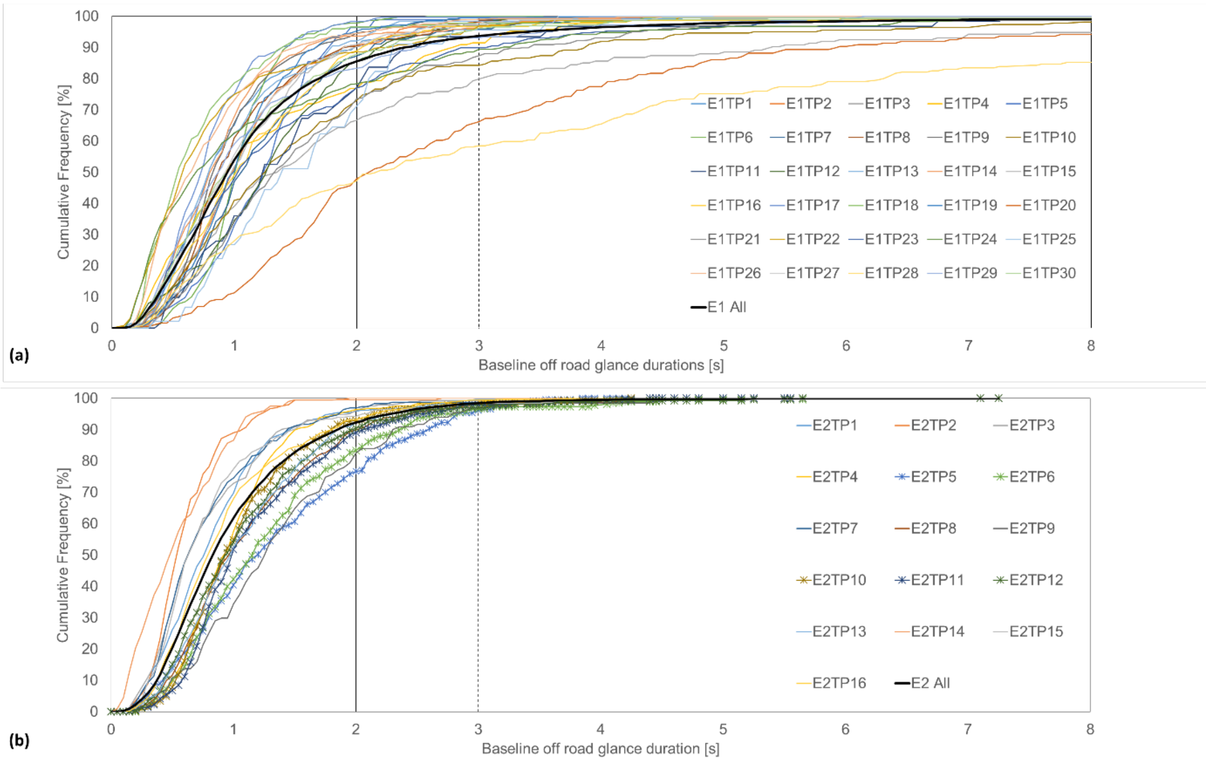

Figure 1. Cumulative off road glance distributions for experiment 1 (a) and experiment 2 (b) for individual participants and for all off road glances per experiment (solid black line). The star marked curves in subplot (b) indicate the individuals that crashed with the obstacle at end of experiment 2. Reference lines indicate glance durations at 2 and 3 seconds respectively.

Correspondingly, the percentage of long off road glances was higher for the participants who crashed compared to the ones that did not crash in experiment 2. This was a clear trend for the percentage of glances longer than 2 seconds (p>0.05) as shown in figure 2b, while it was even more pronounced for the percentage of glances longer than 3 seconds (p<0.01).

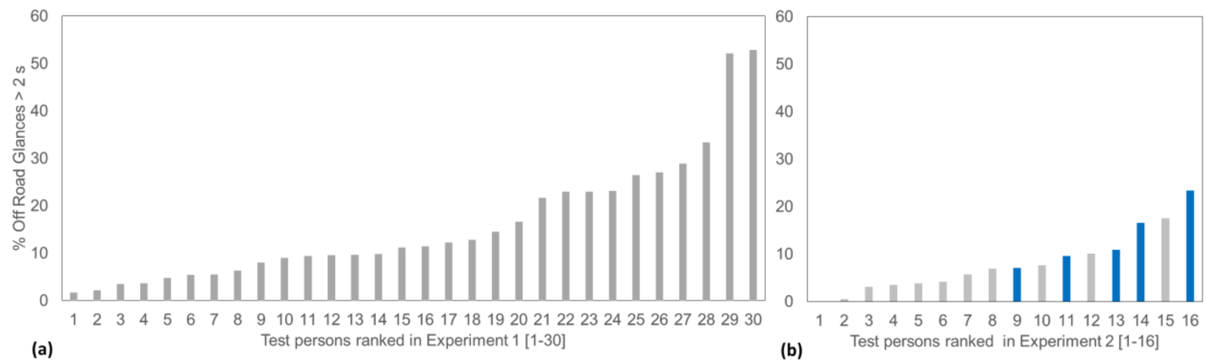

Figure 2. Test persons ranked based on percentage of off road glances longer than 2 seconds for experiment 1 (a) and experiment 2 (b). Blue bars indicate the individuals that crashed with the object in the conflict situation in experiment 2.

Further, the reported level of trust towards the Supervised AD car during the conflict in experiment 1-2 was also correlated to the glance metrics %GDoff>2s (r=0.34, p<0.05) and %GDoff>3s (r=0.370, p<0.05), where higher levels of trust was associated with longer off road glances.

Main conclusions:

- A high level of trust in the Supervised AD car to resolve the conflict was associated with longer off-road glance durations
- A high level of trust was associated with crash involvement in conflicts that required the driver to intervene to avoid a crash.
- There were large individual differences in glance behaviour, both with and without attention reminder, although the attention reminder removed most extreme off-road glances.
- Drivers who reported being calm/relaxed during baseline driving were more likely to crash.

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Does Subjective Data Explain Driver Expectation Mismatch in Highly Reliable Supervised Autonomous Driving?

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Keywords: Automation, Driver-in-the-loop, Expectation, Irony-of-Automation, Mental models

EXTENDED ABSTRACT

Aim and scope

Supervised autonomous driving (Supervised AD) systems involve sustained automation of part of the driving task (e.g. headway control with or without some degree of steering assistance, i.e. SAE Levels 1 & 2 are both supervised). The human is still required to participate in the dynamic driving task by monitoring, and providing fallback by intervening with steering, braking, and accelerating at sensing or actuation limits [1].

As automation performance becomes more reliable and the operational design domain expands (e.g. more situations, speeds, and road types), human factors issues become more significant [2]. For example, operators' tend to reduce their monitoring because of the system's ability to function properly for an extended period of time [3], and *irony of automation* – the better the automation, the less attention drivers will pay to traffic and the system, and the less capable they will be to resume control [4] – becomes a concern. Further, operators can have gaps and misconceptions in their *mental models* of automated systems [5][6], and are often surprised and uncertain of what the automation is doing and will do next [6]. This results in a *first failure effect* – a very poor response to the automation when it initially fails after a period of highly reliable or perfect performance [7].

In three test track studies (the same studies as reported here), Victor et al (in prep) studied driver response to conflicts after highly reliable but supervised AD driving. The test vehicle followed a lead vehicle, keeping precise headway and lane position. After 30 min, a conflict occurred wherein the lead-vehicle cut out of lane to reveal a conflict object in the form of either a stationary balloon car or a stuffed garbage bag. On average, 28% (21/76 drivers) crashed with the conflict object. These crashes occurred regardless of whether drivers were prompted to maintain eyes on road and hands on wheel, and despite explicit supervision instructions. This illustrates the important role of expectations and mental models, showing that a key component of driver-in-the-loop is cognitive (understanding in the brain the need for action), rather than visual (looking at the threat), or having hands-on-wheel.

The purpose of the present research was to study whether the subjective data from these experiments provides further insight into what drivers were thinking and expecting, in particular regarding potential expectation mismatches between what drivers expect themselves to do and the car to do in critical situations.

Method

The three experiments shared the same general methodology (for key details and differences, see Table 1). With highly-reliable driving performance, the test vehicle precisely followed the road and kept a constant headway behind a robot controlled lead vehicle (LV) on the AstaZero test track. After 30 minutes, the TV encountered a conflict object placed in the driving lane: either the ADAC Advanced Emergency Braking System Stationary Target (balloon car event) or a stuffed garbage bag (obstacle event). The conflict object was positioned so participants could see it when passing through a curve just prior to the event (it became obscured again by the LV when the road straightened out). About 20 meters from the conflict object, the LV did an evasive steering maneuver around the object, revealing it in full to the participants. In all three experiments, drivers were required to supervise and could override the automation at any time.

In experiment 1, test participants were given short, general instructions regarding supervision responsibilities and vehicle capabilities. The conflict object was the Balloon car in two laterally different positions. The TV automatically braked and avoided the conflict.

In experiment 2, participants were given instructions that stressed the driver's responsibility to supervise and intervene whenever needed. They also received attention reminders (warning messages in the DIM) if they were visually inattentive. A drift out of lane (drift event) took place after 15 minutes. The conflict object was the stuffed garbage bag. Here, the TV did not brake automatically, so participants needed to intervene to avoid a crash.

In experiment 3, participants were give explicit classroom training on the vehicle's limitations and risk scenarios they needed to be aware of. All received attention reminders if visually inattentive. Half of the participants were also required to always keep their hands on the steering wheel and received a reminder if they failed to do so, while the other half did not need to, as long as they stayed visually attentive. The conflict object was either the balloon car from experiment 1 or the garbage bag from experiment 2. Participants needed to intervene to avoid a crash.

Table 1. An overview of key methodological differences between experiments and conditions.

Experiment	N	HMI	Conflict scenario(s)	Test vehicle response to conflict	Reminder type	Details of instructions
1a	15	Production (Driver support Active/inactive)	Balloon Car fully in lane	Autonomous brake intervention	None	Low
1b	15	Production (Driver support Active/inactive)	Balloon Car partially in lane	Autonomous brake intervention	None	Low
2	16	Static AD HMI + attention reminders in DIM	Drift out of lane & Bag in lane	None	Eyes	Medium
3a	15	Static AD HMI + attention reminders in DIM & sound	Balloon Car partially in lane	None	Eyes	High
3b	15	Static AD HMI + attention reminders in DIM & sound	Bag in lane	None	Eyes	High
3c	15	Static AD HMI + attention reminders in DIM & sound	Bag in lane	None	Eyes & Hands	High
3d	15	Static AD HMI + attention reminders in DIM & sound	Balloon Car partially in lane	None	Eyes & Hands	High

Post-drive, the participants filled in a questionnaire which also served as the basis for a semi-structured interview. Free text responses and interview transcriptions were coded and clustered into themes, and were analyzed together with responses on rating scales using a combination of qualitative and quantitative methods.

Results

Driver Expectations of and Trust in the Autonomous Car.

Of the participants who crashed, 4 of 5 in experiment 2, and 7 of 16 in experiment 3 reported that the reason they did not intervene was that they trusted the car and believed that it would handle the conflict. The other 9 who crashed in experiment 3 reported that they did intervene, but too late or not forcefully enough to avoid a collision.

The participants who did not crash in experiment 2 and 3 either expressed that they saw the object and intervened early to be safe, or intervened late when realizing that the car would not intervene autonomously. Many of the non-crashers expressed uncertainties regarding the car's capability to handle the situation, but still did not perceive the situation as critical since they could override the automation.

Importantly, the participants who crashed reported significantly higher levels of trust in the car compared to the non-crashers. When asked to rate to what extent they trusted the car to handle the situation on a scale between 1 (not at all) and 7 (completely), the average response in both experiment 2 and 3 was below 4 for non-crashers, while above 6 for crashers.

The participants who crashed expressed that they had high expectations on the car, or that they had developed a feeling of safety at least partially due to its driving performance. The non-crashers fell into three groups. They either (1) expressed that they did not have enough trust in the car and therefore intervened themselves, (2) that they felt uncertain about the car's capabilities or (3) that they actually trusted the car to intervene, but in the end were able to avoid a crash anyway.

Effects of Eyes-on-Road and Hands-on-Wheel on Threat Detection.

Due to the effectiveness of the visual attention reminders, all participants who crashed had their eyes on the road prior to and during the conflict. However, 4 of 5 in experiment 2 and 6 of 16 in experiment 3 reported that they did not see the conflict object until after the LV swerved left. This is despite that the gaze coding showed that all these participants actually had their eyes on the road throughout the curve prior to the conflict area, i.e. when the conflict object was visible. Some also expressed that they felt more like passengers than drivers.

The hands-on-wheel instructions did not reduce crash involvement as 30% (9/30 drivers) crashed with hands-on-wheel in groups 3c and 3d.

Conclusions

- Despite clear instructions on vehicle limitations and driver responsibilities, 30 minutes of uneventful driving in a highly-reliable AD car with good driving performance seems enough to generate first failure effects for some drivers.
- Participants that crashed trusted the car and believed that it would handle the conflict, or intervened too late or not forcefully enough to avoid a collision. They had high expectations on the car, or developed a feeling of safety at least partially due to its driving performance.
- Participants that did not crash either intervened early to be safe, or intervened late when realizing that the car would not intervene autonomously.
- Feelings of uncertainty and being responsible were not always enough for drivers to react in a proper way.
- While a precondition for being able to act, having eyes on road and hands on wheel is not the same as being sufficiently in the loop to act on imminent conflict objects.

Acknowledgment: The authors would like to express appreciation for the support of the Swedish FFI project ADEST.

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Influence of motivational aspects and interruption effort of non-driving-related tasks on driver take-over performance in conditionally automated driving

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Keywords: Vehicle Automation; Conditionally Automated Driving; NDRT; Secondary Task; Take-Over;

Introduction

By releasing the driver from the obligation to continuously monitor the driving and system status of his vehicle, Conditionally Automated Driving (Level 3 Automation; SAE, 2014) goes one step beyond Partially Automated Driving, which is already available on the market by several automobile manufacturers. It suffices if the user of such a system is able to respond to a possible Request to Intervene (RtI) within an adequate period of time (NHTSA, 2013). With the necessity of continuous system monitoring being dropped, non-driving-related tasks (NDRTs) that had been labeled distracting or even forbidden during partially automated driving are back on stage and require reassessment.
Comparative studies have shown that different NDRTs have varying effects on take-over times and vehicle stabilization following an RtI (Naujoks, Purucker, Wiedemann, & Marberger, submitted; Vogelpohl, Vollrath, Kühn, Hummel, & Gehlert, 2016). This raises the question if there exist superordinate task characteristics that influence driver availability in take-over situations. Public opinion studies indicate that users of highly automated driving will engage in motivating tasks, such as texting, eating/drinking, surfing or watching movies (Pfleging, Rang, & Broy, 2016; Schoettle & Sivak, 2014), and there is some evidence that highly engaging or interesting tasks are harder to interrupt than less engaging or interesting ones (Horrey & Wickens, 2006; Wickens & Alexander, 2009). We therefore assume that drivers engaged in a highly motivating task will show longer take-over reaction times and poorer take-over quality than those engaged in a less motivating task. NDRTs may also differ in terms of interruption effort, which refers to necessary motoric steps to pause the NDRT and lay related objects aside. We therefore suppose that drivers engaged in tasks with high interruption effort will show longer take-over times and poorer take-over quality than those engaged in a task with low interruption effort. As a first experimental factor, the study at hand compares two NDRTs that are expected to differ in their motivational appeal to the driver. As a second factor, two differently effortful interruption conditions of these tasks are introduced. In a driving simulator experiment, the impact of these manipulations is investigated in an emergency take-over situation with a stranded vehicle on a highway.

Method

The study was conducted in the driving simulator of the Wuerzburg Institute for Traffic Sciences (WIVW GmbH) using the institute's driving simulation software SILAB.
Vehicle automation included lateral and longitudinal guidance according to SAE Level 3 (SAE, 2014) with a fixed set speed of 120 km/h. In case there were slower vehicles ahead, the system followed with a pre-set time-headway of 2 s, and a respective lower speed than the set speed.

Both activation and deactivation of the system were possible by simultaneously pressing two steering wheel buttons that could easily be reached with the thumbs. Deactivation of the system was also possible by braking, but participants were instructed to use the buttons.
The test scenario consisted of a straight drive on a three-lane freeway at 120 km/h. A lead vehicle on the right lane pulled out to the middle lane at a predefined point and gave view of a stranded vehicle. At that point, an RtI was issued and longitudinal guidance was shut off instantly. The Time To Collision (TTC) at the moment of RtI output was approx. 9 s. The RtI was visualized in the vehicle's head-up-display, and was accompanied by two consecutive high frequency warning tones.
As a NDRT, the video game Tetris® was provided on two 8 inch hand held tablets. Driver motivation was manipulated by external rewards: When playing with one of the two tablets (the high motivation tablet), drivers were instructed to give their best to earn extra money depending on their game performance (high motivation condition). For reasons of equality and practicability, every participant received the same total amount of extra money (6 Euros). At different points once in every CAD section in the high motivation condition, the gain of another Euro was announced acoustically. When playing with the other tablet (the low motivation tablet), drivers could not win any money, and the experimenter described the task as a simple pastime without any performance measurement (low motivation condition). Task interruption effort was manipulated by two different interruption instructions: In the high interruption effort condition, drivers had to pause their task on the smartphone, put the device into a plastic box on the co-driver's seat and place a lid on top of the box before taking over vehicle control. For low task interruption effort, it sufficed to pause the smartphone task and lay the device aside, but not into the box. Continuous task processing and correct interruption was monitored by the experimenter.
A complete within-design was used in the study. Every participant completed a high motivation block and a low motivation block in randomized order. The blocks further split up into two identical take-over situations with high and two identical take-over situations with low interruption effort, resulting in 8 take-over situations per participant.
Participants were instructed that when the automated system was active, they did not have to monitor driving and should fully apply themselves to the NDRTs. They were told that whenever they had to take back vehicle control, the system would inform them in time. The different motivation and interruption conditions were explained as well.
The main experiment consisted of eight highly automated driving sections that each lasted approx. 3 min. and were followed by the previously explained take-over situations. After the main drive, participants completed questionnaires, received monetary compensation for their participation and were discharged. The entire procedure took approx. 40 minutes.
A total of $N = 53$ participants with a mean age of 32.3 years ($SD = 9.7$ years) took part in the study. 28 participants were female and 25 male. Participants were recruited from the WIVW test driver panel and had taken part in an extensive driving simulator training (Buld, Krüger, Hoffmann, & Totzke, 2003) prior to the study.

Results

Despite previous training, driving data results revealed exercise effects between the first two take-over situations. To rule out any exercise effects, only the 4 repetition trials (situations 2, 4, 6 and 8) were analyzed.
In an inquiry after the test drive, when drivers had to rate "How dangerous do you consider playing Tetris during real, highly automated highway drives?" on a 15-point Likert scale, the high motivation condition was considered significantly more dangerous ($M = 11.2$, SD

= 3.0) than the low motivation condition (*M* = 9.8, *SD* = 3.3), as can be seen in Figure 1 (left). The high motivation task was also rated more motivating (*M* = 12.4, *SD* = 2.1) and harder to interrupt (*M* = 5.4, *SD* = 4.0) than the low motivating task (*M* = 11.7, *SD* = 2.2 and *M* = 4.8, *SD* = 3.7, respectively), although these differences did not reach significance.

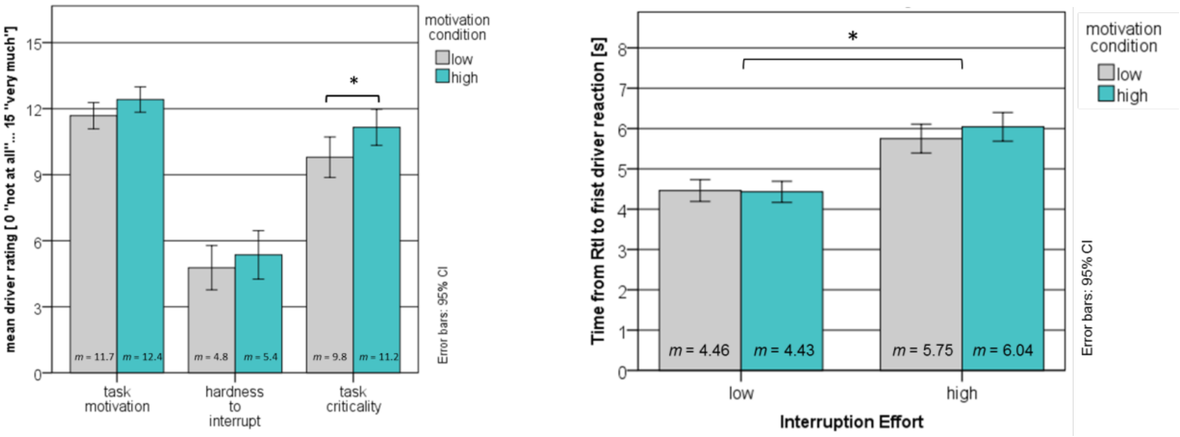

Figure 1. Left: Subjective post-hoc driver rating of task motivation, hardness to interrupt and task criticality depending on motivation condition; Right: Mean driver reaction times following take-over requests, depending on motivation condition and interruption effort condition.

Figure 1 (right) shows the time to first driver reaction after the RtI. First driver reaction was defined as drivers' initial breaking reaction, steering more than 2° steering wheel angle or button press on the steering wheel after RtI emission, depending on which behavior occurred first. A univariate ANOVA revealed that in situations with high interruption effort, drivers reacted significantly slower than in those with low interruption effort ($F(1,222) = 85.49$, $p < .001$). For situations with low manipulated driver motivation, mean reaction times were 4.46 s in the low interruption effort condition (*SD* = 1.03) and 5.75 s in the high interruption effort condition (*SD* = 1.35). For situations with high manipulated driver motivation, mean reaction times were 4.43 s in the low motivation condition (*SD* = .99) and 6.04 s in the high motivation condition (*SD* = 1.31).

Discussion

The study at hand analyzed subjective and objective take-over measures as a function of driver task motivation and task interruption effort. Increased task interruption effort in terms of storing the task device in a box came along with significantly delayed reaction times to the RtI in a range between 1.3s and 1.6s, an equivalent of between 40 and 50 meters at the implemented set speed. Although playing the tablet game for points and money was considered more critical by participants than playing without external rewards in the post-hoc rating, no differences between motivation conditions showed up in RtI reaction times. This finding may reflect the fact that the motivation manipulation used failed to induce significant differences in self-reported driver motivation.

Taken together, the study at hand demonstrated the large impact of task interruption effort on driver reaction times in SAE Level 3 take-over scenarios. High task interruption effort is a typical characteristic of real-life NDRTs that requires increased attention in future research on automated driving.

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Effects of Secondary Tasks on Conditional Automation State Transitions While Driving on Freeways: Judgements and Observations of Driver Workload

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Keywords: Conditionally Automated Driving; Highly Automated Driving; Take-Over; Request to Intervene; Wizard-of-Oz; Workload

Introduction

Within the next years, vehicles will be capable of taking over the driving task in certain environments without the need to be continuously monitored by the user. This so-called conditionally automated driving (L3-automation according to SAE J3016 [1]), unlike highly or fully automated driving, still will require the user as a fallback resource: within a certain time frame, the user must be able to take back manual vehicle control in case of system malfunctions or system boundaries are encountered.

Still, drivers will be allowed to engage in non-driving related tasks (NDRTs) while the vehicle is in motion when the automation system is active. Previous research on control transitions, mostly conducted in driving simulators, reported take-over times between 1 s and 15 s [2]. Authors often suggested the role of NDRTs for the reported take-over time variation [3-5]. More specifically, Marberger et al. [4] proposed a model for the system-initiated transition from automated to manual driving. The authors suggest that the driver take-over time is determined by various task properties and driver related factors, such as the sensory, cognitive and motoric state of the driver, the arousal level and motivational conditions.

The current study aims at exploring the relationship between varying NDRT properties, measures of driver motivation and workload, as well as take-over times during control transitions in a real-vehicle study on German freeways in everyday traffic.

Method

In the study, a fully instrumented Wizard-of-Oz vehicle was used to emulate a conditionally, L3-automated vehicle that is capable of providing full longitudinal and lateral vehicle control, altogether with a complete visual and acoustic HMI, consisting of system specific icons on the head-up display (HUD) and the cluster display, as well as LED-illuminated levers on both sides of the steering wheel. When the automation system was active, vehicle controls were taken over by the co-driver and the experimenter in the Wizard-of-Oz vehicle. The input controllers and feedback devices were fully concealed to the system user in the driver’s seat.

While driving with the active system on German freeways in the metropolitan area of Stuttgart, naïve users engaged in different NDRTs. After approximately either 5 or 15 minutes of automated driving, a Request to Intervene (RtI) was issued, and users were requested to take back manual vehicle control. Figure 1 provides a synoptic overview on the study design.

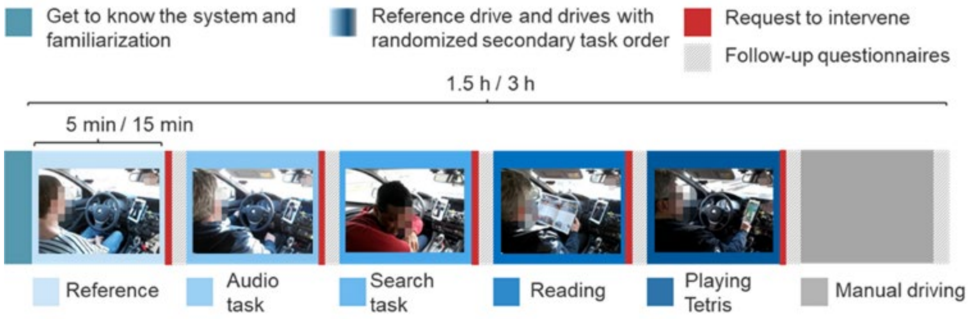

Figure 1. Overview on the study design with the within-subject factor secondary task and the between-subjects factor duration of the automated drive between RtIs.

The naturalistic NDRTs used in the study (an audio listening task, a backseat-searching task, a magazine reading task and a playing Tetris task with a tablet mount) were inspired by common secondary tasks that drivers would likely engage in when using an automated vehicle [6-8]. They were also selected to impose different levels of visual, cognitive, or motoric workload on the driver, and to vary regarding motivational aspects [4]. Besides, a reference task (drivers only had to surveil the vehicle surroundings) and a manual driving section were part of each trial.

After each take-over, participants were asked various questions concerning the secondary task and the transition process. Questions addressed workload (i.e., visual, cognitive, and motoric workload) and motivational aspects were asked on a category scale ranging from 0 (not at all) to 15 (very strong). Besides, take-over times and measures of vehicle stabilization were recorded.

Results

N = 34 drivers of an age of M_{age} = 55 years (SD = 14) of which n = 6 were females participated in the study. 21 drivers had previous experience with ACC systems. 156 valid take-over cases were recorded in the study.

Figure 2 shows participant ratings regarding subjective motivation to work on the task, as well as visual, cognitive and motoric workload judgments for each of the tasks that the participants worked on before the RtI was issued. Univariate ANOVAS were calculated for each of the subjective measures, with secondary task as a factorial predictor. Planned contrasts were included for pairwise comparisons of the secondary tasks, with the reference task serving as a reference category. Overall effects of the secondary task were found for motivation ($F(4,151) = 3.698$, $p = .007$), visual distraction ($F(4,151) = 7.985$, $p = .000$), and motoric workload ($F(4,151) = 2.591$, $p = .039$). For cognitive workload, only a marginally significant effect of secondary task was found ($F(4,151) = 2.339$, $p = .058$). The planned contrasts (all tested against the reference) for motivation showed significant differences for the search task ($p = .018$), and for playing Tetris ($p = .001$). Regarding visual workload, significant effects were found for the search task ($p = .002$), the reading task ($p = .002$), and playing Tetris ($p = .008$). Likewise, for cognitive workload, significant effects were found for the search task ($p = .016$), the reading task ($p = .035$), and playing Tetris ($p = .020$). In the case of motoric workload, planned contrasts only showed a significant effect for the search task ($p = .012$).

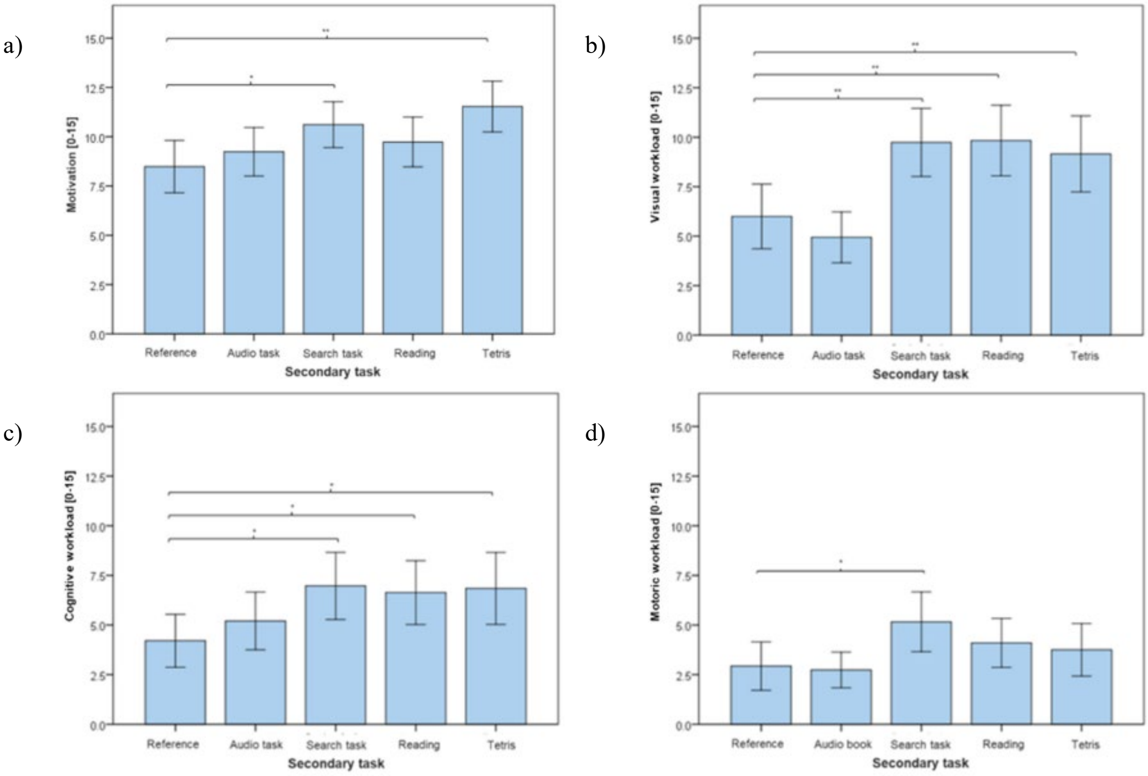

Figure 2: Subjective ratings of (a) the motivation to work on the task, (b) the visual workload, (c) the cognitive workload, and (d) the motoric workload users experience due to working on the task while driving automatically. Mean values and 95%-confidence intervals are shown.

In addition to the subjective measures, objective measures of take-over times and take-over quality were analyzed. As an example, average take-over times ranged between $M_{ref} = 2.97$ s for the reference task and $M_{st} = 5.05$ s for the search task. To assess the relationship between take-over times and subjective task properties, an ANOVA model for the prediction of take-over times from the main effects of the subjective variables motivation, visual workload, cognitive workload and physical workload is calculated. Significant effects were found for visual workload ($F(1,151) = 8.060$, $p = .005$) and motoric workload ($F(1,151) = 5.371$, $p = .022$), but not for motivation ($F(1,151) = 0.356$, $p = .551$) and mental workload ($F(1,151) = 1.105$, $p = .295$).

Discussion

The current study, a first-of-a-kind study to measure take-over times from conditionally automatic to manual driving in real freeway traffic, could show, that NDRTs performed at the RtI severely influence take-over times. NDRTs with subjectively different workload and motivational requirements were investigated, and it could be shown that particularly visual and motoric workload properties have an effect on take-over durations. The results from the study can be used to design comfortable and safe take-over concepts for automated vehicles, and future research should be dedicated to further explore the relationship between NDRT properties and take-over times.

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Impact of a long autonomous driving phase on take-over performance

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Keywords: Level 3 automation; duration; Driver behavior; Drowsiness; Highway chauffeur function; Human factors; Simulator; Watching video while driving

EXTENDED ABSTRACT

With advanced technology on new automation functions, driverless cars are going to be very popular in a near future. As a consequence, drivers' role is about to change: drivers will not drive anymore but will be driven, allowing them to focus on other activities such as playing games or watching a video without worrying about road events.

Our research focused on the "highway chauffeur" function, which will allow long periods of automated driving at high speed. This function corresponds to Level 3 of car automation where the vehicle handles the lateral and longitudinal controls without needing continuous supervision by the driver [1,2]. When all conditions are met, the driver can activate this function by pressing a button on the steering wheel before removing hands from the wheel and feet from the pedals and engaging in another activity. In case of necessity, such as a sensor dysfunction, the system can alert the driver to retake control by replacing hands and feet on the commands with a predefined transition time.

As an irony of automation, while focusing on another task, the driver loses situation awareness. He may be trapped into an "out-of-loop state", which is well known to have a negative impact on driving performance during take-over [3-6]. Although this phenomenon is now very well documented in the human factor literature [7-12], only one study investigated the impact of autonomous driving duration up to 20 min on take-over performance [13]. Therefore, a lack of evidence still remains regarding the purpose for which this function is specially designed: longer non-interrupted autonomous driving durations.

Our main objective was to provide new insight on the impact of one hour of autonomous driving on take-over performance. We hypothesized that a long duration (1 hour) spent in autonomous driving had stronger negative effects on driver's behaviour (in terms of timing and performance quality) in comparison with both a shorter period (10 min) and a reference manual driving (without automation). As an increased level of drowsiness was also expected with longer automation duration, we also questioned as a second goal the benefits of sequencing long periods of autonomous driving with several shorter ones. Thereby, the protocol included two short autonomous driving periods surrounding a longer duration of autonomous driving. The impact of long and short autonomous driving durations was investigated in two traffic conditions, a critical one involving a car accident which the drivers had to bypass and a non-critical one bared of any traffic.

Thirty daily drivers (15 males, 15 females), aged between 35 and 55 years old took place in a dynamic driving simulator at PSA research centre. They were experienced drivers (more than 10000 km/year and 15 years of driving experience), familiar with the practice of ADAS although novice with a dynamic simulator. After being introduced with the study and the

setup, they ran two driving sessions conducted on a highway loop at 110 km with an automatic gearbox. In the first session, participants drove under manual mode in order to provide both simulator and function practices and a manual driving reference (MD) for both traffic conditions. After a short break, participants ran the second session using the automation mode for SHORT (10 min), LONG (1 hour), and again SHORT (10 min) duration conditions, each condition ending with an alert to retake control, leading to a total of 3 take-over requests (TORs): SHORT1, LONG, SHORT2, always presented in this order. During these three automation phases, drivers were engaged in an entertaining task (actually watching a movie displayed on the control screen behind the steering wheel) instead of driving. The objective was to put the driver out of loop and to prevent him/her to take information about the driving conditions. Traffic scenarios were counterbalanced across participants providing either cars accident (CARS) or no car (NC) conditions associated with the TOR. In both cases, the drivers had 10 s to regain control. At this moment, the accident was at 305 m behind the car.

Performance data (action times and car trajectories) were extracted directly from the simulator and recorded for further analysis. The driver's drowsiness state was verbally self-reported after each TOR using a 5-point Likert scale, ranging from "alert / very awake" (1) to "extremely drowsy" (5).

The take-over performance was assessed during: *1) Transition phase*, including time from the TOR until the driver put hands on the steering wheel, first feet application on the pedals (brake or accelerator), and when the function actually disabled. *2) Avoiding manoeuvre,* (for CARS condition only), including time from the TOR until the drivers changed lane and returned on the right lane, distance and time to collision (DTC and TTC, respectively), lateral deviation at the level of the accident, and minimal and maximal lateral speeds. 3) *Stabilization,* (mainly for CARS condition) pointing when participants recovered an appropriate driving behaviour comparable to MD. Standard deviations of lateral deviation, steering angle, longitudinal and lateral speed (averaged by 60 m increments) were compared for each participant in the two duration conditions to their manual driving.

Partial overlapping t-tests [14] were run to examine the impact of LONG autonomous driving duration in comparison to SHORT and MD on the take-over performance. Statistical parametric mapping paired t-tests [15] were used to assess the quality of control.

Transition phase: 74 % of the participants retake control in the first 4 s following the TOR regardless of the driving conditions. Regarding the effect of automation duration, the time of actions occurred approximately 0.5 s later in the LONG condition with significant effects in CARS condition only (see Figure 1 for statistics). There was no significant effect of the traffic condition.

Avoiding manoeuver: After a long period of automation, lane change occurred about 1 s later relative to MD condition, and 0.5 s later relative to the SHORT ones (see Figure 1). TTC and DTC were de facto shorter, which emphasizes a lower safety margin. The lateral speed was also greater in the LONG condition while overtaking and return, stressing a sharper avoiding manoeuvre. Nevertheless, no difference was found in the lateral deviation between conditions, which means a comfortable safety lateral margin (about 1.74 m from the central line; see Figure 2). At the end, no difference was found in the DTC in the right lane, which could suggest a stabilized behaviour after passing the accident.

Stabilization: The variability in the control of the vehicle (SD of the lateral deviation, steering angle, longitudinal and lateral speeds) was higher after a long period of automation when compared to MD, but mainly before the accident. This provided further support that the driving behaviour stabilized very quickly after passing the accident.

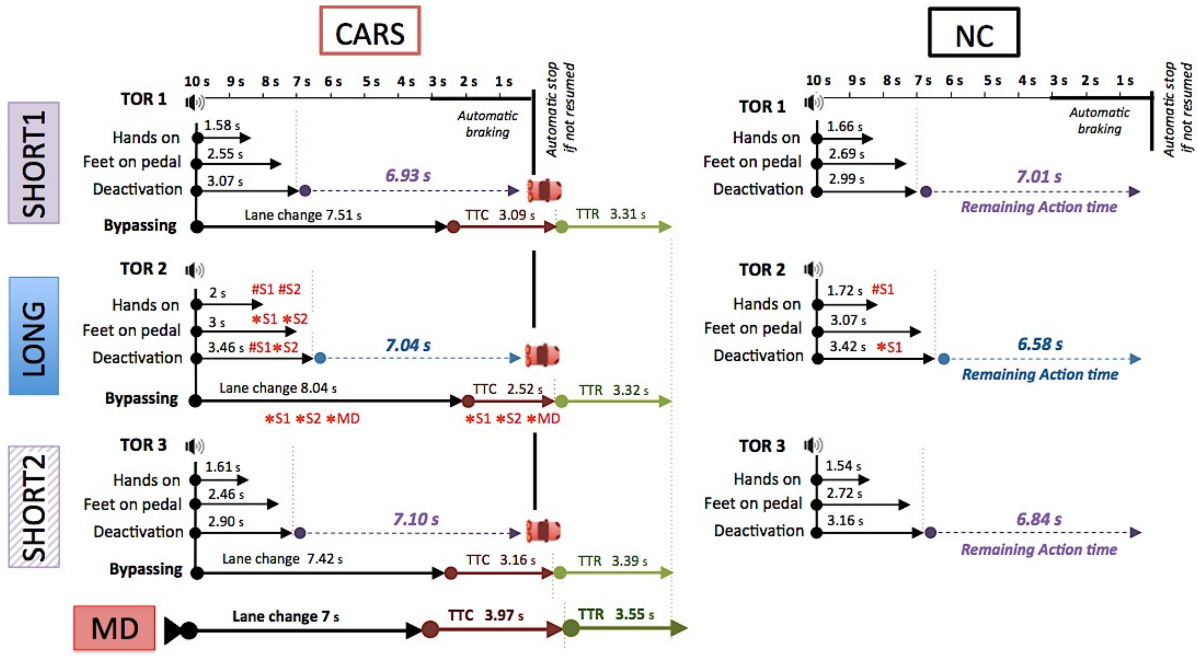

Figure 1. Action times collected during the TORs for each condition. Statistics were reported when significant differences (*p<.05) and tendencies (#p<.1) were reached between LONG and SHORT1 (S1); SHORT2 (S2); Manual driving (MD).

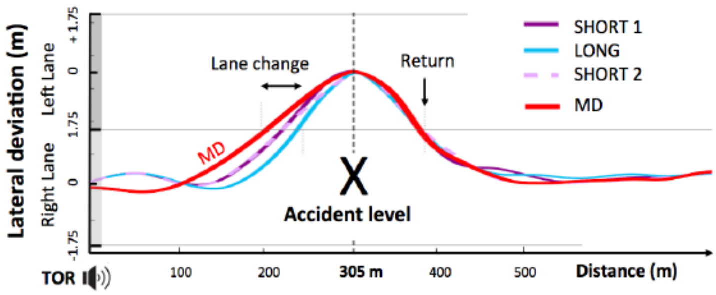

Figure 2. Trajectory profiles from the LONG and SHORT duration conditions and MD reference for the avoiding manoeuvre.

Driver state: Drivers fell into strong drowsiness state after a long period of automation (Mean scores: $M_{SHORT1}=1.77/5 \pm 0.8$; $M_{LONG}=3.33/5 \pm 1$; $M_{SHORT2}=2/5 \pm 0.9$). Forty percent of the subjective drowsiness scores switched from “low and partially drowsy” to “very and extremely drowsy” in the LONG condition. Objectively, six of the 30 participants temporarily slept during the long period of automation. No significant differences were found between the two short conditions.

To conclude, one hour spent in autonomous driving affects the driver’s behaviour toward a decline in the take-over performance and an increase of the drowsiness state. Although the true level of risk remains to be quantified to fully conclude on driver safety, this study warns against the risks associated with a long period of automation, especially in the event of an accident to manage when taking-over [4]. This study also underlines that relatively frequent TORs should be beneficial to the driver taking-over behaviour. To preserve the benefit of long periods of autonomous driving, other perspectives could also be explored to test reliable drowsiness monitoring solutions in order to prevent the out-of-loop state in autonomous vehicles [16]. It could be particularly valuable to investigate displaying more complex situations involving more traffic, others type of secondary task, and longer durations spent in autonomous driving in order to provide a better understanding of the problem in broader situations.

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Influence of automated environments over mind wandering features

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Keywords: Aeronautics, automation, mind wandering, oculometry, perceived workload, trust

EXTENDED ABSTRACT

Increasing safety in critical systems is paramount. To achieve this goal, engineers integrate always higher levels of automation within those systems – e.g. glass-cockpit aircrafts, power plants, autonomous cars. However, human-machine interactions failures have been observed when operators are required to assume manual control. This phenomenon has been called the “out-of-the-loop” (OOTL) performance problem [1]. Operators experiencing OOTL were handicapped in their ability to detect and diagnose automation failure.
If the OOTL performance problem represents a key challenge for system designers, it remains difficult to characterize and quantify after decades of research [2]. While searching for elements explaining observed performance drops, researchers pointed vigilance decrement as a key component of OOTL situations [3].
Among possible causes, mind wandering (MW) has yet received little attention. MW is the human mind propensity to generate thoughts unrelated to the task [4]. Even though MW can be intentional or spontaneous, it attenuates perception and lowers external stimuli processing. The resulting state is an attentional decoupling from the task at hand and a mechanical behavior unable to handle critical events properly. As it diverts operators’ attention from their primary task, it could play an important role in OOTL situations.
We designed two experiments to uncover the dynamic of MW within automated environments varying in reliability. We focused on measuring MW frequency and intensity, and quantifying interactions with operators’ vision of the system – trust and perceived workload.

Environment

For both experiments, we used the LIPS (Laboratoire d’Interactions Pilote-Système). An unmanned air vehicle (UAV) depicted as a plane seen from above stayed at the center of a 2D radar 22-inch screen and moved following waypoints arranged in a semi-straight line with clusters of obstacles along the way.
Two modes were proposed. The first one was the “manual” mode and required participants to manually avoid obstacles by choosing the moment and side for the avoidance maneuver. The second mode was “automated”. Participants were required to monitor the autopilot avoiding obstacles and recover any mistake of the system. Moreover, they had to acknowledge any automated trajectory decision as soon as they saw it.
MW episodes were probed with questionnaires displayed every 2-minutes on average. Participants had to indicate if their state of mind were “Focused on task”, “Around task” (thoughts related to the instructions), “Mind wandering” or “External noise”. We also used an eye-tracker to record MW oculometric markers (pupil diameter, blink frequency, saccade frequency and mean fixation duration).

Experiment 1: MW propensity in highly automated environments

The first experiment focused on comparing MW dynamic within manual and automated environments. We measured MW frequency and oculometric markers. Each participant performed two sessions corresponding to the two modes in a counterbalanced way. Each session lasted 45-minutes, preceded by a 10-minute training. When facing automated mode, participants encountered one mistake during the training and one during the session.

Three main results have been shown: (1) MW increased after some time has elapsed in the automated mode, (2) there was a difference in pupil diameter between MW and focus episodes and (3) oculometric markers were stable between conditions.
The first result was the increase of MW frequency only in the automated condition after some time. Since both conditions lasted the same amount of time, time-related phenomena (drowsiness, habituation, tiredness) alone cannot explain this result. Two explanations could account for this result: complacency or loss of agency. Complacency is an issue of monitoring automation generated by an uncritical reliance on the system. Since no error was presented in the first 30-minutes of the task, participants might redirect their cognitive resources towards more useful and personal matters and mind wander more. On the other hand, agency could also increase MW frequency. Agency is one's feeling of control regarding observed effects. A loss of agency is known to occur in automated environments. It could lead to decrease resources allocated to the supervision task. Both explanations could also be complementary.
The second result was a decrease of pupil diameter during MW compared to focus moments, while no difference was observed for other oculometric markers. Finally, the third result was the stability through time and condition of pupil diameter difference between attentional states. Pupil diameter could therefore be used in a wide variety of environments, including ecological ones like simulators, to measure MW in real-time. Unfortunately, MW detection rates using only pupil diameter are still far from being sufficient.

Experiment 2: interaction between autopilot reliability and MW
Both complacency and a loss of agency could account for the MW frequency increase observed in the previous experiment. We designed a second experiment to investigate the interaction between system reliability and MW. We modified the questionnaire to measure perceived workload and trust regarding the system's ability to avoid obstacles. We used the automated mode of the LIPS to propose two conditions. The first condition, "Risky", consisted of an autopilot with an error rate of 40%. The second condition was called "Safe", where the autopilot did only one mistake throughout the experiment.
Three main results have been shown: (1) MW propensity was not influenced by perceived workload or trust in automated environments, (2) MW created a decoupling from the task and (3) attention is not binary MW - focus.
The first result was the absence of influence of perceived workload and trust over mind wandering rates. This result rules out the possibility of complacency accounting for MW increase observed in the first experiment. It presents MW as being dependent on the very nature of the interaction – either automated or manual – but not on the reliability, thus strengthening the loss of agency hypothesis.
The second result is the influence of MW over both trust and perceived workload. Indeed, participants' perception of workload was attenuated: when participants reported MW episodes, they also reported similar perceived workload between conditions, contrary to "Focus" and "Around" states. Similarly, trust ratings evolved chaotically when associated with MW, while we observed a decreasing linear trend for both other attentional states. Taken together, these observations show that MW led participants to overlook task complexity.
Finally, the third result is the significant difference between "Around" state compared to the two other attentional states. This is in line with the hypothesis of a gradual MW [5]. However, other studies are still needed to assess whether more attentional states exist, and if our attention is really a gradient between focus and MW.

Conclusion
MW not only emerges in automation supervising tasks, but its frequency increases compared to tasks handled manually. Considering the decoupling from the task induced, MW is a dire threat to all critical monitoring activities. We need to study the phenomenon further in order to understand its gradation and develop reliable real-time measures.

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Drivers' response to automation failures: how do driver distraction and regular vigilance affect take over response?

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Background

Recent driving simulator studies have shown that drivers' visual attention to the road centre is much reduced during SAE Level 2 and 3 driving (SAE, 2016), compared to when they are in manual control of the vehicle (Louw et al. 2015; Zeeb, Buchner, & Schrauf, 2016). This reduced visual attention to the road centre is further diminished during driver engagement in other (visual) non-driving-related secondary tasks (NDRTs), which may be voluntary (Carsten et al., 2004) or enforced by the experimental conditions (Louw et al., 2016). Recent real-world observations of drivers in conventional vehicles also suggest higher incidents of driver distraction, with engagement in mobile telephones and satellite navigation systems being particularly prevalent (Huisingh et al., 2015). As the degree of automation in vehicles increases, drivers' engagement with such distracting tasks is also likely to increase (Naujoks, Purucker, & Neukum,2016), perhaps to relieve boredom, or due to driver complacency and a high trust in the automated system's capabilities (Banks et al., 2018), affording them the peace of mind that engaging in NDRTs is safe.

Results from both driving simulator and real-world studies of Level 2 driving illustrate that reduced visual attention to the road centre, further enhanced by visual NRDTs, can be catastrophic, with higher response to critical incidents if drivers are required to take over from the automated system, for instance, to avoid colliding with a lead vehicle (Louw et al., 2016; Louw et al., 2017; Endsley, 2017; Banks et al., 2018). A large number of driving studies have also shown that, when distracted by NDRTs, driver response to in-vehicle or road-based vigilance tasks, such as the Peripheral Detection Task (PDT) or the Detection Response Task (DRT) is impaired, when compared to non-distracted driving conditions (Merat et al., 2015; Merat & Jamson, 2008).

To ensure humans remain sufficiently engaged with the driving task, perhaps also discouraging engagement in NDRTs, Level 2 vehicles currently available on the market are equipped with features that encourage regular contact with the steering wheel, for example by activating pressure sensors or actual steering input. If drivers do not adhere to this requirement, the automated system disengages. As vehicles move from offering SAE Level 2 to 3 automation, drivers are no longer obliged to monitor the driving environment, and will only be asked to respond to a "request to intervene". In these circumstances, drivers are more likely to engage in NDRTs, although they may still wish to occasionally glance towards the forward roadway, as they familiarise themselves with the system's capabilities.

Study Objectives

The aim of the present study was to observe driver behaviour during an SAE Level 2 automated drive, and investigate how their engagement in a visual NDRT and a road-based vigilance task influenced their ability to detect subtle failures in the automated system. In particular, the study investigated the following main research questions: (i) are drivers able to detect a subtle failure of the automated system, cued by changes in proprioceptive feedback from the vehicle, and in the absence of any discernible vehicle-based warnings? (ii) is this detection more noticeable during failures on straight or curved road sections? (iii) does engagement in a visual NDRT delay detection of such failures? (iv) how does engagement in a road-based vigilance task affect behaviour?

Method

Thirty regular drivers (19 male, Mean age = 42.47 years ± 17.49; Mean driving experience: 22 years ± 16.11) were recruited for the study and completed two drives of a 3-lane UK motorway with curved and straight road sections. Following a 15 minute familiarisation drive, participants completed two experimental drives

(Road A and Road B) in a counterbalanced order. Each drive began with a short manual drive, which included engagement in the Arrows NDRT (Jamson & Merat, 2005). Following this manual drive, automation was engaged by drivers, which was available when the vehicle was placed in the centre of the middle lane. When automation was engaged, drivers were required to take their hands off the steering wheel and foot off the pedals, allowing the vehicle to drive at 70 mph, tracking the centre of the road, which contained straight and curved sections. During Road A, drivers were asked to read the words presented on a Variable Message Sign (VMS, see Figure 1, for an example). For Road B, as well as reading the VMS words, drivers were required to complete the Arrows task, which required detecting and touching an upward facing Arrow, present in a 4x4 grid of Arrows on a touchscreen (Figure 1). This was a driver-paced task, which required identification of as many upward facing Arrows as possible, with each detection prompting the presentation of the next 4x4 grid. It was hoped that a 'score to beat' index, kept participants motivated in engaging in this NDRT. In addition to recording response to the Arrows task and number of VMS words cited, participants' response time to automation failures, control of the vehicle after failure, and eye/head tracking were recorded. Each of the two Roads (A and B) contained 6 automation failures, and 10 VMS signs, with 7 of the 10 VMS containing a word. To establish if road curvature had an effect on detection of failures, three failures were presented on straight sections of the road, and three when the vehicle was on a curved section of road for both Road A and B.

Figure 1 – Position of the Arrows NDRT in the vehicle (left) and example of the VMS

Preliminary Results

Overall, results showed a familiarisation by drivers to the failures, with a faster response from participants as more failures were experienced. To establish the effect of engaging in the NDRT on participant response to failures, only responses to the first failures on the straight and curved sections of each road (A and B) are reported in this short overview, with further results, including response to the Arrows task and an overview of drivers' eye and head-tracking behaviour to be reported in the full presentation.

Participants detected the subtle failure of the automation (which resulted in a deceleration of 0.34 m/s^2, after automation failure) quite quickly, taking control of the steering wheel in less than 3 seconds, on average (Take-over Response time or TOR). A 2 (Road Curvature: Straight, Curve) x 2 (Distraction, No Distraction) within-participant Analysis of Variance (ANOVA) revealed a significant main effect of curvature on TOR (F(1,29)=5.62, p=.025, η_p^2=.07), whereby the TOR time was shorter for curve (M=1.69, SD=1.07) than straight (M=2.6, SD=1.96) road sections. There was no main effect of distraction (F(1,29)=2.26, p=.144), η_p^2=.16) and no interactions (F(1,29)=.35, p=.56, η_p^2=.012) – see Figure 2 – suggesting that participants' engagement in the Arrows task does not seem to have affected their ability to detect failures in this study.

Drivers reengaged automation within around 12 seconds, with no significant difference in this reengagement time for straight or curve sections, for Road A and B. However, drivers' control of the vehicle after automation failure was found to be different, with a 2 x 2 within-participant ANOVA on maximum lateral acceleration showing a significant main effect of curvature F(1,25)=10.94, p=.003, η_p^2=.30. A higher value for the curve (M=2.63, SD=1.48) versus straight (M=1.69, SD=1.36) sections, confirms that resuming control from automation is more challenging/potentially hazardous if failure is experienced on curves. There was no main effect of distraction on this value (F(1,25)=0.95, p=.339, η_p^2=.04) but there was a significant interaction between curvature and distraction (F(1,25)=10.94, p=.003, η_p^2=.30). Further analysis showed that in the absence of the Arrows task (Road A) the maximum lateral acceleration was significantly higher when failures occurred on the curved (M = 2.88, SD = 0.93) than straight sections (M = 1.17, SD = 0.92, t(29)=7.84, p<.001). However, this difference was not observed for Road B (t(29)=0.23,p =.82), with a high value for the maximum lateral acceleration observed for both the straight and curve road sections (see Figure 2).

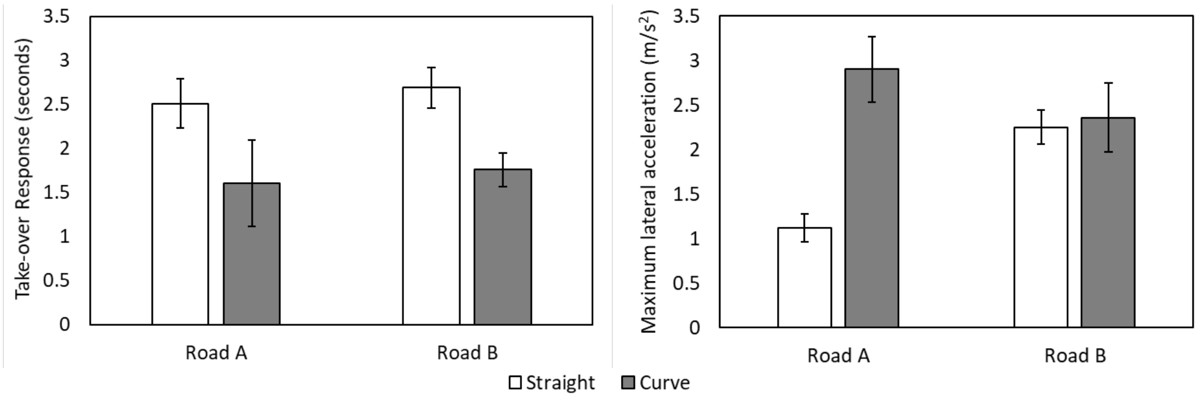

Figure 2 – Take-over response (TOR; Left) and Maximum Lateral Acceleration after TOR (Right) for Road A and Road B

The implications of these findings and their significance for design of driver monitoring systems for Level 3 automation will be discussed.

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A Workshop on Distraction for 15-19-Year Olds

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Keywords: Awareness Raising; Schools; Teenagers; Workshop

EXTENDED ABSTRACT

Distraction is one of the most frequent accident causes in traffic in Austria. Not only drivers are concerned, but also pedestrians walking in the street. A lot of teenagers listen to music, text or make a phone call while participating in traffic. As they are distracted, also by other factors of distraction like face-to-face-conversions or daydreaming, they make mistakes possibly leading to accidents. To raise their awareness of the dangers of distraction a workshop for 15 to 19-year-olds was designed and tested.

There is no obligatory road safety education in Austria for teenagers and pre-drivers. If a measure is offered to young people and accepted by them, it must be attractive and easy to carry through. In addition, the measure should be able to be carried out easily at schools, if these offer themselves as partners. The latter, because schools are a perfect access to reach a wide range of youth.

Why the age group 15 to 19 years? 15-19-year olds are in an important stage of development. Young people spend more and more time in traffic: Travelling to school or work by foot or cycling, meeting their friends, spending leisure time in the streets, and practicing sports in the street, like skating. Later, they use their mopeds or even cars. By determining their mobility, young people also develop their habits. In this phase, they also develop further their sense on dangers in traffic and dangers of their traffic participation. Thus, this is a perfect moment to provide information both on dangers and on intentions to do it better.

It is the aim of the workshop to raise awareness that distraction also concerns young people, that it “concerns me!”. The workshop should be an initial impulse to thinking about and dealing with this topic. This is especially important as young people participate in traffic more and more on their own.

The workshop is offered for senior high schools, vocational schools and polytechnic institutes. It takes place at schools, in the class rooms, and lasts for 100 minutes (this is two teaching lessons). The workshops are held by selected and specially trained moderators (female and male traffic educational experts).

The aim of the workshop is to raise awareness and to enhance knowledge, hence the moderators provide various information on distraction, give numbers and show examples of risks. The adolescents can relate the learned to themselves and their lives through their own previous experiences of distraction. To ensure consistent content and quality, the moderators use a standardized power point presentation including triggers for discussion. Furthermore, there is a screenplay about presenting the arguments, and using activating elements like videos, discussion, quiz and exercises. A big advantage of the workshop is also its attractive design.

Within the workshop, it is defined what distraction means, what its consequences might be and how it can be prevented. During the workshop, young people experience distraction by small exercises, learn about the myth of multitasking and of legal aspects and consequences of distraction in traffic.

The workshop starts with a video clip to catch students’ attention. The video helps to get access to the topic. The young participants are then asked to talk about their own experiences—thus they get involved step by step. As young people experience distraction in traffic quite often, they are able to broadly discuss on the definition and on elements of distraction. To show the scope of the problem, the moderator also provides information and numbers about distraction concerning different modes of traffic participation. This helps to identify distraction as a key problem for different user groups. Within the workshop, the students have to do several exercises in which they have to observe and classify others’ behavior. There is also one exercise on self-experience regarding inattention. The general approach of the workshop is to give information (sometimes a bit humorous), but not to scare young people as this could result in that they avoid further information and discussion.

Although the workshops’ aim is to raise awareness and not to prepare behavioral strategies, at the end of the workshop, the young people should express one intention they want to adopt for their own behavior in traffic.

They can write it down on a small give-away-card, which they receive as a reminder on the workshop.
To successfully adopt new knowledge and to learn, it is important, that a measure is accepted (Four Levels Model by Kirkpatrick & Kirkpatrick, 2006 [1]). If the youngsters like the workshop, there is motivation for more, e.g. to hear the arguments, think about it and maybe change own attitudes and behavior.
In order to further improve the workshop and tailor it to the needs of young people, an evaluation was carried from March to June 2016. At the end of the workshop, the young participants and the moderators filled in a feedback form. The questions covered the overall assessment of the workshop, if the moderator did a good job, if there was new information for the girl/the boy, if she/he would recommend the workshop, what she/he liked most and what should be improved. More than 1,000 questionnaires were filled in and analyzed.
The feedback both of the participating students and of the moderators was very positive. Overall, 63% stated to have learned something new within the workshop and the majority (88%) would recommend it to others. The 50 moderators indicated that the attending students were very motivated and contributed actively throughout the whole workshop.
93% of the young people said that the amount of contents fitted perfectly. They enjoyed videos the most. 73% would not change anything, an additional 10% even wished for more time and contents. Slight adaptions in the workshop were made due to this feedback.
All over 2016, 280 workshops took place in schools all over Austria. Due to the positive feedback, the workshop is now available for all interested schools in Austria. The workshop can be booked on demand. The number of workshops per year is limited now, as the funding is restricted. The high number of workshops nationwide means a broad coverage of youth throughout different school types for this important topic.
As the measure is attractive, it is supported and asked for by schools. From 2017 onwards, every interested school in Austria can order the workshop free of charge and—as lots of schools detected the increasing smartphone use as a problem—the demand is high.

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Extended Abstract for the 6th International Conference on Driver Distraction and Inattention (DDI2018)

Road Safety Campaigns as a countermeasure to reduce inattention and distraction

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Keywords: Advertising; Driver distraction countermeasures; Inattention; Road safety campaigns

Aim and scope

The importance of distraction and other types of inattention as contributing factors in road crashes has been clearly documented. There are many countermeasures to reduce inattention in drivers; influencing and changing drivers' attitude and behaviour is one of them.
The Norwegian Public Roads Administration (NPRA) has used campaigns in their safety work for many years and has developed a targeted and systematic strategy of working with campaigns based on knowledge and quality.
Based on the accident statistics and focus on preventive road safety work in a society with increasing technological advancements, we were assigned to develop a campaign that addresses road safety problems due to inattention and distraction.

Background

Research on risk behaviour and high-risk groups in traffic clearly shows that factors such as distraction and inattention are important risk factors and a significant traffic problem. There is evidence that this is a significant problem. Accident statistics in Norway indicate that distraction and inattention is a risk factor in almost one third of the serious accidents (Sagberg, Høye and Sundfør 2016).
Driving is a complicated and complex task that requires attention from the driver. Being focused and aware of traffic is a prerequisite for a safe transportation system. A driver has a responsibility to be attentive while driving. This is emphasized both in the legislation and in driver training in Norway. Nevertheless, we see that inattention behind the wheel constantly occurs: We "do not drive a car while driving a car", but pay attention to or engage in other activities.
There are two factors that determine whether a competing "side activity" contributes to accidents. First of all it depends on how dangerous the activity is. Secondly, the frequency of the activity is crucial. Even though the activity in itself may not be particularly distracting, the activity may be performed often (by many people) or over a long period of time, which may increase the likelihood of accidents to a level similar to a much more difficult activity performed less often (NHTSA 2010).

Research

To better understand the problem and to identify the extent of inattention and distraction as a risk factor in Norway, four research studies were conducted: Sagberg and Sundfør (2016), Phillips and Sagberg (2016), Sagberg, Høye and Sundfør (2016) and finally Opinion (2017).

Materials and methods

Report 1481/2016 from Institute of Tranport Economics (TØI); performed a literature review as well as a survey in a Norwegian sample (n=4115). TØI report 1535/2016 analysed all road fatalities in Norway during 2011 – 2015, based on data from in-depth analyses from the Norwegian Public Roads Administration. The last study was a national qualitative research project aiming at exploring attitudes regarding inattention and distraction in traffic (N = 88, recruited from four cities in Norway.) The respondents were both genders and of different ages and life stages. The data collection methods were in-depth interviews, in pairs, triads and focus groups.

Important findings

The literature review (Sagberg and Sundfør 2016) shows that the highest risk is taking the eyes off the road. Two seconds seems to be a critical limit for looking away continuously from the roadway, before the risk of safety-critical events increases substantially. However, looking ahead is no guarantee that the driver is attentive. It has been clearly demonstrated that “looked but failed to see” is a common explanation after road crashes. Various aspects of mental load and cognitive distraction may explain this phenomenon.
Estimates in international research regarding the amount of inattention as a risk factor in accidents vary and depend, inter alia, on the methods used and the types of accidents that have been observed. In regard to distraction, the estimate is 13 - 26%, but it is likely that the range is closer to 30% than 20% for inattention and distraction when seen together.
It is also a tendency for the incidence to be highest in the most serious accidents. In Norway, inattention has contributed to almost 1/3 of all fatal accidents with motor vehicles in the period 2011-2015 (Sagberg, Høye and Sundfør 2016). In other words, the prevalence is large and countermeasures are necessary. There is reason to believe that the problem may increase in the future, due to the development of technology in vehicles and the increasing use of nomadic equipment.
Research shows that the reasons for distraction and inattention in traffic are many. Many people think the use of cell phones is highly risky and an important priority area. Texting is an activity that is very dangerous, but very few people do, however, text while driving. International studies show that texting increases the risk of an accident between 22 and 164 times the normal risk, but most surveys show that the actual number of accidents caused by cell phones is less than 1% of the accidents (Sagberg and Sundfør 2016). In the analysis of the Norwegian accidents (fatal accidents only), the use of mobile phones was involved in 2-4% of the accidents (Sagberg, Høye and Sundfør 2016). In other words, the problem exceeds mobile phones. There are many activities that may lead to inattention. Therefore, to work in a comprehensive and preventive manner and reduce inattention as a traffic problem, it is important to see the complexity of the problem.
The qualitative research indicated people’s knowledge and attitudes to inattention and distraction, and their own behaviour in this regard. Knowledge or awareness is not necessarily high or in accordance with perceived risk. Since different types of respondents were interviewed, in various geographical areas, several profiles or segments of drivers were detected. They will be included when developing the campaign.

Conclusion based on research

The results confirm the need for measures regarding inattentive and distractive driving. Additionally the results confirm campaigning as a good and valuable countermeasure.
The research has given a solid scientific platform for developing a national campaign.

National Campaign Strategy

Road safety campaigns are defined by the CAST consortium as:

“purposeful attempts to inform, persuade, or motivate people in view of changing their beliefs and/or behaviour in

order to improve road safety as a whole or in a specific, well-defined large audience, typically within a given time period by means of organised communication activities involving specific media channels often combined with inter-personal support and/or other supportive actions such as enforcement, education, legislation, enhancing personal commitment, rewards, etc." (Cast Road Safety Communication Campaigns, 2010)

The NPRA has used campaigns in their safety work for many years and has developed a targeted and systematic strategy of working with campaigns based on knowledge and quality. We have, based on international research, developed an overall National Campaign Strategy for our campaigns. This strategy provides a stable foundation for all our campaign work and makes our work more efficient. Each campaign has in addition its own tailored strategy.
Research shows that a campaign should combine several measures to be fully effective. Information alone will not be enough. A campaign should strive to combine other measures like enforcement, education and legislation in combination with communication. In combination they are more effective than when operating alone. Further, a campaign needs to be visible and long-lasting to be effective. Thus, all NPRA campaigns last for several years, often 4 years. A campaign also needs to be based on psycho-social theories of behaviour, including behaviour change theories and theories of social persuasion. Additionally, a campaign needs to be specific in regard to target group, objective, message and distribution. All campaigns are evaluated.
The National Campaign Strategy (NPRA 2013) will be the basis when the NPRA develops a campaign on inattention and distraction

Development process

Together with our advertising agency and media agency, we used the research as a basis for developing a strategy for the campaign. The strategy indicates the theoretical models, the objective(s) and target group of the campaign, media channels and timing etc. The strategy influences the production of relevant material and co-measures. The development process is still ongoing. Detailed information will be available in February/March.

Information material

The campaign will be launched in May 2018. The campaign will be presented and discussed at the conference. Evaluation of the launching will be available at the time of the conference. Evaluation of effect on attitude and behaviour will be conducted continuously through the whole 4-year campaign period.

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BY WHAT HUBRIS?

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Keywords: Accident, Automation, Failure, Hand-Off, Training

BACKGROUND

As Level 3 and 4 automated vehicles become increasingly common, automation failures and sudden handoffs due to coding errors, unanticipated events, or hacking will also increase. Despite some encouraging findings [1] we argue that some non-trivial percent of drivers will be ill-equipped to handle such situations. We demonstrate that, in three highly technological industries with better prepared operators and more rigorously designed and tested equipment, accidents and near misses still often occur during such failures and handoffs. We express our concern that specialized driver training is the only realistic solution to this problem, and that there is little or no evidence that this is taking place or contemplated. Finally, we propose a thought experiment to test this hypothesis.

THE PROBLEM

In industries as diverse as commercial aviation, aerospace, and nuclear power, crashes, accidents, and near misses (events) that occur are frequently a result of automation failures, handoffs that are poorly understood, or operator failure to understand the state of the automation – despite the fact that the actors in these fields are very well prepared to handle such issues. In addition to such failures and handoffs, and despite the fact that engineers, trainers, and human factors specialists in these industries plan for single, double, and even triple order system failures, there remain situations that are unexpected and undesigned-for. Through examples including the accidents at Chernobyl and Three Mile Island, the crash of Asiana flight 214 at SFO Airport, and the near disaster aboard the Apollo 10 spacecraft, we will provide concrete evidence to demonstrate these points. As a result of these conerns, we believe that our industry is acting with hubris to all but ignore this issue in the automobile realm.

How does the environment in these three highly technological fields differ from that of automobile driving?

In our three exemplar industries, operators:

- Are highly trained, for both normal and abnormal operating conditions...
  - But automobile drivers in the U.S., receive perfunctory training at best, and none for emergencies
- Are rigorously tested and licensed…
  - But the driver's licensing process in the U.S. does not measure critical driving skills; and the license is valid for at least 5 years, sometimes 10.
- Follow specific procedures that cover both normal and off-normal operations…
  - Automobile drivers follow no procedures while driving, save for the "rules of the road."
- Are medically examined regularly, and must be medically fit to maintain licensure…
  - Drivers are given a standard eye test that measures only static visual acuity, and must meet no continuing medical standards.
- Must demonstrate proficiency in a provisional capacity at the hands of a senior instructor before being permitted to operate…
  - The provisional ("Graduated") license for teens is generally overseen by parents, not experts, and it relates more to time behind the wheel than it does proficiency.

- Undergo periodic retraining and retesting…
    - For drivers, no retraining or retesting is required, except over a certain age.
- May not work if they are under the influence of drugs or alcohol...
    - In the U.S., the BAC limit for driving is 0.08 percent; and there is no specified limit (or test) for drugs. Little random testing is done, and no regular testing.
- The number of operators on duty is typically a team of two or more. In the event of automation error or failure, the problem can be managed by others...
    - Drivers are often alone in their vehicles, and the presence of passengers is rarely of assistance.

In our three chosen industries:

- The equipment being operated is all of a specific type, (e.g. Airbus 380). The operator is “type-rated” and operates only that specific system…
    - The automobile may be any of dozens of brands, hundreds of models, and vehicles on the road may be 20 or more years old, and poorly maintained.

- The equipment being operated is maintained rigorously…
    - Although some states have minimal maintenance requirements, many, including the largest, have none.

- The time scale of unfolding events demanding attention may be minutes or hours…
    - Drivers typically have at most a few seconds to address an impending crash.

- There are comprehensive operating manuals that cover both normal and abnormal operations – manuals that must be read and understood in order to perform the required operations…
    - Even the once ubiquitous owner’s manual is no longer made available to drivers; it has been replaced by online documentation that may or may not be reviewed. And there is no requirement that the operator possess any familiarity with vehicle operating procedures before taking the wheel.
- The software in aviation, aerospace, and nuclear power is typically quite stable over time, and when changes are made, operator retraining is performed prior to the update being placed into service…
    - In automobiles, software updates may occur whenever the manufacturer deems it appropriate (e.g. Tesla), and there is little if any concomitant operator training, thus adding to the likelihood of some unexpected outcome or loss of system reliability.

As has been described elsewhere, with Level 3 and 4 automation drivers are expected to operate in a “hands off” manner, but are also expected to remain alert and attentive in the event of an automation failure or handoff requiring rapid response.

For all of the reasons listed above, we posit that automation failures or handoffs will be present within the automobile population and that drivers may be ill-equipped to respond to them, especially when compared to operators in the other three industries cited. We further posit that these risks are not being adequately addressed, and that most research is being directed at driver acceptance of automation rather than driver understanding of, and response to, such automation when it fails or turns over control to the driver.

In short, this paper demonstrates that, for drivers, few, if any, of the features and benefits that accrue to operators in these three industries is present, and the time scale of unfolding events that may need attention is generally much shorter. Given the documented history of events in these highly controlled and regulated industries, we suggest that it is with considerable hubris that we pay so little attention to these risks to public safety in our domain of the automobile.

A THOUGHT EXPERIMENT

Finally, we propose a thought experiment, in which we hypothesize that, because of societal, social, manufacturing, and cost constraints, the only realistic solution to the problem is specific operator training in the operation, use, (and misuse) of the vehicle's automation, prior to delivery of a new vehicle to its owner. Specifically,

- We can't or won't change the vast majority of factors that lead to the potential for these errors in the automotive world:

- The diversity and variety of vehicles in the traffic stream
- The wide variety of software applications and solutions applied to cars
- The time period available for response to malfunctions or automation handoffs that may occur on the road
- The medical qualifications of drivers
- The testing and licensure process
- The diversity of the driver cohort
- The procedures and ground rules to be followed by drivers

And while we can't afford to train drivers to the levels of astronauts, pilots, and power plant engineers, we can train them in the basics of response to automation and how to respond to automation failures or handoffs. As automobile owner's manuals are disappearing, being replaced by computer media or online manuals, even driver training may be thought of as deteriorating. Thus, some specialty training in the use of a vehicle's automation, and how to quickly respond if the automation fails or gives a hand-off, may become critical for the reduction of crashes in the automation near term future.This training could be addressed by part-task simulation.

The proposed thought experiment is designed to test the hypothesis that such training can improve the likelihood of a successful outcome when the automation fails or requires a sudden hand-off to the motor vehicle operator. Of course, even dedicated training cannot solve the issue of impaired or distracted drivers. But for the "alert and attentive" driver (the "gold standard" in legal cases), such training could go a long way to reducing the likelihood of crashes related to automation issues.

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Exploring Drivers' Visual Behaviour During Take-Over Requests

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Keywords: Visual Behaviour; Transfer of Control; Highly-Automated Driving

EXTENDED ABSTRACT

The potential to engage in distracting in-vehicle activities is recognised as a major contributor to driver demand during manual driving, and comprehensive guidelines have been published and widely adopted as industry best practice (e.g. [1]). These aim to guide the design and evaluation of in-vehicle devices and tasks, whilst discouraging those that are deemed to be too visually and/or manually demanding. Such guidelines do not currently apply to HMIs and devices employed during automated driving. This is understandable, if you consider that the 'driver' is not in control of their vehicle, and therefore cannot be distracted. However, this statement only holds true in a fully-autonomous vehicle, where the driver is completely removed from the driving task and would not be expected to resume manual control at any time. While the driver remains within the control-feedback loop to some extent (i.e. during intermediate, or 'semi-automated' driving states), the risks associated with driver distraction are likely to remain.

The focus of a driver's visual attention during a take-over request (TOR) (i.e. when a request is made to transfer control from the automated system back to the driver) is therefore likely to be important, but it is currently unclear what constitutes 'appropriate' behaviour in this situation. For example, a 'takeover-HMI' can assist drivers by alerting them of the imminent need to take control, making them aware of potential hazards, and explaining the behaviour of their vehicle – factors that are critical in re-establishing situational awareness. However, engaging with the takeover-HMI requires that some of a driver's visual attention is directed towards this (rather than road) during the hand-over of control. This causes a potential conflict: if a driver's attention is directed towards the HMI, they may be distracted from critical events occurring in the real-world (outside the scope of the HMI), that may be better attended to first-hand. This suggests that HMIs associated with TORs have the potential to distract drivers, and should therefore undergo some form of distraction assessment. However, although recognised distraction thresholds for manual driving are based on well-understood metrics, and substantiated by extensive naturalistic driving data [2], no equivalent body of empirical data exist for hand-overs. Consequently, defining what constitutes 'appropriate' visual behaviour during a take-over request – and how this translates to acceptance criteria – is as yet unclear.

Method

To explore where drivers are naturally inclined to direct their visual attention during take-over requests, and provide empirical data to inform the debate, we examined drivers' visual behaviour immediately after a request had been issued to resume manual control

Figure 1. Driving simulator and congested motorway scenario used during study.

following a period of automated driving. Sixty-four drivers undertook episodes of highly-automated driving on a congested motorway scenario in a medium-fidelity driving simulator (Figure 1). The simulator was modified to mimic a vehicle with 'traffic-jam assist' proximity sensing and control. The technology underpinning such systems is already well-established, comprising adaptive cruise control and lane keeping technologies, and enables 'highly-automated' driving in congested road situations (i.e. 'traffic jams'). Such systems therefore rely upon the presence of other road users in the host vehicle's proximity, as well as lane mediation lines, to determine primary control actions.

Drivers were asked to resume manual driving from the traffic-jam assist system in four different TOR use-cases (Table 1). Each use-case was supported by a bespoke TOR-HMI (comparable between use-cases), providing an ego-centric visual depiction of the host and nearby vehicles, and the roadway ahead. In addition, drivers were provided with a text-based statement (presented on the screen) describing the behaviour of the vehicle and the required input from the driver. Finally, a count-down indicated when drivers would need to intervene. Drivers were notified of any changes or updates to the HMI via an auditory tone.

Participants completed two types of journey for each use-case – firstly, while engaged with a distracting secondary task/device (an immersive game on an iPad, demanding visual, manual and cognitive attention) ('Distracted'), and secondly, when they were encouraged to maintain vigilance with the driving scene and system monitoring task ('Not-distracted'); conditions were counterbalanced. During both drives, participants were aware that they may be required to resume manual control, given 'appropriate' notice (in line with the definition of 'highly-automated' driving [3]). Participants wore SMI eye-tracking glasses (ETG) to capture eye movements throughout the study. To ease the burden on participants, and avoid

Take-Over Request	Example	Details
Unexpected-Non-Emergency (UNE)	Loss of lane markings/traffic dispersal (where the automated system relies on these features to guide the vehicle).	5.0s hand-over with no associated braking, i.e. car coasts until driver re-engages with the primary controls.
Unexpected-Comfort Brake (UCB)	Minor sensor failure.	5.0-second hand-over, with 'comfort' braking.
Unexpected-Emergency Brake (UEB)	Critical system fault.	5.0-second hand-over, with emergency braking.
Expected-Non-Emergency (ENE)	Vehicle approaches part of the route that does not support automated driving, such as exiting from the motorway.	50-second hand-over, accompanied by a further 'take control' request delivered 15.0s prior to hand-over.

Table 1. Take-over request use-cases investigated during the study

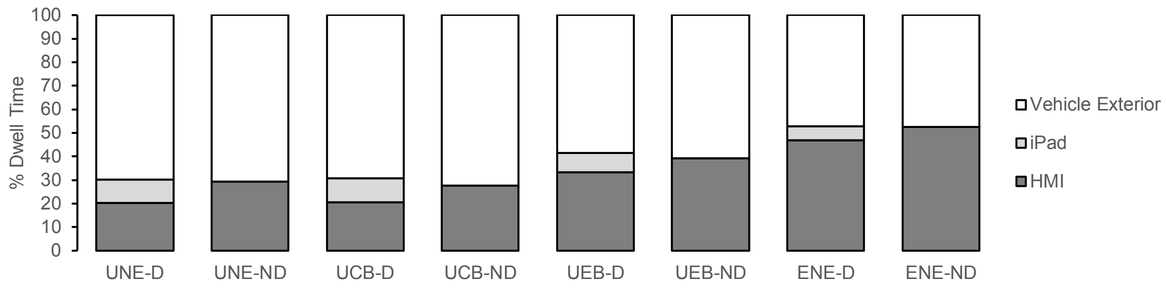

Figure 2. Percentage dwell times for each use-case (D=Distracted, ND=Not-Distracted)

multiple repeated TORs in short duration, the research was conducted as four separate, self-contained mini-studies (each employing 16 participants), and thus, results are effectively presented as 'between-subjects'.

Results and Analysis

Visual behaviour was analysed using semantic gaze mapping, with areas-of-interest (AOIs) comprising the 'take-over HMI' and 'iPad' (where appropriate) ('off-road'), and 'vehicle exterior' ('on-road'). The focus of the investigation was to consider how drivers shared their vision between the vehicle interior and exterior during the TOR, and as such, visual dwell time (rather than individual glance data *per se*) is presented (Figure 2).

A repeated-measures ANOVA comparing the percentage dwell time 'on-road' and 'off-road', shows that there were significant differences between use-cases ($F(7,105)=7.96$, $p < .001$), with drivers directing a significantly lower proportion of their vision 'off-road' for UNE and UCB, compared to both UEB and ENE. Given that UEB involved emergency braking, it is possible that drivers in this situation were seeking further information regarding why their vehicle had suddenly braked (i.e. what had constituted the emergency) – it is interesting to note that they attempted to acquire this information from the HMI and not from the 'real-world'. Similarly, drivers spent significantly longer (proportionally) with their attention directed inside the vehicle (towards the HMI/iPad) during the extended hand-over (ENE). In this situation, drivers may have expected further information regarding the impending hand-over (additional route guidance etc.), and felt there was adequate time to acquire this from the HMI before resuming manual control.

It is also evident that when drivers were actively engaged in a secondary task ('Distracted'), they continued to devote significant visual attention to this (i.e. to the iPad), perhaps to finish their current game, even after the take-over request had been made (on average between 6 and 10% of the time). Moreover, there were no significant differences between the proportion of vision directed 'off-road' and 'on-road' during Distracted and Not-Distracted conditions for each use-case. This shows that the time spent attending to the secondary task during the TOR was at the expense of attention directed to the HMI, and not to the external road scene, suggesting that there was a 'natural' balance between vision directed inside and outside the vehicle during each TOR, with drivers generally directing more attention externally (circa 70% of dwell-time for UNE and UCB).

Although it remains unclear from these data how drivers' visual behaviour during the hand-over impacted on their ability to actually resume control of their vehicle, or their subsequent driving performance (see: [4] for a detailed comparison), a clear implication of the findings is that the take-over HMI is an important factor (in terms of design and content) during take-over requests, and should therefore be considered with respect to potential distraction effects.

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Cognitive Workload and Personality Style in Pilots
Heart Rate Study

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Keywords: Cognitive Workload; Conscientiousness; ECG; Flight Simulation; Neuroticism; Personality.

EXTENDED ABSTRACT

Introduction

The cognitive overload and emotion experienced by drivers become a primordial issue to study distraction. This is also the case in aviation, where pilots are commonly exposed to different sources of cognitive and emotional stressors and distractors [1]. Therefore, the integration of an online monitoring to assess the cognitive variations into the cockpit would be highly desirable to alert of delicate mental states. To this aim, reliable physiological measures are required. Electrocardiography (ECG) can be considered as one of the most suitable and cost-effective techniques providing powerful and relevant features to study driver distraction and cognitive workload [2, 3]. Heart rate (HR) and heart rate variability (HRV) parameters extracted from ECG signals are employed in aeronautics to determine the impact of different levels of mental overload in performance and decision-making [4, 5]. According to their findings, an increase in HR together with a decrease in HRV will be expected when cognitive workload becomes higher.

Furthermore, the personality is an important factor to take into consideration for drivers and pilots [6, 7]. Several research works have indicated a particular personality profile in pilots, whose neuroticism component is significantly lower than the population norm [8], while they score higher on the conscientiousness facets [9]. Given that physiological responses in general, and the cardiovascular activity in particular, are affected by personality traits [10, 11], it is important to consider this issue in order to better control individual differences and to reach a fine-grained interpretation of the ECG measures linked to the pilot distraction produced by a supplementary task simultaneous to the flight. In this pilot study, the HR modulation susceptibility to arousal level elicited by a social stressor and the cognitive workload is study in 21 private pilots.

Materials and Methods

Twenty pilots (only male; 22.7 ± 3.7 years) participated in the study. ECG signal was recorded (sampling rate = 1 MHz) along the whole experiment by BrainVision Recorder 1.21 (© Brain Products GmbH, Gilching, Germany). The experiment took place in an AL-50 simulator and consisted in two dual-task scenarios which required the simultaneous accomplishment of a pre-established flight plan and a secondary task based on target stimulus discrimination. During the first scenario, pilots were alone to accomplish the task, whereas for the second one, we modulated emotional state similarly to [12] by the filming the participant and involving him in a competition with the other participants.

Both flight scenarios lasted approximately 35 minutes and were analogous in term of difficulty. A strict timing for the flight instructions was specified. Speed (measured in knots), heading (degrees) and altitude (m) parameters were collected during the simulations (sampling rate of 1Hz). The performance was considered as acceptable when the deviations of the expected parameters fell into a margin. Any deviation greater than ±5 units, from the requested flight parameter, was counted as an error. The secondary task consisted of pressing a 7 inches touch-screen as quickly as possible after hearing some isolated numbers integrated among unrelated Air Traffic Control instructions. The task was presented during the cruise and subdivided in two inter-subject counterbalanced phases 12 minutes: Low Cognitive Workload (LCW) phase, where the participant was instructed to press the screen if the heard numbers meet a simple attribute (magnitude or parity); High Cognitive Workload (HCW) phase, where the attribute depended on the color of the numbers displayed on the screen.

All the participants completed the Neuroticism (N) and Conscientiousness (C) subscales of the French version of the Big Five Inventory personality dimensions scale [13]. For each subscale, participants indicated how accurately 9 traits described them on a 5-point scale, ranging from 1 (very inaccurate) to 5 (very accurate). The responses were averaged to obtain the neuroticism and the conscientiousness levels. By combining these dimensions, we were able to identify two different groups into the impulse control personality style [14]. An analysis of variance (ANOVA) of repeated measures was performed: 2 levels of cognitive workload: LCW and HCW, 2 levels of arousal: High and Low and one between-subject factor: personality style (2 levels). Post hoc analysis was based on HSD Tukey's. The cluster analysis to determine the membership of the two personality style (according to neuroticism and conscientiousness simultaneously) groups was based on a simple *K*-means algorithm ($K = 2$) with random center value initialization and setting a maximum of 10 iterations.

Results

Globally, a main effect of cognition was found for HR: $F(1,19) = 4.56$, $p = .046$, $\eta_p^2 = .19$, showing a greater value for HCW ($M = 86.55$ bpm, $SD = 15.18$) compared to LCW ($M = 85.14$ bpm, $SD = 15.47$) condition ($p = .013$). No main effect of arousal and no interaction between cognition and arousal were statistically significant analyzing the whole group.

The centers of the personality style clusters are showed in Table 1. The *group 1* (higher level of neuroticism and lower conscientiousness: N+C-) and the *group 2* (lower level of neuroticism and higher conscientiousness: N-C+) are composed of 9 and 11 participants, respectively.

Table 1. Centers of the personality style clusters considering two personality traits

	Neuroticism (N)	Conscience (C)
Group 1	2.20	3.39
Group 2	1.64	4.52

No main effect of personality group was found in HR. However, an interaction linked to cognitive workload was statistically significant: ($F(1,18) = 7.96$, $p = .01$, $\eta_p^2 = .31$). Post hoc analysis confirmed a significant increase between LCW ($M = 81.48$, $SD = 15.10$) and HCW ($M = 84.64$, $SD = 16.55$) in HR for group 1 only ($p = .007$), while the HR values for group 2 remained stable (see Figure 1). According to the cluster analysis, it seems that HR modulation due to cognitive demands was more remarkable for pilots scoring higher in neuroticism and lower in conscientiousness (N+C-) (Figure 1). No interaction between personality style and arousal level was found.

Figure 1. Means ± standard error of HR for Low and High Cognitive Workload for the two groups of participants (Group 1: N+C-; Group 2: N-C+). ** $p \leq .01$.

Discussion

As expected, HR was higher when cognitive workload increased, despite the surprising lack of arousal effect, arguably due to the safe simulated environment where a veritable vital risk did not exist [15].

Although our participants demonstrated moderate scores on neuroticism, in agreement with the results reported by [8], the higher level of this trait together with a lower score of conscientiousness were sufficient to produce quantifiable effects on HR, with increased response to cognitive workload only in the group 1 (N+C-), consistently with previous research works [11]. The group 2 (N-C+), remained unaffected by cognitive workload variations, with globally higher HR values than the group 1.

Most likely, pilots scoring higher in neuroticism and lower in conscientiousness better adapted their effort to the difficulty of the task (lower HR when task was simple, higher HR when task was more complex). Another interpretation of the result would be linked to the conscientiousness, since pilots with higher level of this trait could keep a higher level of vigilance over time, as evidenced by faster HR [16]. Therefore, even if neuroticism is the least dominant personality trait in pilots [17], this result is relevant to implement the interfaces of highly automated aviation system where the operator mental state is crucial to react to certain situations [18].

Interestingly, knowing which personality traits show greater physiological adaptability to cognitive workload variations can be useful to take into consideration in the selection of future pilots as well as in the application in similar contexts like the emerging autonomous vehicles. However, the limitation of the relatively small sample size leads us to be cautious with our conclusions. It would be desirable to complete the study in a larger population and to analyze the HRV parameters to complement HR.

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Driver cognitive workload estimation through cardiovascular activity: a working memory approach

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Keywords: Cardiovascular activity, cognitive workload, dual task, visuospatial sketchpad, working memory.

EXTENDED ABSTRACT

Introduction

The present work investigates the cardiovascular activity linked to the cognitive workload induced by the realisation of a supplemenary mental task to driving in a simulator. Specifically, heart rate (HR) and heart rate variability (HRV) are computed to establish the physiological modulations under different types of cognitive demands in order to identify indicators to monitor driver state.

Given that driving is a complex task where the executive functions requiring memory, visual attention, decision-making and flexibility are required [1], the study of concurrent tasks sharing the same cognitive resources is crucial to assess driver's mental workload and performance. For instance, to determine the influence of driver's distraction on driving performance, different additional tasks such as conversation and mobile handling in a real-setting have been employed in previous research works [2]. On the other side, mental arithmetic tasks have been largely employed to increase cognitive workload to analyze distinct aspects of driver behavior [3].

To disentangle how different cognitive workload categories and psychological processes impact driver physiology, this study, based on the Baddeley's model of the working memory (WM) [4], explores the differentiated effects of two cognitive mechanims: listening associated or not with mental processing. According to this model, there are four subdivisions composing WM: the phonological loop which is involved in our ability to maintain and process verbal information, the visuospatial sketchpad responsible for mental image manipulation, the episodic buffer which relays between WM and long-term memory and the central executive for the administration of the three other subdivisions. Moreover, the concept of sensory memory is considered as a primary information processing stage [5]. Specifically, the echoic memory, which is a short-term storage of auditory information, is relevant for auditory distraction.

Besides the behavioral data, other objective markers are desirable to monitor driver's cognitive workload and to foresee potential risky situations. One of the most sensitive and cost effective measure to this aim is the electrocardiogram (ECG). In [6], HR increments with increasing task demand, manipulated by means of an "N-back" task, while driving. These results are corroborated by several studies on the topic. Furthermore, the temporal HRV parameters are suggested to be suitable for the identification of instantaneous stress indicators [7]. Indeed, HRV is pointed as an accurate marker of emotion-regulatory ability [8]. Following this line, the present study aims at complementing the results reported in [9], where the authors were interested especially in evoked cardiac response, by analyzing more deeply the links between WM components, mental arithmetic and cardiac signals within longer time periods.

Materials and method

Eighteen healthy subjects (10 males, 22.7±1.4 years) were recruited via an online procedure. All participants presented normal or corrected visual acuity and none of them had a history of cardiovascular diseases. A valid driving license for at least 3 years was required. All participants were asked to sign a written consent and agree to no financial compensation. Between 6 and 8 participants had to be removed from the different statistical comparisons due to technical problem during the recording.

The driving simulator consisted of a Peugeot 308 surrounded by seven video projection screens. Participants drove in straight lines and curves in an urban residential zone with sparse traffic. The vehicle was equipped with a manual transmission, and the steering wheel had a force feedback system. The ECG signal was recorded by MP150 Biopac system. The heart physiology parameters used were the HR, and the root mean squared standard deviation of the differences of successive normal-to-normal intervals (RMSSD) [10]. All collected data were analysed with Matlab, using the toolbox *HRVanalysis* [11].

The participants performed different tasks of 4-minutes length: a passive listening of "beeps" (beep listening -BL), a beep counting (beep processing -BP); a passive listening of direction instructions (word listening -WL) and a mental displacement within a previously memorized 5×5 grid following the direction instructions and including an arithmetic task (word processing -WP). The participants carried out these tasks as single tasks (ST) as well as simultaneously to the driving task (DT). The protocol is explained in detail in [9].

Four statistical analyses of variance (ANOVA 2×2) were conducted by using SPSS 13.0 software. Every ANOVA was constituted by two factors, the first one was always the driving (levels: DT and ST) and the last one permitted us to study different WM components as follows. First, BL vs. WL levels permitted us to study the contribution of the phonological loop. Second, BL vs. BP corresponded to the cumulated contribution of the phonological loop, which was necessary to mentally repeat the last heard number, and the episodic buffer that allow the updating of the information (the "plus one"). Third, WP vs. WL allowed the study of the cumulated contribution of the episodic buffer and the visuospatial sketchpad. Finally, the contrast between BP and WP permitted the study the contribution of the visuospatial sketchpad (see Fig. 1).

Results

Concerning HR, a main effect of driving was found (between DT and ST conditions) for all the ANOVAs ($p \leq .01$), showing an increase of HR for DT (Table 1). Moreover, a significant main effect was evidenced between WP and BP condition ($p < .001$), with an increase of HR for WP (Table 1).

		BL	WL	BP	WP
HR	ST	81.9 ± 15.8	79.9 ± 12.0	76.2 ± 11.5	83.0 ± 13.2
	DT	90.8 ± 19.4	87.6 ± 14.9	83.2 ± 12.5	88.1 ± 13.5
RMSSD	ST	39.3 ± 25.6	41.5 ± 20.8	44.6 ± 24.0	39.9 ± 21.0
	DT	39.6 ± 28.9	33.9 ± 22.1	35.2 ± 19.1	32.6 ± 17.6

Table 1: HR and RMSSD values (Mean ± SD) for every experimental condition (see section "Materials and method").

Concerning RMSSD, a main effect of driving was found only when WP condition was included in the ANOVA, i.e. between BP and WP conditions ($F(1,12) = 14.2$; $p = .003$) and between WP and WL conditions ($F(1,11) = 8.60$; $p = .014$). For RMSSD a main effect of the cognitive workload was evidenced between BP and WP condition ($F(1,11) = 7.99$; $p = .016$), showing that RMSSD decreases when the cognitive workload increases (Table 1).

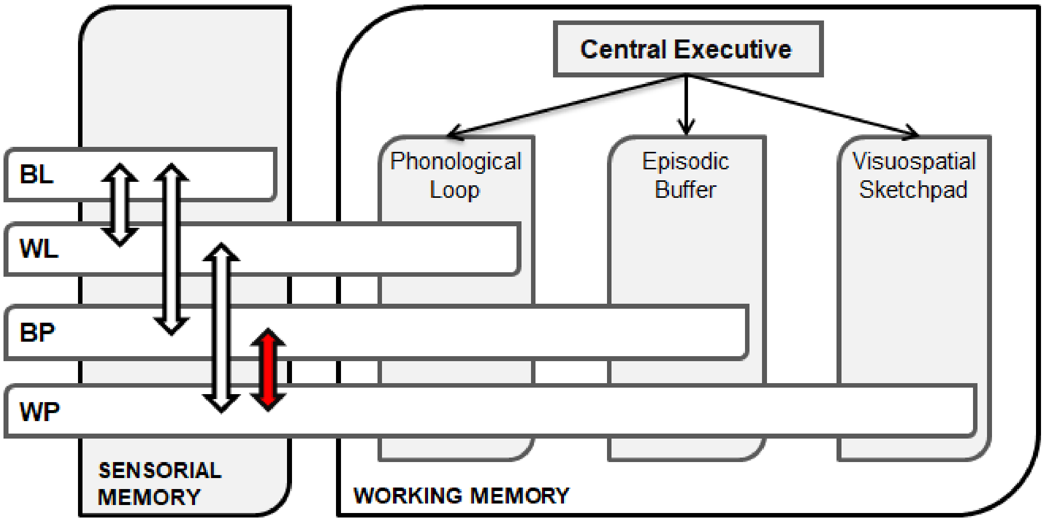

Figure 1: Working memory components involved for every experimental condition. BL: Beep Listening; WL: Word Listening; BP: Beep Processing; WP: Word Processing. The arrows represent the comparisons between different conditions, the darkest one representing the significant difference between BP and WP (visuospatial-semantic effect) on both HR and RMSSD. The working memory model is based on Baddeley's model [4].

Discussion

The aim of this study was to highlight the type of additional task which impacts significantly HR and HRV. As expected, results show that driving actually increases HR. However, although higher HR could be associated with increased cognitive workload in driving, as reported in other works [6, 10], it is important to take the contribution of driving motion into account [12] because it could bias the results. In our case, HRV might be less sensitive to movements, as there were not always significant differences between DT and ST.

In addition, there were significant differences between WP and BP both for HR and HRV, illustrating the impact of maintaining the grid in the working memory. The driving situation requires a high level of cognitive resources from the visuospatial sketchpad [13]. Therefore, the addition of a task, where the visuospatial sketchpad is also involved, can overflow the remaining available cognitive resources [14] generating a significant overload. Nevertheless, contrary to our expectations, there was no significant difference between WL and WP. This fact is probably due to the word meanings, which were direction instructions appealing, even in an unintentional manner, to the visuospatial sketchpad, as other research works hint [15].

Of note, the visuospatial displacement based on word instructions together with the mental arithmetic operation is arguably harder than counting beeps, which consist in a one-by-one update of working memory [9]. Thus, the modulation found on HR and HRV could not only be due to the visuospatial component, but also to the difficulty of the calculation.

Finally, according to the conservation of resources model [16], when cognitive workload increases, an induced stress appears, which activates an emotional regulation processes, manifested on a HRV reduction [8]. Our results are in agreement with these findings, suggesting an increase in the stress when participants are confronted to dual tasks involving similar WM components.

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Working towards a Meaningful Transition of Human Control over Automated Driving Systems

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Introduction

With the perpetual rise of vehicle automation technology, the call for human control over increasingly complex automated systems is becoming more urgent. The well-known six levels of automation, defined by the Society of Automotive Engineers [1], are scoped from a technical viewpoint, rather than a human viewpoint. With the levels ranging from level 0, the vehicle having no automation whatsoever, to level 5, the vehicle being fully automated under every condition, the human is expected to adapt to the system corresponding to its respective level of automation. As the level of automation increases, the human driver is gradually turned into a supervisor of an automated system. This paradigm shift has already been known to be less than desirable from other domains [e.g., 2, 3, 4], but currently still appears to be the leading identification of different levels of control of an automated vehicle.

Within the field of automated weaponry, the notion of *meaningful human control* has been coined [e.g., 5, 6], due to its ethical implications. This notion can easily be extended to the automated driving domain, where ethical dilemmas such as the trolley problem are becoming ever more realistic to consider. Especially when considering automated systems are far less easily accepted to be safe than a human driver [7], and fatalities are considered up to five times worse when made by an automated driving system [8]. Moreover, if we want to have automation to be beneficial (to the driver, the environment, or the world as a whole), for example in terms of safety, a Human Factors perspective is warranted [9, 10].

The current study aims to investigate the notion of meaningful human control over automated driving systems, by quantitatively assessing the role change of the driver, and propose a novel framework of levels of automation, from a human-oriented perspective.

Method

Adapting the human performance model of Rasmussen [11], an inventory was made of the required amount of skills, rules and knowledge a human driver is expected to have in order to be eligible for driving. Set against the six levels of automation, a matrix was designed showing the paradigm shift in absolute numbers in its current form.

The first step in achieving a quantified matrix was identifying the respective sets of skills, rules and knowledge required from a human driver based on basic driver training, as defined by European policy makers. These numbers formed the baseline of this study (i.e., level 0, or manual driving).

The set of skills has been derived from the Road Safety Charter working group [12], resulting in a total of 129 distinguishable skills. The set of rules has been derived from the Vienna Convention on Road Traffic [13], including its recent (March 23, 2016) amendment in light of the deployment of automated vehicle technologies, and resulted in a total of 254 distinguishable rules that apply to the human driver, either directly or indirectly. Driver knowledge, as defined by Rasmussen [11], first had to be specified in more detail, in order to be able to obtain a set to adhere to. According to Rasmussen's definition, knowledge-based behaviour entails the goal-controlled, in-situ planned and tested handling of an unfamiliar situation, and is thus only gained through experience. For novice drivers, this can even be basic driver skills or rules as they learn them [14]. For the sake of consistency, in this study, we adhere to basic licensed drivers. The set of knowledge-based behaviour can then be thought of as containing experiences from professional driver training. Note: The list of potential professional driver training courses is extensive, ranging from defensive training to armoured vehicle driver

training, and from special braking skills to driving in adverse weather conditions. The categorisation of the set of knowledge-based behaviour is currently still under construction. The following steps are therefore also in progress.
The second step will be to determine how many skills, rules, and knowledge applies during the various levels of automation. This will then provide us with an overview of the current state of affairs regarding human control requirements over automation.
The third step will be to develop a human-oriented ladder of levels of control. Several Human Factors experts in the automated driving domain will be asked to share their view on a meaningful, human-oriented transition of control towards full automation, based on the sets of skills, rules and knowledge collected in the first step.

Expected Results

On the one hand, a quantified framework of the current state of affairs regarding the required amount of human control over an automated driving system will be presented, while on the other, a newly developed framework of meaningful human control over automated driving systems will be proposed. The latter will entail a summarization of the experts' views on what they consider to be a meaningful transition of human control.
Next, the two frameworks will be compared, and critical mismatches between the two frameworks will be identified.

Preliminary Discussion

This study aimed at quantitatively assessing the current requirements of drivers regarding their levels of control over automated driving systems by adhering to Rasmussen's [11] model on human performance. Consequently, by using expert views on the matter, a human-oriented framework on control over automated driving systems is proposed.
The discussion in this study will be aimed towards the expected mismatch between the proposed, human-oriented framework, and the current technique-oriented framework as defined by the SAE [1]. Recommendations will be regarding guiding policy- and lawmakers, as well as industry, towards a human-oriented approach for the design of policies and laws, and automated driving systems. As the problem may occur that drivers of automated vehicles wind up in a state of underload [e.g., 15, 16] the paradigm shift that currently occurs appears misplaced. A meaningful distribution of human control over automated driving systems would avoid or at least minimize known Human Factors problems associated with automated driving systems, such as skill degredation, behavioural adaptation, and driver underload [see e.g., 9 for an overview], consequently making automated driving systems more like they are intended to, namely safer and more beneficial to all stakeholders involved.

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Considering the Chain of Meaningful Human Control in Vehicle Automation for Driver Inattention

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Keywords: automated driving systems, driver inattention, meaningful human control, vehicle automation

EXTENDED ABSTRACT

Scope and objective

Much has been made about the potential of vehicle automation to improve road traffic safety. Often references are made to stats like the more than 30,000 people killed each year on roads in the US [1] and an estimate that more than 90% of these accidents were caused by human error [2]. It is true that automated vehicles will never be drunk, distracted or fatigued, which is estimated to account for 41%, 10% and 2.5% of accidents in the US [3]. In theory well-designed fully autonomous vehicles should be able to eradicate many accidents caused by human error. However, full vehicle autonomy is not expected for many decades if at all [4, 5], therefore the main focus should solidly be on the transitional levels of automation in which a driver has to maintain some sort of control or at least be able to monitor and retake control if required. The area of ‘transition of control’ in partially automated vehicles has attracted a lot of attention. There is a growing consensus that drivers are not able to effectively maintain attention on a monitoring task for long periods of time and retake control in a sufficiently timely manner [6, 7]. Inattention and distraction plays an important part in this [6]. We therefore see that more tasks are transferred to vehicle systems with increasing automation, and logically a shift in the chain of control occurs. This shift means drivers retain or are given new tasks to carry out with uncertain levels of achievability due to limitations in attention.

Recently, a new path of thought in regard to vehicle automation has arisen that focusses on general human ability to maintain control over any level of automation: Meaningful Human Control (MHC) [8]. MHC originates from discussions regarding autonomous weapon systems, which are deemed to be required to remain within meaningful human control [9]. A generic paraphrase of the principle of MHC is that systems must preserve MHC over actions, that is: “... humans not computers and their algorithms should ultimately remain in control of, and thus morally responsible for relevant decisions about operations.” The transition of the concept to vehicle automation is a logical one, as with vehicles humans must also maintain generic control over a system that is there to aid mobility, but also has the potential to cause undesirable, unsafe or even dangerous situations. To understand how MHC can be maintained under different levels of vehicle automation, the chain of control must first be constructed. Thereafter it becomes easier to derive what the effects are of distraction and inattention and how these can possibly be addressed within the design of an automated vehicle system.

In this contribution we give a description of the main components of vehicle automation control and of the chain of control with a focus on the effects of driver inattention and how these may be addressed from the perspective of Meaningful Human Control. The conceptual framework of the automated driving system components is constructed based on the general consensus found in literature. The resulting analysis gives valuable tools to further research and understand MHC in vehicle automation to aid driver control in transitional levels of vehicle automation.

Conceptual framework of the automated driving system core-components

The core components are defined as the main components of importance per category based on the current accepted state of the art. Four categories are defined to aid the classification: Driver, Vehicle, Infrastructure and Environment. In some cases choices are made where there is no clear consensus in literature, to allow the classification to fit with the natural flow of control in ADS. The driver and vehicle categories are shown here.

By definition, driving behaviour has a direct influence on traffic flow and most of the resulting traffic flow phenomena. For this reason, the '**Driver**' is a key part of control in any driving system, and thus also a system that incorporates automated features. To fully describe the core driver components, driver traits and state is accompanied by driver performance, which comprises perception, cognition and action. The perception-cognition-action cycle results not only in the physical action performed by the driver, but also influences the driver's state (e.g., fatigued or stressed). The driver components are shown in Figure 1.

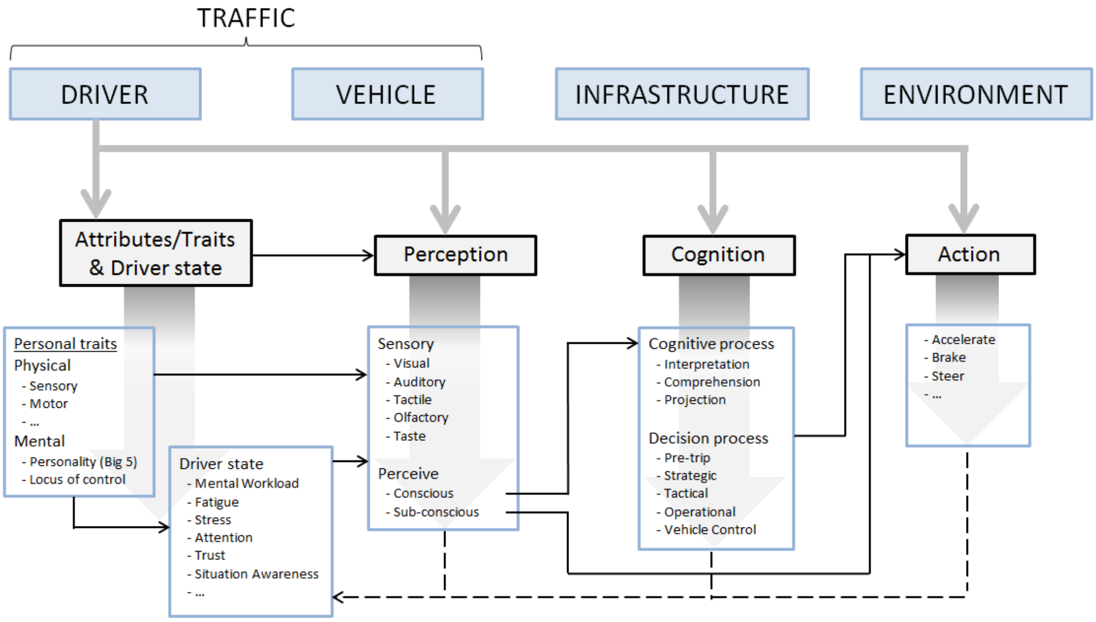

Figure 1. Driver core-components

The domain of automotive systems is well-established and there is a generally accepted classification of components of vehicles. At the generic component level a sub-division is made into the sub-categories: Sensing, Control and Actuation (see Figure 2). For a full description and full justification of the choices made in the construction of the framework and the underlying literature review, we refer to [10]. This will also be elaborated on in the full paper.

Chain of control for Meaningful Human Control of automated vehicles

In manual vehicles, the primary sensing systems and interfaces offer an overview of the current status of a vehicle. Some information is used by the vehicle itself for stabilisation, especially where driver assistance systems are present (e.g. cruise control, ABS, etc). However most of the sensing is relayed to the driver, who then takes actions based on the vehicle sensing in combination with the driver's perception of the environment and infrastructure to control the vehicle [11]. The driver's control actions translate to physical vehicle movement on the sub-category level of actuation. The type of sensing, control or actuation does not significantly affect the classification.

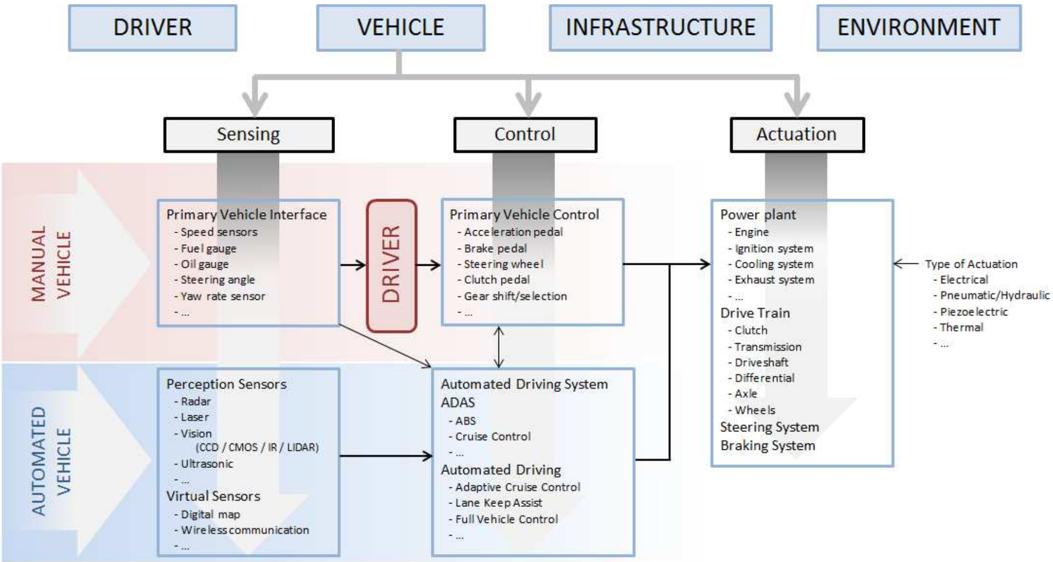

Figure 2. Vehicle core-components

For vehicles with some level of automated driving systems, additional components are present and the chain of control and interaction between components can be different. Additional sensing will often be present in vehicles with automation, primarily perception sensors, which can assist or take-over certain monitoring tasks from a driver. Also for higher level and cooperative automation, virtual sensors may be present to aid positioning and external information generation [12]. The automation control is fed by all relevant sensing components and can give feedback and interact with human control. The actuation from automated control is in practice no different from that of manual control on the generic level [11], although on a more detailed level there are additional connections from the control to the underlying sub-components that are not explicitly shown in this framework. In the full paper, more space is spent detailing the chain of control.

Addressing inattention by means of MHC design

With increasing level of automation, the role of the driver in the control loop decreases [13]. This consequentially reduces the attentional demands placed upon and the mental workload experienced by driver, which in turn reduces the attentional resource pools required, and leads to inattention [14-16].

The chain of control with higher automation levels shifts the place where MHC is applied from primarily the driver to increasingly the design of the Automated Driving System (ADS). This places various demands on both the system design and the driver performance. Firstly, the ADS must be designed to 'deal' with various situations described in its operational design domain in a way acceptable to the driver and to human intuition and acceptability. This also involves ethical considerations of choices made by the ADS [8]. Secondly, the driver's role also changes as they must interact with the ADS to exert MHC over a system for which physical operational control is only partially possible. This places design demands on the ADS and additionally on the driver's tasks.

In the full paper we will go into this in much more detail, however from this it should be apparent that many current perceived designs might lack in this regard to finding a balance between MHC through driver-ADS interaction, which in turn leads to inattention. We hope that the introduction of the aforementioned framework leads the way to turning the design process around to focus on full driver-ADS system design from the perspective of MHC. The presence of MHC does not necessarily demand the driver being in the loop, but does demand a consideration of how control is maintained in a desirable fashion.

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Studying the impact of negative mood-induced mind wandering on young male driving behaviour

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Keywords: mood, mind wandering, physiology, risky driving, young drivers, individual differences

Introduction

Road traffic crashes are the leading cause of death among youth worldwide [1]. Risky driving behaviours, such as speeding and tailgating, are responsible for the majority of road traffic crashes [2, 3]. Male drivers under 25 are especially prone to risky driving and are overrepresented in fatal injury crashes [4, 5]. While research has identified inexperience [6] and developmental factors [7] that contribute to crash risk, there are substantial gaps in scientific understanding concerning state and trait variables that can lead to risky driving in this population.

Risky driving results from complex interactions between affect, cognition, and environment [8]. For example, risky driving is more prevalent among those suffering from depression, which is characterized by negative moods, cognitive deficits, and rumination, as in repetitive thoughts about one's emotional distress and its circumstances [9, 10]. Rumination is a form of mind wandering, which encompasses spontaneous thoughts that are unrelated to ongoing tasks and the immediate environment [11–13]. Multiple studies have now linked mind wandering to crash responsibility [14, 15] as well as risky driving behaviours, such as increased speed, reduced headway distance, reduced visual scanning, and delayed responses to sudden braking events [16, 17]. Therefore, mind wandering may be partly responsible for the heightened prevalence of risky driving among those with mood disorders.

Negative moods can also trigger mind wandering in healthy individuals, which could contribute to risky driving. For example, one study used experience sampling on smartphones to show that negative moods tend to precede mind wandering during daily activities [18]. Another study revealed increased self-reports of mind wandering and more errors on a sustained attention task after inducing a negative mood [19]: previous research found that lapses in sustained attention can predict faster mean speeds among young male drivers in a simulator [20]. Additionally, compared to controls, dysphoric individuals show greater performance deficits and changes in heart rate accompanying frequent mind wandering during tasks [21], possibly signifying the heightened emotional salience of their off-task thoughts. Thus, negative mood-induced mind wandering may have a particularly detrimental impact on driving performance, which may be objectively detectable through physiology.

Individual differences in rumination tendency and executive control, a cognitive mechanism that directs attention to goal-relevant thought and behaviour, could moderate the impact of negative mood-induced mind wandering on driving behaviour. Driving performance benefits from greater executive control [22, 23] and numerous studies show that mind wandering interferes with this faculty [24]. Additionally, greater rumination predicted executive impairment among a community sample of undergraduate students following a negative mood induction, with those exhibiting low executive control at baseline being impacted the most [25, 26]. These findings suggest that negative moods may particularly impact driving performance for those with high rumination tendency and low executive control.

At the same time, research suggests that executive control is necessary for sustaining mind wandering [27]. For example, those with high executive control mind wander more when task demands are low compared to those with low executive control [28]. Thus, those with high rumination tendency and high baseline executive control (i.e., in a neutral mood state), may exhibit greater driving decrements after a negative mood induction. Taken together, these findings suggest that rumination tendency and executive control may moderate the extent to which negative moods impact driving performance via mind wandering, but it is unclear how these factors may interact.

Purpose

While research has linked negative moods and mind wandering to risky driving, it has yet to clarify the mechanism by which these factors may increase risky driving in the vulnerable young driver population. Our study seeks to determine whether negative moods increase the frequency of mind wandering and its impact on driving performance in healthy male drivers aged 20 to 24. Additionally, we examine whether greater physiological responses accompany greater driving deficits associated with negative-mood induced mind wandering. Finally, we explore the contribution of individual differences in mind wandering tendency, rumination tendency, and executive control.

Materials and Methods

Participants: We are currently recruiting 80 healthy male drivers aged 20 to 24 from the greater Montreal (Quebec, Canada) area. Participants must hold a valid driver's license and have normal or corrected-to-normal vision and hearing. Participants must not have simulation sickness, major traffic violations (e.g., driving while impaired), a mood disorder (e.g., depression), attention deficit disorder, problem drug or alcohol use, or be intoxicated at the time of testing.

Baseline measurement: Errors on the Sustained Attention to Response Task (SART; [29]) will function as a behavioural measure of mind wandering tendency while experience sampling during the Metronome Response Task (MRT; [30]) will assess subjective dimensions of mind wandering tendency (e.g., intentionality, meta-awareness, stimulus-dependence). The Ruminative Response Scale (RRS; [31]) will index individual differences in the tendency to ruminate. The Simon Task [32], a computerized adaptation of the Stroop, will measure baseline differences in executive functioning.

Mood induction: We will induce a negative or neutral mood by manipulating feedback on a bogus intelligence test. Participants in the negative mood group will be told that their performance is indicative of their intelligence and capabilities in various domains. After completing the test, consisting of 15 Raven's Advanced Progressive Matrices [33], they will receive feedback indicating that their performance was below average. Participants in the neutral mood group will be told that the intelligence test is in development and that their responses will be used to calibrate its difficulty. After completing the test, they will receive no feedback. The Positive and Negative Affect Scale (PANAS; [34]) will assess mood pre- and post-induction as a manipulation check.

Post-manipulation measurement: A driving simulator (see Figure 1) developed at the Université de Sherbrooke will record driving behaviour, such as speed, headway distance, and lateral variability at a rate of 60 Hz. Participants will report mind wandering versus attentive driving by pressing buttons on the steering wheel in response to experience sampling probe-tones presented at semi-random intervals throughout the simulation. Changes in heart rate measured with a BIOPAC® ECG system as well as cortical activity measured with a 16-channel

OpenBCI® EEG system will index physiological responses to mind wandering during the simulation.

Figure 1. The driving simulator developed at the Université de Sherbrooke.

Expected Results

We anticipate that negative mood will precipitate more mind wandering that has a greater impact on driving performance compared to neutral mood as indicated by:

1. More mind wandering and riskier driving (i.e., faster speed, reduced headway distance, and greater lateral variability) in the negative mood group compared to the neutral mood group.
2. Greater risky driving during 10 second epochs prior to subjective indications of mind wandering in the negative mood group compared to the neutral mood group.
3. Correlations between the extent of driving decrement and physiological responses to mind wandering (i.e., faster heart rate, greater alpha EEG activity) during 10 second epochs prior to subjective indications of mind wandering.
4. Moderation by mind wandering tendency, rumination tendency, and executive control at baseline.

Implications

This study may substantiate mind wandering as a mechanism by which negative mood influences driving behaviour in young males. Examining individual differences as well as real-time subjective, behavioural, and physiological variation linked to mind wandering could lead to the development of preventive interventions and predictive technologies.

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Under which driving contexts do drivers decide to engage in mobile phone related tasks? An analysis of European naturalistic driving data

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EXTENDED ABSTRACT

In recent years, the use of mobile phones while driving has increased tremendously [1, 2]. However, mobile phone interaction while driving, especially writing text messages, has adverse effects on driving performances. Texting can lead to longer reaction times [e.g., 3, 4] and more lane deviations [e.g., 5, 6]. This is also shown in an alarmingly high crash risk of texting compared to other common secondary tasks (e.g., eating, talking) while driving [7, 8]. At the same time, there is evidence from simulator studies that drivers use self-regulatory strategies to decrease the driving demand during secondary task engagement, for example by slowing down the speed [e.g., 6, 4] or increasing the distance to the lead vehicle [e.g., 3]. Analyses of naturalistic driving data showed, however, that these effects are rather small, if they are found at all [9, 10]. It seems more likely that drivers decide strategically *when* to engage in a secondary task while driving. Previous research indicates that drivers engage in secondary tasks more likely when driving with a low speed or when stopping [e.g., 10, 11] or when driving straight ahead [e.g., 12]. Unfortunately, so far, there are only a few studies on this topic that based on naturalistic driving data. Aim of the present study was to identify the driving contexts under which drivers decide to engage in mobile phone related tasks using naturalistic driving data.

Method

The current analysis is based on European naturalistic driving data collected in the UDRIVE project [13]. Within UDRIVE 120 cars in five countries (France, Germany, Poland, United Kingdom, and Netherlands) were equipped with a data acquisition system that was developed within the project. Drivers were observed in their natural driving behaviour over up to two years. Overall, 192 car drivers participated in the study.

The analysis relies on a dataset which contains four randomly selected trips per driver. For our analysis we used all trip segments in which a mobile phone interaction took place. The trip segments were annotated using video data regarding the *main mobile phone related task* (i.e., conversation hand-held, conversation hands-free, reading hand-held, reading hands-free, texting/ browsing, holding, other), *task initiation* and *task conclusion*. At task initiation (I-0) we also annotated if *other passengers* were present (i.e., yes, no) as well as *weather* (i.e., clear, rain, snow, fog, other) and *lighting conditions* (i.e., daylight, dawn/ dusk, darkness). *Locality* (i.e., urban-residential, urban-motorway, rural, motorway/ highway, other), *traffic density* (i.e., free flow, free flow with restriction, stable flow, unstable flow, traffic jam/ stop-and-go, other), *stopping* (i.e., yes, no) and *turning* (i.e., yes, no) were annotated at I-0 and also 30 s before the task was initiated (I-30).

Overall, 305 trip segments were annotated. 269 of these trip segments were relevant, i.e. contained a clear mobile phone related task (in some cases it was e.g. not clear if the driver engaged in a hands-free mobile phone conversation or talked with a passenger). For further analyses, we decided to select randomly one trip segment of the trip, if multiple trip segments per task category stemmed from one trip. This was done to avoid an overrepresentation of single trips. Thus, 104 trip segments were excluded from the analysis (see Table 1).

Task category	Dataset with all trip segments	Dataset with one trip segment per trip
Conversation hand-held	19	18
Conversation hands-free	7	6
Texting/ browsing	143	64
Reading hand-held	37	30
Reading hands-free	8	8
Holding	21	16
Other	34	23

Table 1. Frequencies across mobile phone tasks for the dataset including all trip segments and the dataset with one segment per trip.

Results

In most of the annotated trip segments drivers used their mobile phone for texting or browsing (see Table 1). The mean duration of texting or browsing was 46 s (SD = 50.78), ranging from 3 s to 271 s. In 16% of the trip segments other passengers were present at I-0. Most of the trip segments in which drivers decided to engage in texting or browsing took place in daylight (78%), under clear weather conditions (93%) and in an urban area (68%).

Prevalence ratios regarding locality, traffic density, stopping and turning at I-0 in comparison to I-30 were calculated to assess the association between the frequency of different contextual factors and the initiation of texting or browsing tasks (see Table 2). Associations were found regarding traffic density, stopping and turning. Specifically, the data show that a stable traffic flow was observed significantly less often at I-0 than at I-30. In contrast, the prevalence of the “other traffic density” category was two times higher at I-0 than at I-30. This category contains all events in which the vehicle was stopped (e.g., at a red light) and therefore traffic density could not be assessed. This is also reflected in the high prevalence ratio of stopping, indicating that the prevalence of a stopped vehicle at I-0 was 3.5 times higher than at I-30. Furthermore, we found a significant prevalence ratio regarding turning, such that turning occurred less often at I-0 in comparison to I-30.

Further analyses were performed for the other mobile phone related categories. The categories “conversation hand-held” and “conversation hands-free”, “reading hand-held” and “reading hands-free” as well as “holding” and “other” were combined. Results were similar to those of texting or browsing tasks.

Contextual factor	Prevalence ratio	95th CI
Locality		
Urban residential	0.92	0.67-1.25
Urban motorway	0.92	0.34-2.45
Rural	1.60	0.50-5.21
Motorway/ Highway	0.57	0.20-1.66
Other	2.45	0.68-8.79
Traffic density		
Free flow	0.55	0.26-1.17
Free flow with restriction	0.55	0.14-2.21
Stable flow	0.37*	0.17-0.78
Unstable flow	0.92	0.13-6.32
Traffic jam/ Stop-and-go	1.38	0.52-3.64
Other	3.17*	1.69-12.71
Stopping	3.58*	1.95-5.93
Turning	0.20*	0.05-0.91

Note. * Significant prevalence ratios (i.e., 95th CI does not cross 1).

Table 2. Prevalence ratios and 95th confidence intervals regarding locality, traffic density, stopping and turning for texting or browsing tasks.

Conclusions

In line with other authors we found that drivers engage more likely in secondary tasks when the vehicle was stopping [10, 11], i.e. drivers choose situations where the driving task demand is low. In contrast, making turns or driving in a stable traffic flow was significantly less likely at task initiation. In such situations, the traffic conditions can change rapidly, which might result in a high driving task demand for the driver. It appears that drivers strategically decide when to engage in a mobile phone related task by choosing situations where the driving task demand is low. Hence, traffic conditions, driving manoeuvres and the current movement of the vehicle are important factors when investigating drivers' self-regulatory behaviour.

However, it has to be noted that the sample sizes of the present study are rather small. Analyses that are based on larger sample sizes shall be performed to validate our findings. Furthermore, it has to be kept in mind that our analysis relies on a comparison of contextual factors within a single trip. This was done to examine whether the traffic situation 30 seconds prior to drivers' engagement in a mobile phone related task differed from that at task initiation. This may have led the driver to consciously choose to (not) engage in the mobile phone related task at that precise moment. However, the influence of other factors, such as passenger presence, cannot be investigated with this approach. For this, comparisons with baseline trips (i.e., trips without secondary task engagement) would be necessary.

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A preliminary simulator study to investigate the effects of digital mirror failures on driving and glance behaviour, situation awareness, criticality and trust

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Abstract: Camera-based 'rear-view' displays within vehicles can improve aerodynamics and the field of view. However, digital technology may fail. Specifically for lane change situations, malfunctions may result in insufficient visual information and unsafe manoeuvres. Moreover, a degraded source may lead to distraction, compromised trust and thus lower acceptance. A driving simulator experiment aimed to determine the impact of a digital mirror failure on driving and visual behaviour, situation awareness (SA), criticality ratings and trust. Therefore, the existing 'wing mirrors' were replaced with in-vehicle LCD screens. In three drives in a UK motorway scenario, 19 drivers were instructed to perform ten lane-changes. During the second drive, the right (offside) digital mirror failed immediately after the instruction to move from the middle to the right ('fast') lane. Results show that the failure led to larger speed variation, more rear-view-mirror and slightly more over-the-shoulder checks, but increased observations of the right (failed) mirror, indicating distraction. Cumulative SA was not affected, but ratings for instability, complexity and variability increased. Drivers also recognised the heightened criticality. Unsurprisingly, trust decreased, potentially motivating the compensatory behaviours. In the third drive, which was free from failures, behaviours, criticality and trust returned to pre-failure levels, indicating no persistent long-term effects.

1. Introduction

The concept of mirrorless cars involves the replacement of traditional side mirrors with camera-based displays placed within vehicles, thereby improving vehicle aerodynamics and improving the field of view. Technological advancements mean that modern in-vehicle electronics are generally robust and highly reliable, with current systems able to successfully replace or augment aspects of vehicle control, such as braking and steering [1]. Nevertheless, digital technology may fail. A failure is defined as "an event that occurs when the delivered service deviates from correct service" [2, p. 2]. Hence, a failure constitutes the situation in which a system is not doing what it is intended to do. Besides faults related to the software and electronic circuits, camera-based systems are also susceptible to environmental factors that may limit the camera's vision, such as rain, dirt and ice, sun glare, or image distortions in low sunlight conditions. Despite the most diligent efforts to ensure the correct functioning of digital mirrors, designers need to envision scenarios in which a failure occurs. In the case of digital mirrors, it could potentially cause a frozen, blank or otherwise incorrectly displayed image. Specifically, for situations in which drivers' awareness of the sides and back of their car depends on digital mirrors, malfunctions (or excessive dirt / sun glare) may result in insufficient visual information and unsafe manoeuvres. Moreover, display failures may lead to significant levels of distraction, as drivers may (repeatedly) attempt to extract information from a degraded or even misleading source. In order to measure the impact of failures, Neukum and Krüger [3] developed a criticality scale, assessing the subjectively experienced degree of disturbance, ranging from imperceptible to uncontrollable, along with an 11-point scale, shown in Table 1.

Ultimately, negative experiences can compromise trust, which is "…the attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability" [4, p. 54]. Driving provides many such uncertain situations, in which drivers depend on mirror images to build sufficient awareness before making decisions. Decreased trust can then impact on the acceptance of technology [4-6]. For instance, numerous accounts of railway and aviation accidents resulting from the ignorance of alarms [cf. 7] illustrate how a lack of trust can lead to dangerous disuse. In addition, it is evident that trust is inversely related to the extent a device is monitored [6]. Hence, trust is particularly important for systems that provide a substitute for well-established, essential devices (such as a side mirror for a vehicle).

Table 1 Criticality rating scale

uncontrollable	dangerous			unpleasant			harmless			imperceptible
10	9	8	7	6	5	4	3	2	1	0

1.1. The current study

The current study aimed primarily to determine whether drivers responded to a digital mirror failure with compensatory behaviours and changes in self-reported trust. In terms of the former, they could change their speed and adjust their visual search such as using the rear-view mirror or conducting over-the-shoulder checks. Moreover, in order to better understand these effects, the research also aimed to investigate impacts of a failure on further subjective measures including situation awareness (SA) and criticality ratings. Because of the low likelihood of a digital mirror failure, repeated occurrences were not included in the present study.

Of interest to this analysis were the lane changes in which failures occurred, as well as the corresponding lane changes in the drives without failures. This was decided in order to measure effects of failures on subsequent mirror use when the mirror is functioning correctly.

2. Methodology

2.1. Mirror Failure Condition

In order to measure the effects of digital mirror failures, the drivers were subjected to a failure condition of the right (offside) digital mirror. The failure occurred at a dedicated but unpredictable time, immediately after being instructed to move from the middle into the right hand ('fast') lane, followed by subsequent lane change instructions. The failure always occurred during Drive 2 and involved the mirror turning blue for approximately 1 second followed by a frozen image with a road clear of traffic being presented, shown in Fig. 1.

Fig. 1. *Frozen image displayed in the right-hand mirror when the failure occurred*

2.2. Design

The study was conducted with a repeated-measures design, with one factor, Drive. This factor consists of three levels, Drive 1 to 3. The first Drive was a baseline Drive, where no failures occurred. During the second Drive, the failure occurred at a dedicated, but for the participant unpredictable time and remained until the end of this Drive. During the third Drive, no failures occurred, to measure whether the participants displayed any residual behaviours and attitudes that reflect carry-on effects after experiencing failure.

2.3. Apparatus

The experiment was conducted using a busy UK motorway scenario in a medium-fidelity driving simulator at the University of Nottingham. The simulator is normally equipped with external LCD wing mirrors, but for the current study these were replaced with separate LCD panels inside the vehicle, as shown in Fig. 2. The rear-view mirror remained unchanged. The right-hand screen was connected to an HDMI switch, so the experimenter was able to change the screen input. This meant the screen briefly flashed blue due to the temporarily missing signal, followed by an image emulating a frozen motorway scene, as shown above.

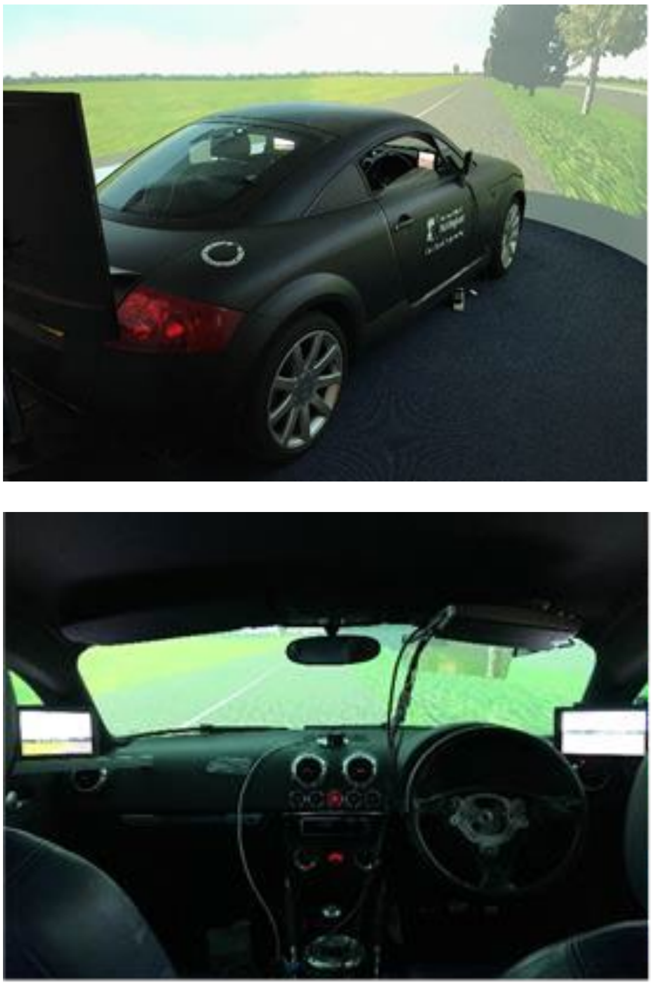

Fig. 2. *University of Nottingham driving simulator*
(a) Fixed-base driving simulator **(b)** Digital mirror setup

2.4. Participants

Participants were recruited via an advertisement email to the staff and postgraduate students at the university as well as personally contacting colleagues and friends. In total, 19 regular drivers participated in the study, ranging from the age groups 18-29 to 60-69, and an average annual mileage of 3,516 miles (SD = 3,059 miles). As a gesture of appreciation, the participants were handed £10 shopping vouchers.

2.5. Procedure

At the beginning of the session, the participants were briefed on the study, without being informed about the failures, to avoid expectation. The drivers were then asked to fill in a consent form and a demographic questionnaire. The experiment involved three separate Drives (each approximately 10 minutes long). In each Drive, the participants were instructed to perform several lane-change manoeuvres while being surrounded by ambient traffic. These were delivered by voice instructions, which had been pre-recorded and were automatically played at specified distances down the road. The failure was triggered manually by the experimenter with a button press. Due to expected different speeds of the participants, it was not possible to closely control the location of the cars in the adjacent lane in relation to the participant vehicle. The lane change manoeuvres and the location of the mirror failure are illustrated in Fig. 3. Before the completion of the session, the participants were debriefed and it was explained to them that the purpose of the study involved the digital mirror failures.

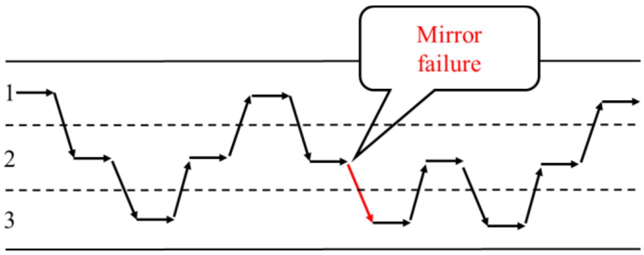

Fig. 3. *Plan view of the motorway with lane changes, showing the placement of the mirror failure within Drive 2*

2.6. Measures

Participants' reactions were recorded by the driving simulator software, operationalised as the speed and speed variation and lane position, as well as cameras inside the vehicle. The video recordings were then coded to identify glances into the digital mirrors, the rear-view mirror and over-the-shoulder checks. SA was measured with a 12-item questionnaire by Taylor and Selcon **[8]**. Trust was measured with a questionnaire by Jian et al. **[9]** and criticality with the criticality rating scale **[3]**.

2.7. Analysis

Of interest to this analysis was the lane change in which the failure occurred (Drive 2), as well as the corresponding lane changes in the Drives without failures (Drives 1 and 3). The time window for data gathering was from the onset of the failure until the successful completion of the lane change manoeuvre. If no lane change occurred, the data window lasted until the following lane change instruction.

The analysis was conducted with SPPS, using multivariate ANOVAs with Drive as within-subjects factor. In case the assumptions of parametric tests were violated, a Friedman test was performed instead, with Wilcoxon signed-rank tests for pairwise comparisons. All pairwise comparisons were Bonferroni-corrected.

3. Results

3.1. Driving measures

When the mirror right failed, six drivers did not perform the lane change that was instructed at that time. One of these drivers then also omitted the corresponding lane change in Drive 3. Generally, the drivers did not change their mean speed following the failure ($p = .150$). However, the analysis of the standard deviation of speed produced a main effect [$F(2, 36) = 3.45$, $p = .043$], which was due to larger speed changes in Drive 2 (mean = 10.22 m/s, SD = 4.08 m/s) compared to Drive 3 (mean = 7.16 m/s, SD = 3.01 m/s, $p = .025$). There was a main effect for the lateral variation [$F(1.234, 22.217) = 4.41$, $p = .040$], but post-hoc comparisons did not flag up significant differences.

3.2. Glance Behaviour

Only 4 of the 19 drivers performed a check over their shoulder in Drive 2, when the failure occurred, which was still more compared to 2 participants in Drives 1 and 3. However, due to the small numbers, this variable was not statistically analysed. Friedman tests of the mirror glances identified main effects for the number of glances to the right [$\chi2(2, N = 19) = 20.48$, $p < .001$] and rear mirrors [$\chi2(2, N = 19) = 21.26$, $p < .001$]. Pairwise comparisons showed an increase of glances into the right mirror by 113% from Drive 1 to 2 ($p = .003$), followed by a 51% decrease in Drive 3 ($p < .001$). Glances into the rear-view mirror increased by 184% from Drive 1 to 2 ($p < .001$) and then lowered by 63% in Drive 3 ($p = .003$). There were no significant pairwise differences between Drives 1 and 3.

3.3. Subjective SA

The cumulative SA score was higher on average in Drive 2 compared to the Drives without failure, but the effect was not significant ($p = .059$). When comparing the separate items, it was found that, from Drive 1 to 2, there were increases in instability ($p = .036$), complexity ($p =.024$) and variability ($p = .003$). Then, complexity decreased in Drive 3 ($p = .036$). No item produced a significant difference in SA between Drive 1 and 3.

3.4. Criticality

In Drive 1, the average critical rating was 2.79 and thus within the range of 'harmless'. An ANOVA of the criticality ratings produced a significant main effect [$F(1.21, 21.76) = 18.69$, $p < .001$]. Pairwise post-hoc comparisons assigned this effect to an increase in criticality ratings by 79% from Drive 1 to Drive 2 ($p = .004$) into 'unpleasant' as well as a subsequent decrease to 2.47 ('harmless', $p < .001$).

3.5. Subjective Trust

An ANOVA of the cumulative trust score resulted in a significant main effect [$F(2, 36) = 15.92$, $p < .001$]. Pairwise comparisons assigned this effect to a lowered trust score, by 67% from Drive 1 to 2 ($p < .001$), and a subsequent 141%

increase in Drive 3 (p = .001). Trust did not differ between Drive 1 and 3 (p = .359).

When considering the separate questionnaire items, pairwise Wilcoxon signed-rank tests showed that ratings worsened from Drive 1 to 2 for wariness (p = .021), harmfulness (p = .006), confidence (p = .003), dependability (p = .012), reliance (p = .001) and trust (p < .001). Answers then improved in Drive 3 for wariness (p = .033), harmfulness (p = .003), integrity (p = .042), reliance (p = .012) and trust (p = .001). Box plots of results are provided in Fig. 4.

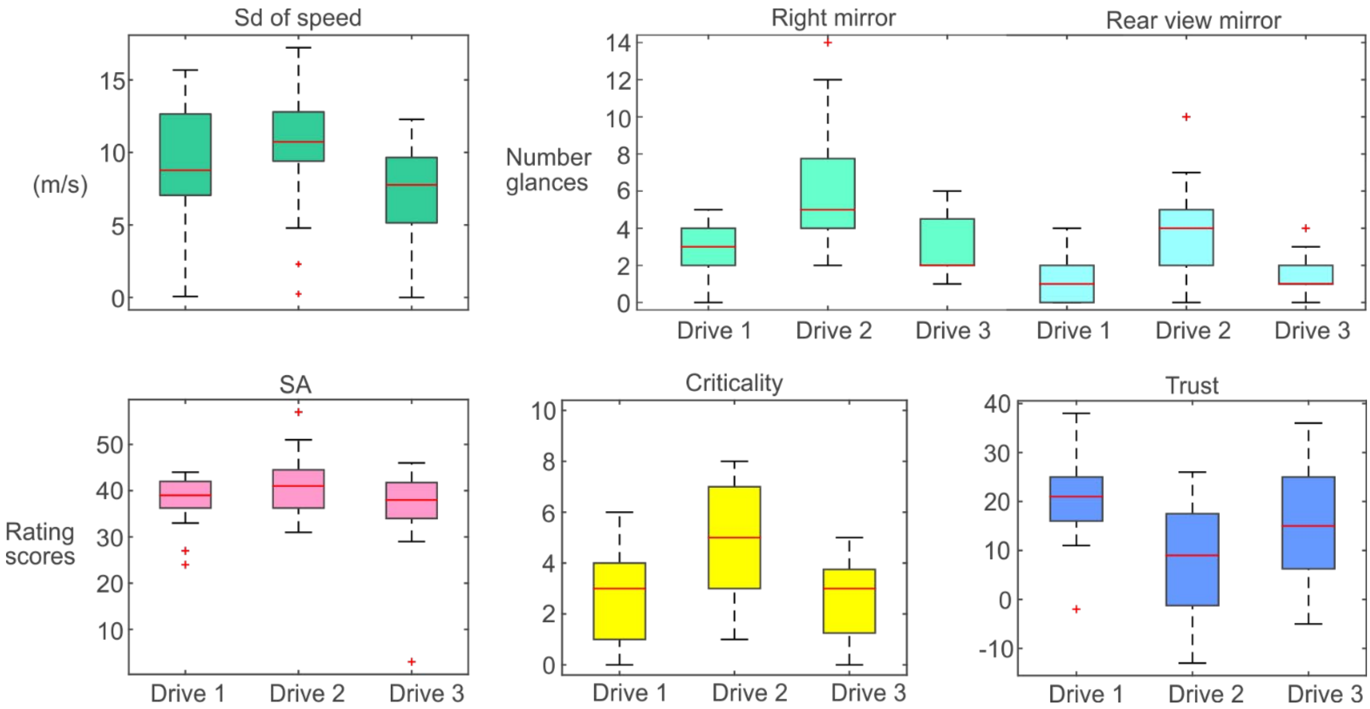

Fig. 4. *Box plots of summary measures*

4. Discussion

The present study investigated the effects of a 'frozen-image' failure of the digital mirror system on driving and visual behaviour, SA, criticality ratings and trust, measured in a driving simulator study supplemented with video recordings and questionnaires. Results show that the failure led to significant changes in behaviours. Although mean speed and lateral variation were not significantly affected, speed variation was higher following the failure (leading to non-significant decreases in mean speed). The drivers also compensated by looking more often into the rear-view mirror. Using the centre mirror seemed to have been the first course of action for the drivers, once they realised the failure. A slight increase in over-the-shoulder (blind-spot) checks could also be observed, but the number was generally unexpectedly low. It is a possibility that the driving simulator environment did not provide the visual experience that is realistic enough to support such checks, even during a mirror failure. However, an analysis of lane changes during a naturalistic driving study in the US [10] supports the observation that drivers tend to rely on rear-view-mirrors, more than on the respective side mirror, and the least on blind-spot checks. It has indeed been shown that brief rear-view-mirror checks decrease crash and near-crash risk [11]. Hence, possibly due to these compensatory behaviours, cumulative SA was not significantly affected, but the individual items: instability, complexity and variability were increased. It also appears that the drivers recognised the heightened criticality, rising from 'harmless' to 'unpleasant'. The finding that the participants looked at the right (failed) mirror more indicates a potential distraction effect [12, 13]. The frozen image can be misleading, but the flashing blue screen preceding the frozen image might have mitigated that effect. The clarity of the situation was indicated by the timely increase in compensatory behaviours. In addition, when prompted by the experimenter at the end of the session, 17 of the 19 participants mentioned the failure, and none of them explicitly attributed it to the driving simulator equipment. Hence, it is suggested that a clear warning symbol, which immediately communicated the mirror's state to the driver, could be useful in the case of such a failure. In this way, it could help the drivers build a correct mental model of the situation, which can result in potentially safer and more appropriate reactions [14, 15].

Ultimately, despite the difficulties of the situation, no collisions occurred, but the experimenter observed several 'near-misses', highlighting a potentially increased crash risk when failures occurred. The fact that six drivers refused to change into the fast lane with a failed mirror shows how these drivers prioritised safety, which is remarkable in the face of experimental instructions and the potentially associated social desirability [16].

The analysis of the trust questionnaire shows that trust in the digital mirrors was influenced by whether a failure occurred in a Drive or not, but only for the actual failure situation, not for the following failure-free Drive. In

Drive 2, trust in the technology decreased significantly, cumulatively and for most separate items. In summary, the mirror failure conditions significantly decreased self-reported trust. This adjustment in trust could have motivated the drivers to perform the compensatory behaviours, which were appropriate in this case.

There were no significant differences in any of the dependent variables between the first and third Drives, which were both free from failures. Hence, driving and visual behaviours, SA and perceived criticality returned to pre-failure levels when the digital mirror returned to normal functioning, but the reconstruction of previous trust levels is especially interesting. The finding that the impact on trust did not influence the later Drive can indicate that trust, in situations with a functioning mirror, is not influenced by earlier failures. However, the trust construct measured in questionnaires is considered potentially weak, and does not always translate into actual behaviour [17]. Another possible explanation for the restoration of trust involves an increased general exposure of the society to technology and therefore a higher level of initial trust [18]. In addition, even if people's expectations of a system are not met during the first uses, the expectations may be simply adjusted, so that trust is not necessarily affected [19].

5. Conclusions

The findings of the current study show how drivers may react when digital mirrors fail, particularly in critical situations such as lane changes. When a failure occurred in the simulator, the drivers performed compensatory behaviours such as changing their speed and performing more glances into rear-view mirrors, and thus maintained some degree of SA. However, the alternative mirror views do not provide sufficient information about the driver's side view of the car and the number of necessary over-the-shoulder checks was low. At the same time, increased glances into the failed mirror indicate its distracting effect. Subjectively, drivers rated the criticality of the situation as 'unpleasant' and indicated lowered trust in the technology. Behavioural and subjective measures, including trust, were restored once the mirror returned to full functionality, suggesting no lasting effects of the failure. Future research needs to investigate digital mirror failures in the real world, because a driving simulator study is only able to deliver initial indications, particularly as the graphics cannot replace a real-world view. A wider range of different manoeuvres can further aid the understanding of mirror use and responses to failures. It also needs to be considered whether a frozen image without an obviously flashing blue screen beforehand can be more difficult to realise and thus misleading and distracting. On the flipside, a permanent blue screen or clear failure symbols could mitigate distraction and motivate better compensatory actions.

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Comprehensive Analysis of Traffic Accidents related to Inattention investigated by the Czech In-depth Accident Study

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Keywords: Inattention; Human Factor; In-depth Accident Analysis; driver; Distraction

Introduction

Driver inattention is the major problem in road safety and generally belongs to the main causes of traffic accidents. Driver inattention occurs when driver fails to pay sufficient attention to activities that are required for safe driving [5]. In the literature, there are very few definitions of driver inattention and those that exist, like driver distraction, vary in meaning.

This study aims to analyse inattention - related accidents regarding the information and experience from a driver and traffic environment data collected by Czech In-depth Accident Study. Secondly, it aims to determine risk factors leading to inattention of driver of personal vehicle and to describe inattention risk scenarios including traffic environment type and traffic situation, taking sociodemographic information and driving experience into account. The study describes the hidden risk factors and causes behind the inattention and suggests the situations and scenarios prone to reinforce it.

Data collection was performed within the research project Czech In-depth Accident Study, which was initiated by Transport Research Centre in 2011. The project focuses on road accidents with injuries on a defined region of South Moravia. The road accidents are chosen according to a statistical selection with the aim to cover a representative sample. The current sample of in-depth data from the CZIDAS included 1586 crashes from 2011 - 2017, in which at least one participant was admitted to the hospital due to crash – related injuries. The in – depth accident investigation team documents all the relevant information on traffic environment, vehicles and human factor, at the scene immediately after the occurrence of a traffic accident.

The investigation includes individual interview of a psychologist with traffic accident participants, focused on all relevant information related to causes (traffic situation, actual mental and physical condition of a participant, incidental circumstances, etc.) course (e.g. reactions) and consequences of the accident (injuries); including basic and sociodemographic information about the participant (sex, age, driving experience, etc.). Interviewing participants is the effective tool of how to understand direct and indirect risk factors leading to inattention and distracted driving in a context of real road accident situations.

Both, quantitative and qualitative analyses were applied to analyse accident causation and determine inattention risk scenario types, including traffic environment and actual situation as well as the condition of a driver.

Using qualitative content analysis of the drivers´ interview reports taking a theoretical psychology background into account, several causes of inattention were identified, such as multitasking (overloading attention), distraction (mental and physical), route unfamiliarity, routine and monotonous drive, “the end-of-the-drive

syndrome”, time pressure, fatigue, health condition and drugs influence, etc.
As evidenced by the results of Czech In-depth Accident Study (CZIDAS) from the amount of analysed traffic accidents, 41 % of analysed accidents have been caused by inattention.
For the driver of personal vehicles, several causes of inattention were identified. As the most often cause of the accidents of all age groups, overloading attention has been identified (39 % from all accidents caused by inattention). Other frequent causes of accidents have been distraction and monotonicity, respectively routine ride. Drivers could be more inattentive on familiar road. As was resulted by CZIDAS, most of the road traffic accidents have occurred on the driver familiar road (more than 70 %). The Pearson´s chi-squared test indicated statistically significant differences in the road familiarity. On the familiar road routine ride and monotonicity increased the crash risk (as has been indicated by sign scheme). On the unfamiliar road, driver attention has been diverted into driving and navigation or route searching.
In – depth crash data allows use analyse pre-crash circumstances including also information about the mental state of driver, which in one of the main benefit compared to the naturalistic driving studies. Data from in-depth studies are also more detailed compared to the police database. Thanks to the individual approach to interviewing road accident participants and impossibility to use data for liability determination (information is strictly confidential), drivers more likely provide information about the proper circumstances leading to the accident.
The main limitation of in-depth study is reliability of the subjective reports and validation of some of those information using information from external sources (police and medical records) and internal sources (reconstruction of the accident scenario using simulation software).
Despite some limitations, data from in-depth studies provides very important information to understand the process of driver´s inattention, to predict it and to improve the interactions in the human- traffic environment - vehicle system to increase the road safety.

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Predictors and Risk Perception of Using Cell Phone while Driving among Young Adult Drivers

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Keywords: Attitude; Distracted driving; Driving experience; Risk perception; Young adult drivers

EXTENDED ABSTRACT

Background: The increasing number of young adults engaging in distracted driving (DD) particularly using cell phone while driving, has inevitably caused public health concerns worldwide. The Philippines being touted as the "texting and social media capital of the world", is projected to see a rise in the number of drivers who will engage in mobile phone use during driving in the next coming years. This study aims to determine the predictors, risk perception and prevalence of distracted driving among resident doctor drivers, aged less than 30 years old, of the University of the Philippines-Philippine General Hospital (UP-PGH), who are using a cell phone (texting and calling) while driving.

Methods: The research was conducted over two months: the survey was first distributed to the target population followed by a focus group discussion. The study design was cross-sectional with tool questionnaires given to all year levels (1st to 5th year) of residents in training at UP-PGH as total enumeration was employed to capture the subset of drivers in the target population. The trainee residents were chosen as their age range were within the 24-30 years, which was within the age group of interest and the study was conducted from July to Aug 2017. Ethics approval from UP-Manila Research Ethics Board (UPM-REB-2017-149-01) was secured prior to initiation of the survey.

The structured questionnaire was developed based on the objectives of the study, review of the related literature [1], [2] and constructed in a way that was more apt to the local setting. It consisted of 4 sections, namely, socio-demographic, risk perception, distracted driving behavior survey and attitude toward distracted driving. The measurement tool had six questions on the sociodemographic profile and an added question inquired to the knowledge of the Anti-Distracted Driving Law of the Philippines [3] penalizing the act. The section on risk perception had four (4) questions that included the use of hands-free devices, the dangers of a cell phone that can result to collision/crash and cell phone use being as dangerous as alcohol-impaired driving. Responses were based on a 5-point Likert scale of: 1=Strongly Disagree, 2= Disagree, 3=Neutral, 4=Agree, 5=Agree. In order to differentiate the perception of risk, responses were collapsed into two categories: safe risk perception was defined as Likert Scales that agreed to statements complying with established national laws on distracted driving known as Anti-Distracted Driving Act (RA 10913). According to this law, performance by a motorist of any of the following acts in a motor vehicle in motion or temporarily stopped at a red light, whether diplomatic, public or private, is considered unlawful; (a) Using a mobile communications device to write, send, or read a text-based communication or to make or receive calls, and other similar acts; and (b) Using an electronic entertainment or computing device to play games, watch movies, surf the internet, compose messages, read e-books[2]. While those responses under the Likert Scales that were contrary to this Act, including ‘neutral’ answers, were considered unsafe risk perception.

The distracted driving survey focusing only on cell phone use while driving was adopted from and was a modified version of the 11-item Distracted Driving Survey of Bergmark et al. which was a validated tool to measure cell phone-related distracted driving for drivers age 24 and below [4]. It had four (4) questions that probed on cell phone and hands-free device use and if respondents used their cell phone to view applications such maps, directions and social media while driving in the past 30 days; the response was binary, recorded either yes or no.

Finally, five (5) questions that dealt with the attitude were patterned after the items used by Harrison to evaluate college students' perceptions on text messaging while driving [3]. The response was similar to risk perception using the same 5-point Likert Scale, and interpretation was similarly collapsed to two groups: safe attitude (Likert Scales in agreement with DD Laws) and unsafe attitude (Likert Scales, including ‘neutral,' that were against DD Laws).

The FGD topics were guided by several reports addressing distracted driving in countries that had extensively studied this risky driving behavior [5], [6], [7]. The principal investigator conducted the FGD among trainee residents of the Department of Emergency Medicine and it explored the issues included in the structured survey.

Chi-square and multivariate logistic regression were used to analyse data. Odds ratio with a 95% confidence interval was used as summary statistics.

Results: A total of 393 residents answered the survey but only 175 drivers (44.52%) aged 25-30 years old were included in the final analysis satisfying the inclusion criteria. The mean age of the driving respondents was 27.90 + 1.34, the youngest being 25 years old and the oldest was 30. More than half (54.29%) were men and 52.98% fell in the combined mid-range family annual income of Php 100, 001 to Php 1 million (~USD 1,935 to USD 19,357). One hundred two (58.96%) admitted being involved in a road traffic crash (RTC) mostly as a driver (42.86%), while 26.37% were as a passenger and 30.77% as both. Regarding driving experience, 85.55% had been driving for >2 years, and a considerable percentage (94.29%) knew that distracted driving was penalized under the "Anti-Distracted Driving" law (Table1).

Although overall risk perception had no significant findings between cell phone users and non-users, more residents who used a cell phone while driving perceived using hands-free devices safer (p=0.030). A considerable proportion of residents (65.22%) composed or read text, called or answered calls while driving and 84.47% accessed their handphones to view maps, directions or navigation applications. More than half (55.90%) used hands-free devices and almost the same number of residents viewed and read messages on social media.

The overall reported cellphone use was 146 or 90.68% out of the 161 residents. The mean age was 27.39 ± 1.34, with more males (56.85%) and 40% had an annual family income of more than Php 1 million (~ >USD 19,357). Almost 60 percent were involved in RTC mostly as a driver (42.67%), and 87.59 % were driving for > 2 years. Only 7 (4.79%) of the 146 cellphone users admitted not knowing the implementation of the "Anti-Distracted Driving" Law. Distracted drivers had a significantly higher overall unsafe attitude (p=0.007), and the same significant result was noted on the unsafe attitude of using handphones even if the driver knew it was dangerous to do so while driving a vehicle (p=0.003).

Univariate logistic regression analysis revealed risk perception (p=0.046), years of driving (p=0.001) and attitude (p=0.005) as possible predictors of cellphone use while driving. Final multiple logistic regression model showed attitude and years of driving to be the only significant predictors (Table 2).

Insights gathered from the FGD were that younger, male drivers with higher educational attainment and higher annual family income engaged more in distracted driving than their counterparts. Prevalence of using cell phone while driving was high among the group with or without hands-free devices due to the utilization of navigational apps. The reasons cited were that calls were usually answered or made to significant persons e.g. girlfriends, parents or workmates. One interesting perception was that it was thought to be prevalent in the younger generation of drivers because they have somewhat acquired a "reflex" to answer ringing cell phones in any situation. Driving in an uphill path or dangerous road condition were few of the situations wherein cell phone will not be used. The dangerous consequence of being involved in a road traffic crash was recognized by the majority but this did not deter them from engaging in this practice as it was sometimes inevitable to use navigational or directional apps. All agreed that drivers using mobile phones when driving should be penalized, but all also noted that the current laws in the country were quite lax in its enforcement. The use of hands-free devices were thought to be safer means of using phones while driving because these devices were perceived not to impair cognition.

The recommended countermeasures were through school-based measures, quadruple advertisement, driver's license regulation and technology.

Conclusions:

The high prevalence of cell phone use (texting, reading a text, calling or receiving calls) in the present study provided support to the findings of most researchers on mobile phone use while driving. Although there was no significant difference in the overall risk perception among cell phone users vs non-users, a significant association was noted on the perception that hands-free devices are safer to use. Overall unsafe attitude was higher among drivers operating cell phones while driving and the same significant result was noted on the unsafe attitude of using handphone even when the driver was knowledgeable of its dangers when used while driving. The only significant predictors were attitude and years of driving of more than 2 years. Recommended countermeasures to address this risky driving behavior included assigning a social stigma to distracted driving through quadruple media advertisement, innovations in car engineering, development of built-in telecommunications hardware and lastly, a more strict and consistent enforcement of traffic laws.

Table 1. Sociodemographic Profile of Drivers

Data	***n= 175***		
1. Age (years)	***Mean*** 27.90 ± 1.34 (min= 25; max= 30)		
		Number	%
2. Sex	Male	95	54.29
	Female	80	45.71
3. Financial Status (USD 1=Php 51.66)*	Php100,000 and less (<USD1,935)	16	9.52
	Php100,001 to P500,000 (USD1,935- 9,679)	44	26.19
	Php500,001 to P1,000,000 (USD-9,679-19,357)	45	26.79
	Php1,000,001 and above (>USD 19,357)	63	37.50
4. Involvement in RTC	No	71	41.04
	Yes	102	58.96
	As driver	39	42.86
	As passenger	24	26.37
	Both	28	30.77
5. Driving for how many years?	$\leq$2	25	14.45
	> 2	148	85.55
6. Do you know that distracted driving is penalized under the "anti-distracted driving" law?	Yes	165	94.29
	No	10	5.71

*Conversion rate of US dollar to Philippine peso (Php) as 28 Oct 2017 (XE Currency Converter: USD to PHP, 2017)

Table 2. Summary of Multiple Logistic Regression Predicting Use of Cellphone while Driving

Variable	**Full Model** (All Predictors) OR (p-value)	**Reduced Model 1** (Age omitted) OR (p-value)	**Reduced Model 2** (Age and Income omitted) OR (p-value)	**Reduced Model 3** (Age, Income, and RTA Involvement omitted) OR (p-value)	**Reduced Model 4** (Age, Income, RTA Involvement and Gender omitted) OR (p-value)	**Reduced Model 5** (Age, Income, RTA Involvement, Gender and Risk Perception omitted) OR (p-value)	**Reduced Model 6** (Age, Income, RTA Involvement, Gender, Risk Perception and ADDL Knowledge omitted) OR (p-value)
Age	1.00 (0.987)	-	-	-	-	-	-
Gender							
Male (Reference)	-	-	-	-	-	-	-
Female	0.74 (0.657)	0.74 (0.656)	0.70 (0.576)	0.68 (0.543)	-	-	-
Annual Family Income							
Php100,000 and less (<USD1,935)= Reference	-	-	-	-	-	-	-
Php100,001 to P500,000 (USD1,935- 9,679)	0.94 (0.959)	0.94 (0.959)	-	-	-	-	-
Php500,001 to P1,000,000 (USD-9,679-19,357)	2.85 (0.431)	2.85 (0.431)	-	-	-	-	-
Php1,000,001 and above (>USD 19,357)	2.26 (0.526)	2.26 (0.523)	-	-	-	-	-

Variable	**Full Model** (All Predictors)	**Reduced Model 1** (Age omitted)	**Reduced Model 2** (Age and Income omitted)	**Reduced Model 3** (Age, Income, and RTA Involvement omitted)	**Reduced Model 4** (Age, Income, RTA Involvement and Gender omitted)	**Reduced Model 5** (Age, Income, RTA Involvement, Gender and Risk Perception omitted)	**Reduced Model 6** (Age, Income, RTA Involvement, Gender, Risk Perception and ADDL Knowledge omitted)
Involvement in a Road Traffic Accident (RTA)							
No (Reference)	-	-	-	-	-	-	-
Yes	1.43 (0.597)	1.43 (0.597)	1.11 (0.870)	-	-	-	-
Knowledge of Anti-Distracted Driving Law							
No (Reference)	-	-	-	-	-	-	-
Yes	4.77 (0.181)	4.80 (0.156)	3.26 (0.240)	3.09 (0.250)	3.17 (0.240)	4.01 (0.135)	-
Risk Perception of Distracted Driving							
Safe Risk (Reference)	-	-	-	-	-	-	-
Unsafe Risk	1.33 (0.765)	1.32 (0.763)	2.30 (0.284)	2.34 (0.273)	2.42 (0.252)	-	-
Attitude on Using Cellphone while Driving							
Safe Attitude (Reference)	-	-	-	-	-	-	-
Unsafe Attitude	2.91 (0.147)	2.92 (0.141)	3.20 (0.081)	3.18 (0.082)	3.27 (0.072)	**4.01 (0.028)**	**3.61 (0.039)**
Years of Driving							
<= 2 years (Reference)	-	-	-	-	-	-	-
> 2 years	**6.52 (0.009)**	**6.50 (0.006)**	**5.53 (0.007)**	**5.58 (0.007)**	**6.12 (0.003)**	**6.32 (0.003)**	**6.35 (0.002)**

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Can the effect of low doses of alcohol on subjective and physiological alertness of young drivers be balanced by effort?

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Keywords: alcohol, EEG, effort, driving experience, vigilance

Introduction

Young novice drivers have a high risk of crashes and a linear relationship has been demonstrated between blood alcohol concentration (BAC) and crash risk for this population [1, 2]. They are also over represented in crashes linked to long period of driving. Generally, it is well known that the major part of sleep (or fatigue)-related crashes takes place during the two daily periods of physiological decrease of alertness [3]. Moreover, a monotonous road environment can influence the level of alertness [4]. Thus, effort of novice drivers higher when alertness is low and the lack of resources can explain this result [5].
Consequently, the aim of this work is to evaluate the combined effect of these factors of accident (alcohol and driving experience) on driving performance. The hypothesis is that an increase of effort decreases alertness, notably when drivers lack of experience or in presence of alcohol, but could be balanced by an additional effort until a certain threshold.

Experimental protocol

Fifteen young novice drivers (YND: 18 years, less than two months of driving license) and fifteen young experienced drivers (YED: 21 years, 3 years of driving license) participated in three simulated driving sessions in which BACs were randomly manipulated (0.0, 0.2 and 0.5 g/l). The order of the session was counterbalanced. Every session took place between 1:45 and 3:45 pm, around half an hour after the drink. The task consisted to drive on a circuit representing a typical highway road during 45 min and to maintain a steady speed (110 km/h) and a stable position on the right lane. After each driving session, participants filled out NASA-TLX questionnaire and Thayer checklist.
Only objective alertness (EEG), self-reported alertness (Thayer) and effort (NASA-TLX) were analysed here. Generalized linear models (GLM) were applied to data, completed with correlations.
The study was granted ethical approval by the French local ethics committee and by the French Health Products Safety Agency.

Results

Results of Generalized Linear Models (GLM) showed an effect of effort on alertness (^{2}(1) = 87.78, $p < .001$) and reciprocally of alertness on effort (^{2}(1) = 66.15, $p < .001$) ($r = -.305$). Thus, when the drivers felt they were alert their effort decreased. However, the group * effort interaction (^{2}(1) = 19.34, $p < .001$) specified that this link could be weaker for YEDs ($r = -.217$) than for YNDs ($r = -.423$).
Results of GLM also showed that YNDs' mean alertness was lower than YED one (^{2}(1) = 8.88, $p < .003$). Self-reported alertness (^{2}(1) = 24.06, $p < .001$) and effort (^{2}(1) = 8.34, $p < .004$) also varied as a function of group. YNDs estimated to be less alert and make more effort than YEDs (Table 1).

	YED	YND
EEG [3]	5.14 (5.64)	5.9 (4.76)

Effort (Nasa)	12.42 (4.33)	12.16 (2.89)
Alertness (Thayer)	0.83 (0.55)	1.04 (0.73)

Table 1. Mean EEG index, effort and alertness as a function of experience (SD between brackets).

The interaction group * EEG index on the estimated effort (^{2}(1) = 4.22, $p < .04$) is illustrated by a correlation for the YED (r = -.125) whose effort estimation increases with increasing EEG index that is with the decrease of alertness [2] (Table 2).
The effect of group * alcohol interaction on EEG index (^{2}(2) = 7.42, $p < .02$) and on effort (^{2}(2) = 33.85, $p < .001$) specified that YEDs' EEG index with 0 and 0.2 g/l did not significantly vary but were associated to a higher alertness level than with 0.5 g/l ($p < .001$), they also made less effort without alcohol than with alcohol ($p < .001$). YNDs' EEG index was higher with 0.5 g/l than 0.0 g/l ($p < .02$), their EEG index with 0.2 g/l did not differ significantly from 0.0 g/l and 0.5 g/l, their estimated effort were significantly higher with 0.5 g/l than with 0.0 g/l and 0.2 g/l ($p < .001$) (Table 2).

YED	0.0 g/l	0.2 g/l	0.5 g/l
Mean EEG [3]	4.33 (3.89)	4.19 (2.57)	7.11 (8.57)
Effort (Nasa)	10.50 (5.85)	12.82 (2.52)	13.16 (3.41)
Alertness (Thayer)	1.16 (0.64)	0.96 (0.69)	0.98 (0.89)

YND			
Mean EEG [3]	5.07 (3.71)	5.89 (4.50)	6.74 (5.72)
Effort (Nasa)	12.13 (4.40)	11.73 (4.34)	13.4 (4.08)
Alertness (Thayer)	0.97 (0.73)	0.78 (0.34)	0.71 (0.45)

Table 2. Mean EEG index, effort and alertness as a function of alcohol and experience (SD between brackets).

Alcohol and alertness interacted (^{2}(2) = 7.43, $p < .02$): it was notably with 0.5 g/l that alertness and EEG index were correlated (r = .165). Thus, with 0.5 g/l, the more the drivers felt themselves awake and the less they really were. The effect of alcohol * effort interaction on EEG (^{2}(2) = 16.45, $p < .001$) specified that it was only without alcohol that the increase in effort leads to an increase in alertness (r = -.276).

Conclusion

Results indicate some balanced effect between self-reported effort and alertness. This balanced effect permits to conserve good performance whatever the level of driving experience. Effort production thus compensates lack of alertness until a certain threshold. In fact, and as postulated this relationship seems stronger for YNDs than for YEDs. Young novice drivers also consider themselves less alert than experienced young drivers, and their EEG measures actually show a lower level of physiological alertness than YEDs, result which is consistent with the extra effort they feel when they perform driving activity [5]. This higher effort is probably due to their lack of experience. They also are less able than YEDs to regulate their effort when their alertness decreases and could be more sensible to alcohol effect.
Effort only promotes alertness in the driving session without alcohol and it can be assumed that low doses of alcohol (0.2 and 0.5 g/l) do not allow to regulate the effort necessary to safety driving. Note also that with the higher dose of alcohol the more the drivers felt themselves awake and the less they really were.
These first results thus reflect a parallel between subjective and physiological alertness according to the level of experience of the drivers and a better estimation of the effort to be provided when the alertness of the drivers is weak and they are more experienced. They must however be confirmed by behavioral data but highlight the interest to study combined effect of different factors influencing driving performance.

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Smartphone based Electronic Records of Naturalistic Driver Actions

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Keywords: ADHD; Naturalistic Study; Smartphone Usage

INTRODUCTION & PURPOSE

Naturalistic Driving Studies (NDS) are widely accepted as a valuable research method for understanding driver behavior. In most studies, participants' vehicles are instrumented with sensors for speed, acceleration, distance to lead vehicle, lane position and even nearby pedestrian locations. Such instrumentation is still expensive due to complex and time consuming (de)installation processes and due to specialized data transfer and handling costs. The widespread usage of smartphones presents opportunities for conducting low cost, large scale naturalistic studies where the data is collected from the smartphone kinematic sensors and not from the vehicle's sensors. The usage of smartphones incorporates additional advantages for research beyond the practical considerations of costs: smartphones include sensors (e.g. the touch screen) and data logs (as phone call, text, and app usage logs) that can provide interesting insights about smartphone related distraction. The purpose of the SERNADA (Smartphone based Electronic Records of NAturalistic Driver Actions) project that we present here, is to facilitate learning about drivers' behavior using the smartphone capabilities. This paper describes the various features collected in the SERNADA study and presents several research questions that can be addressed using the collected data. Researchers are invited to use this paper to plan their own low-cost naturalistic studies or to use the SERNADA database to explore driver actions.
The information collected in SERNADA is unique in comparison to other NDS in three main aspects:

- Driving behavior data were collected using the participants' smartphones instead of the in-vehicle monitoring system.
- The smartphone includes interesting data streams about phone usage. These include screen touches, incoming and outgoing messages and phone calls, and a log of the smartphone applications that were used.
- A special effort was made to recruit participants with ADHD diagnosis in addition to non-ADHD drivers.

METHOD

Participants

Participants (N=80) were recruited for a study aimed to learn about real driving behavior. Each participant joined the study for a period of at least four weeks. The incentive to participate was a lottery for a new smartphone. In addition, psychology students received participation points (psychology students are required to accumulate experiment points over the course of their studies). The incentive was given for participation and not as a reward for safe driving. Before they started the experiment, participants completed a short demographic questionnaire (age, gender, driving experience).

Equipment and data arrangement

The data accumulated in SERNADA is very rich; It consists of driving behavior and phone usage data in the form of electronic records of events by five categories (Driving events, GPS events, Foreground App, Screen status, and Communication). Two off-the-shelf smartphone applications were used to collect the data. App 1

monitored the smartphone accelerometer and GPS to identify driving events such as acceleration, braking and turning, as well as their combinations (e.g. “braking into a turn”). The events identification procedure is documented in [1]. This information includes the time stamp and the location of the driving events. GPS events (location and speed) were transmitted every 15 seconds. App 2 logged information about three categories of smartphone usage events: The “Screen events” category included two events of changing the status of the smartphone screen: "screen on” or “screen off”. The “Foreground App” category represented events in which an app operated on the phone screen. Some examples are: WhatsApp, Waze, Contacts, and Facebook. The third category - “Communication events” constituted of incoming/outgoing calls/SMS, including those from specialized communication apps as Skype and WhatsApp. The information that we accumulated during the study included 31,173 driving events, 212,106 GPS events, 39,042 screen events, 37,632 Foreground app events, and 4,933 communication events. The events had time stamps, location, and speed.
To demonstrate the richness of the data we present in Figure 1 information about a single trip. The figure is divided into several horizontal panels by black lines. The upper panel shows the speed against time where each point represents either a GPS or a driving event. The names of the driving events are plotted near the points that designate them. The label size (and color) is larger (and darker) as the maximal absolute value of the acceleration either in the longitudinal or in the lateral direction is higher. These indices are sometimes used to determine the aggressiveness (or safety) of the driving event [2]. To demonstrate, a relatively extreme (high acceleration value) ‘Turning’ event occurred at 12:50 at 40km/h, and the overall speed pattern suggests that roughly between 13:00 and 13:45 the driver was using an interurban road. The second panel is the screen On and Off status. The green and red icons represent these statuses, respectively. The time span that the green icons (On) followed the red icons (Off) was longer compared to the time span between Red (Off) and Green (On) icons. This means that the driver kept the screen on for most of the trip. The foreground panel (third from the top) shows which app was in the foreground according to the corresponding time stamps (x-axis). The label size is determined by the number of screen touches which ranged between 0 and 24 (the latter, for an app name “Musix”). Finally, the communication (fourth) panel showed that three outgoing and three incoming calls took place during this trip. Specifically, between 13:00 and 13:30 where the driving speed was relatively high (above 80 km/h).

Figure 1: SERNADA events by their category

RESEARCH IMPLICATIONS

The data collected in SERNADA give researchers an opportunity to investigate a wide variety of topics, including the usage pattern of smartphones and its effect on driving safety. Further, the cell phone data do not only provide information about calls that took place during driving but also about the usage of cell phones in general. There are several research questions that can be addressed using the SERNADA database. We note several of these questions: First, the SERNADA database is unique as it holds information for both ADHD and non-ADHD drivers. This allows several investigations for example about the differences between drivers with ADHD and drivers without ADHD in terms of road behaviors and of smartphone usage patterns. Another option is to evaluate whether road behaviors can serve as indicators for ADHD. Second, after three weeks of driving, an intervention took place among 40 drivers in the sample- incoming text messaged were blocked but calls or outgoing messages were allowed. One interesting option is to investigate the safety benefits of such intervention. Another option is to test the linkage between driving speed and the occurrence of extreme driving events according to either lateral or longitudinal acceleration values. One can also investigate the durations that applications (Music app for example) were on the foreground and the extent to which they encouraged further interaction (e.g. screen touches) with the smartphone.

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The influence of the position of navigation systems on visual attention while driving

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Keywords: Attention; Distraction; Eye-tracking; Naturalistic driving; Navigation system; Road Safety

Aim and scope

Overall, the use of navigation systems leads to an improvement of road safety: users cover less distance and spend less time in traffic [1]. However, at the same time, using a navigation system can be distracting. Indeed, one has to divide his/her attention between the driving task and the navigation task. Previous research already examined the distracting effects related to navigation systems [e.g., 2,3]. However, in a world where navigation systems are omnipresent, the main question is no longer *if* it is distracting but rather *how* we can minimize these distracting effects. That is the aim of the current research. In the first study we examined by means of a survey which navigation set-ups are most commonly used. Based on the results of this survey, we are currently preparing a naturalistic driving study in which we compare visual distraction (by means of eye-tracking) between the two most commonly used set-ups.

Study 1

Materials and Methods

Participants

1182 respondents started the online questionnaire and fulfilled the driving criteria: They possess a driving license Category B for at least two years and drive more than 1500 km per year. 180 of these respondents indicated that they never use a navigation system while driving and were discarded for further analyses. Our final sample thus consisted of 1002 respondents. Age, sex and language of the respondents were weighted according to the Belgian population (mean age = 56 years with a range from 20-89; 34% men; 66% Dutch speaking/ 34% French speaking).

Questionnaire

Participants fulfilled an online questionnaire programmed with keysurvey software (www.keysurvey.com). In total 25 questions were posed and the questionnaire took about 10 minutes to fulfill. The most important questions we asked where the following:

- Which of the following navigation-systems do you have? (fixed system, portable system, navigation app on tablet or smartphone)
- To what extent do you use the following ways to navigate to an unknown destination? (road signs, paper map or print-out of the route, I memorize my route beforehand, fixed system, portable system, navigation app on tablet or smartphone)
- Do you use a fastening system for installing your portable system and/or your smartphone/tablet. And if so, where do you install these fastening systems ?
- Do you use the visual, the auditive or both sources of information of your navigation system?
- How do you orient your smartphone/tablet (horizontally or vertically).

Results

First of all, we asked which of the three different navigation systems (fixed system, portable system or navigation app) respondents have in their car. Approximately half of the respondents possessed a fixed navigation system in the car (50.2%). 46.8% of the respondents was in the possession of a portable navigation system and 34.4% was in the possession of a navigation app on their tablet or smartphone.

Second, we asked how frequently respondents used different options to navigate to an unknown destination. We added the percentage of respondents that answered 'almost always' and 'often' to each of these options and then ranked the different options accordingly in Table 1.

Ranking	percentage	Options to navigate to an unknown place
1	57,3%	Road signs
2	**42,8%**	**Fixed navigation system**
3	33,7%	I memorize my route beforehand
4	**32,1%**	**Portable navigation system**
5	**23.26%**	**Navigation app on tablet or smartphone**
6	10.3%	Paper map or print-out of the route
7	2.3%	Other (instructions of friends, instructions from passengers,..)

Table 1. Ranking of the percentage of respondents that use different navigation options, with electronic options in bold.

Third, as concerns the use of a fastening system, it seems that most of the respondents that use a portable system use a fastening system to fixate this device in the car (79.82%). However, the percentage of respondents that use a fastening system to install their tablet or smartphone is tremendously smaller, only 46.02% of the users of navigation apps, uses a fastening system.

When a fastening system is used to fixate a portable navigation device it is fixated most often at the front window (74.17%) and to a lesser degree on the dashboard (21.08%). Further, it seems that location 8 of the front window (see Figure 1) is the most common place to install the fastening system (59.56% of the respondents choose number 8 as the most common place where they fixate their system).

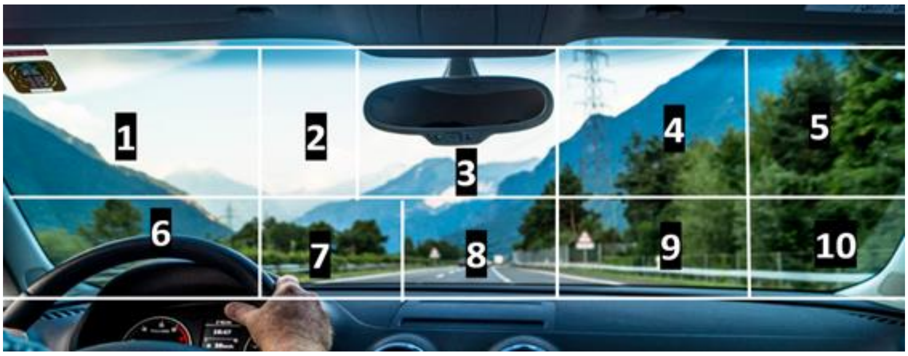

Figure 1. Different locations of the front window numbered from 1-10

As concerns the tablet or smartphone it seems that the most popular place to fixate them is the car ventilation grid (45.31%), followed by the front window (26.79%) and the dashboard (18.93%). Again, if the device is fixated at the front window, location 8 is the most popular location (63.53%).

Fourth, it seems that most respondents make use of both the visual and auditive information on their device (78.7% uses almost always or often both sources of information) and that most respondents (64.52%) place their smartphone or tablet in a vertically oriented position.

Main conclusions

The main conclusions of this questionnaire are twofold. First of all, we see that respondents make use of a wide variety of options to navigate to an unknown destination (road signs, paper maps,..). When we focus on the three electronic navigation devices, we see that fixed and portable navigation systems are the two most popular systems. When we examine the location of these portable systems, it seems that in most of the cases they are placed at the front window at location 8 (see Figure 1). Therefore in our naturalistic driving study (Study 2) we will compare these two set-ups. Moreover, in one set-up we will place a navigation system at a location comparable to the location of a fixed navigation system (i.e. right from the steering wheel at the height of the middle of the steering wheel, POSITION 1). In the second set-up we will fixate the navigation device at the front window in location 8 (POSITION 2).

Second, most respondents make use of both the visual and auditive information and place their smartphone or tablet in a vertical position. Therefore, in study 2 we will use both visual and auditive information and place a smartphone in a vertical position at the two locations described above (POSITION 1 and POSITION 2).

Study 2

Materials and Methods

Participants

30 participants will be tested. These participants (50% men, 50% women) will possess a driving license category B for at least two years, drive more than 1500km/year, will be between 26 and 55 years of age and will be familiar with the use of a navigation system in the car.

Design

A within subjects design will be used. Every participant will drive the same route of approximately 10 km in an urban area. The task of the participant will be to follow the directions of the navigation device (i.e. a smartphone with a navigation app). Half of the route will be driven with the device in POSITION 1, the other half of the route will be driven with the device in POSITION 2. The order of these two positions (first or second half of the route) will be counterbalanced over participants.

During the ride the eye movements of participants will be registered by eye-tracking glasses from pupil labs (https://pupil-labs.com/).

Analyses

Dependent variables in this eye-tracking study will be the number and the duration of fixations at the navigation system and at other areas of interest (vulnerable road users, the car mirrors, the road). Further, the number of fixations exceeding 2seconds will be measured and the x and y eye-coordinates during the whole ride will be registered.

These variables will then be compared between the two conditions of the experiment (POSITION 1 and POSITION 2). Linear mixed effect models will be used to model the data. This allows us to take into account random variation obtained by the repeated testing of the same participants.

The fieldwork is planned in April, so the data of this second study will definitely be analyzed and ready to present at the DDI conference in October.

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Effects of cognitive effort on simulated driving performance of adults with and without dyslexia

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Keywords: Cell phone; Cognitive effort; Dyslexia; Driver distraction; Traffic signs; Variable Message Signs

EXTENDED ABSTRACT

Aim of the study

Driving a vehicle is a complex, multi-task activity that relies on sensory, attentional, and high-level cognitive skills. Among the different tasks involved in driving, drivers have to read, for example, when they are searching a specific destination on an orientation traffic sign, or when a Variable Message Sign (VMS) is displaying a warning message. Not reading relevant information timely and accurately can have serious consequences. The main goal of the present study is to determine whether adults with dyslexia, a relatively common neurodevelopmental disorder affecting reading skills, are struggling with situations of driving that impose increased cognitive effort. The rationale is that the dyslexic adults have to invest more effort in reading while driving, and thus adding a high attentional demanding task would lead to greater impairment in performance. Therefore, specific countermeasures should be considered in plans aimed at reducing inequalities between the diverse groups of drivers (e.g., using on-board driver-assistance systems to complement the information given by traffic signs).

Background

Reading while driving can be especially tough for people with dyslexia. Dyslexia is a neurodevelopmental disorder characterized by difficulties in learning and using reading skills, despite adequate instruction, normal intelligence, and intact overt sensory abilities. The prevalence of dyslexia has been estimated to be between 6 % and 8.5 % of the population (Moll et al., 2014). During school years, most dyslexics develop compensatory strategies in an attempt to improve reading performance. However, their difficulties usually persist into the adult life (Beitchman & Young, 1997; Brunswick et al., 1999).

Dyslexia is strongly related with an impairment in phonologic processing (Peterson & Pennington, 2012). However, recent research suggests that other alterations can be also present in dyslexia, concerning the functioning of the neurocognitive mechanisms involved in visual attention (Vidyasagar & Pammer, 2009; Vidyasagar, 2013). Interestingly, these alterations might also have consequences on tasks involved in driving that do not require the processing of words, such as the detection of peripheral visual targets (Sigmundson, 2005). In addition, Fisher, Chekaluk & Irwin (2016), and Taylor, Chekaluk & Irwin (2016) found a relationship between the scores in a self-report measure of dyslexia for adults and performance in a driving simulator.

Previous studies in our laboratory provided additional evidence on the difficulties of drivers with dyslexia. For example, we have reported that adults with dyslexia using a driver simulator make more errors in reading names of towns displayed on traffic signs, and they need to be closer to the traffic sign to read a long than a short name (Tejero, Roca, & Insa, in press). We have also reported that drivers with dyslexia correctly read the message displayed on a VMS when they were about 22 m closer to the sign, as compared to drivers without dyslexia (Roca, Tejero, & Insa, 2018). Importantly, we also found that some aspects of the basic control of driving, such as keeping a constant speed, deteriorates in adults with dyslexia when the driver is approaching to a traffic sign displaying a text message, but not in other sections of the simulated road where drivers were not required to read.

In short, the previous results point out that dyslexic drivers are at a disadvantage, not only in obtaining written information while driving, but also in controlling the vehicle speed while reading a traffic sign. Importantly, our data suggest that the impairment in driving performance might be a consequence of the increased cognitive demands that reading imposes. But these previous studies were not directly analyzing the impact of increased cognitive effort and, therefore, the question is what would happen when the driving situations are more complex. As previously said, the present study will focus on the examination of driver's performance when the driver has to deal with reading text displayed on a traffic sign, while performing an additional attentional-demanding task, such as a cell phone call. It is well known that concurrent attentional tasks deteriorate driving performance (Brookhuis, de Vries, & de Waard, 1991; Lamble, Kauranen, Laakso, & Summala, 1999; Strayer and Johnston, 2001; Strayer, Drews, & Johnston, 2003). Our expectation is that the driving performance will be impaired by an attentional demanding task to a greater extent in adults with dyslexia than in adults without dyslexia, when the driver is approaching to a VMS displaying a text message.

Methods

Two groups of 22 participants each (participants with and without dyslexia, matched in age, sex, intelligence, and driving experience) were recruited to drive on a simulated motorway. The participants were asked to keep the right lane and drive at a constant speed of 120 km/h, excepting some sections where the posted speed limit was 80 km/h. They were also told that they should read the text message displayed on every VMS and indicate, as soon as possible, whether the VMS informed about 'dangerous' circumstances (e.g., '*attention pedestrians in the tunnel*') or 'informative' circumstances (e.g., '*attention inspect your vehicle tyres*'), by using one of two levers (i.e., a left lever for 'dangerous' messages, and a right lever for 'informative' messages, both of them located behind the steering wheel). In this way, we could check whether or not the participant had attentively read the VMS. We used three different danger messages, and three information messages, repeated three times each, on different trials. Therefore, eighteen VMS were presented along the route, at random order. Before the experimental session, participants practiced to give the correct response to each message. The participants were asked to give their responses without neglecting driving.

Each participant completed the previous task three times. The first time (no distraction condition) they just had to drive and read the VMS. During the second and third times (conceptual or visuospatial conditions, presented in counterbalanced order by participant), a series of audio messages simulated incoming cell phone calls while the participants were approaching each VMS. All audio messages comprised a call ringtone and a question. Half of the questions were designed to elicit conceptual cognitive processing (e.g., "*Which instrument is usually made of wood, a guitar or a drum*?), while the other half induced a visuospatial processing (e.g., "*Which figure has the shape of a tie, 8 or 4*?"). Participants were instructed to answer orally the questions as soon as they could correctly do it, without neglecting the driving task nor the VMS reading task. The order of responses to the task involving VMS reading and the simulated phone calls was elective for the participant.

Separate ANOVA with Task, as a within-subject factor (no distraction / conceptual distraction / visuospatial distraction), and Group, as a between-subject factor (with dyslexia / without dyslexia), were performed for three different measures. We analysed the participant's correct response distance to the VMS, and the accuracy when responding to the VMS and to the oral questions. Driving performance was analysed by means of the speed variability and the standard deviation of lateral position (SDLP).

Results & discussion

First, as for the VMS reading task, overall, there were no significant differences between participants with and without dyslexia in accuracy (with dyslexia: 92.5 %, without dyslexia: 94 %), with no interaction with Task (no distraction/conceptual distraction/visuospatial distraction). However, for participants with dyslexia, the high accuracy in the reading task came with a cost. For correctly responding, the distance to the VMS at which the response was given was, on average, shorter for the participants with dyslexia (with dyslexia: 70 m, without dyslexia: 97 m; $p < .001$), with no interaction with task condition (i.e., the cost was similar regardless whether or not the participant was engaged in answering a question from a simulated phone call, and regardless the type of question). As there were no overall, significant differences between the two groups in mean vehicle speed, nor in vehicle speed variability, during vehicle approach to the VMS, these results suggest that the participants with dyslexia needed more time to give correct responses to VMS. In addition, note that reading difficulties in participants with dyslexia manifested even in the easiest condition (no distraction condition), which is consistent with the previous literature reporting that adults with dyslexia struggle when reading the contents of traffic signs (Roca, Tejero, & Insa, 2018; Tejero, Roca, & Insa, 2018).

Second, the percentage of correct responses to the oral questions from the simulated phone call task was slightly lower for the participants with dyslexia than for the control participants (with dyslexia: 95.2 %, without dyslexia: 97.3 %; $p = .04$). However, considering that there might have been a trade-off between performance in the task involving reading VMS and performance in the simulated phone call task, we also computed a combined accuracy measure (i.e., a combined correct response = correct responses in both tasks, error = no correct response in any of the tasks). For this combined accuracy measure, the results showed a significant Group x Task condition interaction effect ($p < .002$). Post-hoc analyses suggested that this effect was due to group differences in the conceptual distraction condition only, in which the participants with dyslexia obtained lower combined accuracy percentages (with dyslexia: 88.1 %, without dyslexia: 94.7 %; $p = .02$), with no differences between the two groups in the other task conditions (no distraction, or visuospatial distraction). The participants without dyslexia obtained combined accuracy percentages lower in the visuospatial distraction condition (88%) than in the other two task conditions (no distraction: 95 %, conceptual distraction: 95%), a result which is consistent with previous studies on the effects of cognitive distraction on driving using samples of drivers from general population. In contrast, the participants with dyslexia obtained combined accuracy percentages similar in the two task conditions with distraction (visuospatial distraction: 85%, conceptual distraction: 88%), which, in addition, were lower than in the condition with no distraction (96%), suggesting that drivers with dyslexia have trouble managing reading VMS while being engaged in a phone call and driving.

As previously said, neither mean vehicle speed or vehicle speed variability during vehicle approach to the VMS differed between the two groups. In addition, no significant effects were found from the analysis of the variability of vehicle lateral deviation. Therefore, the results did not support that the addition of an oral question while attempting to read a VMS and driving would lead to a greater impairment of vehicle control in adults with dyslexia.

As a whole, our results are consistent with the idea that dyslexia can have consequences on the processing of information displayed on traffic signs while driving, especially, in high-attention-demand conditions. Therefore, specific countermeasures, such as using on-board driver-assistance systems to complement the information given by traffic signs, must be considered in plans aimed at increasing traffic safety and fluidity.

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Auditory and visual messages for drivers with and without dyslexia: effects on a car following task

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Keywords: Variable Message Signs; Dyslexia; Auditory Messages; Countermeasures

EXTENDED ABSTRACT

Aim of the study

The study of the specific needs of drivers with disabilities and the development of universal design measures in the transport system have become important fields of research. The aim of the present work was to study how drivers with and without reading disabilities (e.g., dyslexia) manage visual and auditory messages while performing a car following task. According to previous research, adults with dyslexia are still struggling with the reading of text messages in traffic signs while driving (e.g., Tejero, Insa, & Roca, in press; Roca, Tejero, & Insa, 2018). However, the previous studies focused on the processing of visual information. In the current study, we analyze the potential use of oral messages to complement the traffic information given to drivers with and without dyslexia in Variable Message Signs (VMS).

Background

A quick and accurate acquisition of information from traffic signs or in-vehicle systems can be critical for traffic safety. Unfortunately, some individual differences (e.g., a reading disability) can affect the identification of such messages and, as a result, a driver can misunderstand the situation and make a wrong decision. The present work focuses on dyslexia, a neurocognitive disorder affecting the learning and use of the reading skills. People with dyslexia may read more slowly or make more errors, especially in high-demanding situations. In addition, adults with dyslexia may as well show poor performance in other tasks involving attention (e.g., Bosse, Tainturier & Valdois, 2007; Bogon et al., 2014).

Reading a traffic sign while keeping appropriate control of the vehicle can be conceived as a sort of dual task (e.g., when the driver has to read text displayed on a traffic sign and, at the same time, has to keep a safe following distance). Visual and attentional resources are required by both tasks, and, consequently, such a dual-task will require increased visual and attentional demands, as compared to the individual tasks. Therefore, considering the reading and the attentional difficulties of the people with dyslexia, reading written messages while driving can be especially challenging for them.

Previous research on dyslexia and driving has focused on the processing of information received via the visual system (e.g., Tejero, Insa, & Roca, in press; Roca, Tejero, & Insa, 2018). Regarding the use of the auditory channel, using oral messages to complement text in traffic signs could be a potential countermeasure to help drivers' with dyslexia improve the acquisition of information. In fact, such a measure might potentially benefit any driver, with or without dyslexia, in non-optimal attentional or perceptual driving conditions (see, for example, Ghirardelli & Scharine, 2009; Liu, 2001; but see also Wickens & Gosney, 2003). Interestingly, there is also some evidence that drivers prefer the auditory modality for some messages, and even more, they remember the message better if it is received via the auditory than the visual system e.g., those related to the route guidance (Dalton, Agarwal, Fraenkel, Baichoo, & Masry, 2013). In consequence, our hypothesis was that, not only drivers with dyslexia, but also normally reading drivers, would benefit from the availability of complementary audio versions of traffic sign content, which would be reflected both on measures of the processing of the message and driving performance.

Method

A group of twenty adults with dyslexia, and a group of twenty normally reading individuals (matched in sex, age, and IQ) participated in a driving simulation experiment. Their age ranged from 18 to 47 years (mean = 24.8). All the participants were native in Spanish. We used a Carnetsoft driving simulator (https://www.rijschool-simulator.nl/). Participants drove along a route in a motorway environment, where a series of VMS displayed messages written in Spanish, and they had to complete two tasks at the same time: a car-following task and a reading task.

Regarding the first task, they were instructed to drive in the right lane and keep a constant distance to a preceding car (about 50 meters), which travelled at a speed of 80 km/h or 100 km/h. Critically, every time the participant was at 350 meters from a VMS (a distance at which the VMS was not legible yet), the leading car started to quickly decelerate from 100 to 80 km/h, with a deceleration rate that was different in each trial. Therefore, participants had to adapt their distance to the preceding car accordingly with such deceleration, while approaching the VMS and trying to read its content.

In addition to the car-following task, participants were also asked to read the messages displayed on the VMS in order to classify the message as a ‘keep-lane message’ (i.e., a VMS informing on circumstances that would not require a lane change, such as ‘MANDATORY RIGHT LANE’) or a ‘change-lane message’ (i.e., a VMS informing on circumstances that would require a lane change, such as ‘MANDATORY LEFT LANE’). They were instructed to respond as far as possible from the VMS, without making errors, and maintaining driving performance. There were eight different messages, four of them were ‘keep-lane messages’ and the other four were ‘change-lane messages’. The required response was pressing a right lever (keep-lane) or a left lever (change-lane), which were located behind the steering wheel.

Task trials were defined as the sections beginning at the time when the preceding car was at 350 m from a VMS, and ending at the time when the driver’s manual response to the VMS was initiated or, if no response occurred, at the time when the driver’s vehicle was just at the place where the VMS was posted. Each participant completed the experimental driving task twice, presented in a counterbalanced order by participant: a) one in which the messages were displayed on a VMS as previously described (visual condition); and b) another one in which the message displayed on the VMS was additionally sent as an auditory message, starting just a few seconds before it was possible read the VMS (visual & auditory condition). In each of these two task conditions, 24 trials (8 messages x 3 repetitions) were randomly presented for each participant (48 trials in total). Before the experimental trials, the participants completed a training session on the driving task and a block of practice trials of the message classification task separately.

Separate ANOVA with Task condition, as a within-subject factor (visual versus visual & auditory), and Group, as a between-subject factor (with dyslexia versus without dyslexia), were performed for three different measures: response accuracy (% of correct classification of the messages), mean response distance (meters from the VMS at which correct responses were given), and the standard deviation of the distance to the preceding car (the higher the standard deviation, the worse the participant’s ability to adjust his/her speed to the leading vehicle). Post-hoc analyses were also performed to test the significance of differences among particular conditions.

Results & discussion

Accuracy in the classification of the messages was overall better ($p<.001$) in the visual & auditory condition (98.1 % of correct responses) than in the visual condition (95.2 %), with no significant differences between the two groups, nor an interaction effect. Therefore, the availability of an oral version of the message displayed on the VMS had a general positive impact on task performance in terms of accuracy, both for the participants with and without dyslexia.

Regarding the mean response distance, the interaction Task condition x Group produced a significant effect (p=.009). As expected, in both groups, the visual & auditory condition produced an overall mean distance longer than the visual condition did (p<.001). Importantly, the mean response distance in the visual condition (with no oral message) was 18.5 m longer for the participants with dyslexia than for the participants without dyslexia (p=.02), suggesting that the former participants are at a disadvantage in processing text messages displayed on VMS. In contrast, such differences virtually vanished in the visual & auditory condition (the difference between the two groups within this condition was 1.9 m, no statistically significant).

As for driving performance, the standard deviation of the mean distance to the preceding car during the trial was higher in the visual condition (6.9) than in the visual & auditory condition (6.0) for all participants (p<.001), with no differences between the two groups, nor an interaction effect. Since the participants were told to keep a steady distance, this result suggest that the addition of the oral version of the message also had a positive impact on the driving performance, allowing better adjustment of the vehicle speed while the leading car was decelerating.

In short, all the participants, with and without dyslexia, not only responded at a longer distance when an auditory message was presented together with the visual message, but they were also more accurate in completing the reading task and more able to keep a steady distance to the preceding car. Moreover, the addition of the oral message seemed to cancel the disadvantage of drivers with dyslexia when processing single text messages displayed on VMS. Therefore, these results suggest that combining visual and oral messages can be a useful measure aimed at drivers with or without reading difficulties.

In our view, this study may have relevant potential applications to improve traffic safety and fluidity, not only for the reading-impaired individuals, but also for any driver in non-optimal attentional or perceptual driving conditions.

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Efficient Monocular Point-of-Gaze Estimation on Multiple Screens and 3D Face Tracking for Driver Behavior Analysis

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Keywords: Point-of-Gaze Estimation; 3D Face Tracking; Driver Behavior Analysis; Deep Learning

EXTENDED ABSTRACT

In this work, we present an efficient monocular method to estimate the point of gaze (PoG), considering that it can lie on different screens around the user, and to track the user's face in the 3D space, for driver behavior analysis. Typically, state-of-the-art eye gaze estimation techniques obtain the PoG on one screen, only. However, in the case of driving simulators there are usually more than one, e.g., one for the front view, one for each side view, another one for the dashboard, etc (Figure 1). As there can be different objects of interest at different locations of each screen, the accurate estimation of the gaze fixations and saccades derived from the PoG on each screen is important for driver behavior analysis [1]. Additionally, it is also preferable to simplify the installation and calibration of sensors and to reduce the power consumption as much as possible, avoiding alternative possibilities such as placing a dedicated PoG estimator for each screen. Thus, we only consider one monocular camera in front of the driver and a humble CPU, e.g., those included in an embedded PC or a smartphone.

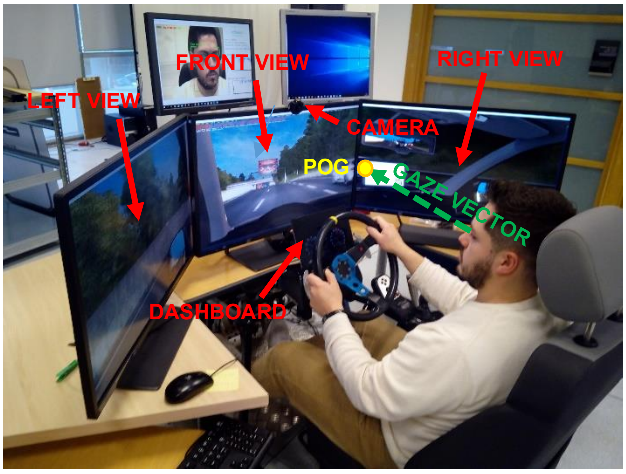

Figure 1. Multi-screen simulator setup for driver behavior analysis, based on human-machine interaction, including PoG and 3D face tracking.

In automotive platforms, visual features of the face and eye regions of a driver provide cues about their degree of alertness, perception and vehicle control. Knowledge about driver cognitive state helps to predict, for example, if the driver intends to change lanes or is aware about obstacles and thereby avoid fatal accidents. These systems use eye tracking setups mounted on a car's dashboard along with computing hardware running machine vision algorithms, with computational capabilities far below from those of off-the-shelf desktop

PCs. Major sources of error in automotive systems arise principally from platform and user head movements, variable illumination, and occlusion due to shadows or users wearing glasses, which need to be handled robustly but also efficiently due to the computational constraints.

The current state of the art of eye gaze estimation systems applied to automotive platforms includes different kind of approaches and uses. There are approaches that consider eye movement features (e.g., fixations, saccades, smooth pursuits, etc) for deriving driver cognitive states, such as driver distraction [2]. Other approaches apply classification techniques to eye images related with different gaze zones, to detect where the driver is looking at while driving [3]. There are also approaches that track facial features, 3D head poses and gaze directions relative to the car geometry to detect eyes-of-the road condition of the driver [4]. Other approaches study the driver's gaze behavior (e.g., glance frequency and glance time) to evaluate the driving performance when they interact with other devices (e.g., a portable navigation system) while driving [5]. Finally, there are also approaches that study the dynamics between head pose and gaze behavior of drivers to predict gaze locations from the position and orientation of a driver's head [6] or to categorize different kind of driver behaviors while driving [7].

Our main motivation in this work is to increase the grade of sophistication of all this kind use cases by developing a more accurate, more robust, but still efficient method for estimating the head pose and eye gaze of drivers, compared to previous approaches.

Figure 2 shows the general overview of the workflow of our approach, where the input is a monocular image grabbed by one camera in front of the driver and the output are his/her estimated PoG with respect to the considered screens and his/her facial mesh in the 3D space, which includes information about his/her head position, orientation and expression.

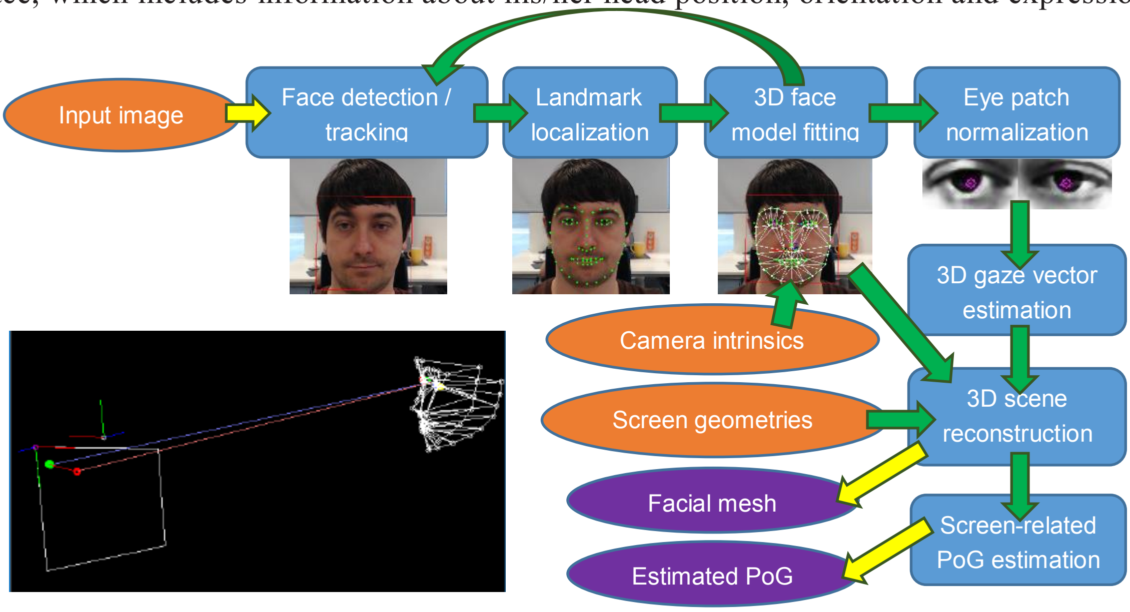

Figure 2. Workflow of the multi-planar PoG estimation and 3D face tracking approach.

This approach is a hybrid between efficient appearance-based and model-based computer vision procedures. The appearance-based procedures rely on trained classification and regression models (face detection, landmark detection and gaze vector estimation), while the model-based (face tracking and face model adjustment), rely on geometric 3D graphical models. The main procedures are explained next:

Face detection / tracking: For the localization of the driver's face region two stages are distinguished: (1) the initial face detection and posterior re-detections when the tracking is lost, and (2) the in-between face tracking. This is relevant as tracking algorithms typically are more efficient and require less memory than those for face detection. Thus, the face detection algorithm is only activated when the driver's face is not being tracked. The detection is done with the SSD deep neural network [8], which has shown to be robust under challenging conditions, trained specifically with multiple-pose faces, while the tracking is based on CLNF [9], applied at landmark level, which has a good balance between computational cost and localization reliability and stability. The landmark distribution is constrained by a parametric 3D face model, to avoid impossible human facial shapes. The tracking is considered to be lost when the image under the face region does not correspond to a human face, according to the learned face pattern.

Landmark localization: As explained for the previous procedure, CLNF is applied for the face landmark localization once the driver's face region is determined.

3D face model fitting: A parametric 3D model is adjusted to the localized landmarks using a sequence of three optimization stages. This process estimates the face position, shape and gesture parameters (in that order) minimizing the error distance between the given landmarks and the projection of the 3D vertices, assuming a full perspective projection.

3D gaze vector estimation: Once the different facial parts are localized, the image regions around both eyes are extracted, and their shape and intensity distributions are normalized, so that a deep neural network, based on [10], can infer the corresponding 3D gaze vectors. Then, an overall gaze vector of the user is calculated as the mean vector of both eyes with its origin at the midpoint of both eyes.

3D scene reconstruction: The different elements that compose the scene (camera, face, gaze vectors, screens) are placed in the same space, where the origin is located at the camera. In this context, we can estimate the PoG related to the considered potential targets, i.e., the screens. Thus, the intersections of the overall 3D gaze vector with the planes that contain each screen is calculated with an efficient line-plane intersection geometric procedure.

Screen-related PoG estimation: Finally, a point-in-polygon strategy [11] is applied to see if any of the calculated PoGs lies within any of the screens. In the case that the overall gaze vector does not intersect any screen, we provide the PoG on the same plane as that of the closest screen.

We have done some experiments to evaluate the PoG estimation method in different aspects:

Accuracy: We have compared the PoG with respect to several target points located around the screens with and without an additional calibration stage. Experiments show how there is a reduction in the error when the data is calibrated, but the error for the uncalibrated estimations are also reasonable in automotive applications.

Efficiency: We have integrated it in and iPhone SE (in which the Operating System is iOS 10.3.2, the core of our program is in C++ and the interface in C#) and in a Docomo (in which the Operating System is Android 6, the core of our program is in C++ and the interface in Java). The measured FPS in each are 30 and 20 respectively.

One of the advantages of this method is that it can be integrated in embedded hardware systems with low computational capabilities, with sufficient robustness for driver behavior analysis. Future work will principally focus on optimizing the deep neural network designs to further improve their efficiency in CPUs.

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Detection technology for driver's non-normal physiological state for vehicle safety

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Keywords: AdaBoost, Anger, Distraction, Drowsy, Kohonen neural network

EXTENDED ABSTRACT

The aim of this research is to enhance performance of vehicle safety by comprising driver's physiological state alert function in cooperation with artificial intelligence (hereinafter; AI) technology for autonomous driving [1] [2] [3]. Signal processing technology was used to identify driver's physiological state, which technologies are image processing and pattern recognition as well as neural network. One of candidate of pattern recognition method is AdaBoost [4] which is known as boosting method in machine learning area. The other is Kohonen neural network (hereinafter; KNN) which uses self-organizing map [5]. Therefrom, this research reviewed previous research of driver's states monitoring technology. Then this research refined previous research of analytical results of traffic incidents data collected by Internet survey on real-world experience basis [6]. The number of traffic fatalities as of 2017 [7] has declined under 3, 700, 69 years after, because of enhancement of vehicle safety as well as comprehensive safety counter-measure of elderly person. However, the number of injuries has still exceeded some 0.5 million. Further enhancement of road traffic safety is urgent challenge to create sustainable mobile society.

Research of driver's distraction as well as drowsiness state has started in the middle of 1990's by ASV project in Japan, and, also AWAKE and AIDE project in EU Framework Programme. After that many research with regards to drowsiness has been executed, any practical drowsiness detection method may be introduced into production vehicle. Several cases as to face direction detection and eye closing detection method are introduced into production vehicle as well as attention assist system. There is few case as to anger state detection. Currently lots of automakers have been developing autonomous vehicle in cooperation with AI. These autonomous vehicles may enhance safety function by judging comprehensive driver's physiological state, vehicle control status and road environment situation as well as alerting imminent risk information to a driver. In the sense, driver's physiological detection may be key issue to be incorporated into driver's physiological states adaptive driving safety function, which leads enhancement of safety of autonomous driving system.

According previous research, root cause of traffic accidents is almost human error which is 90% [8] [9] [10]. This research reviewed driver's non-normal physiological states by analyzing real world traffic incidents data collected by Internet survey. Results of analysis based on this survey showed that major non-normal psychosomatic states include "haste" (26.6%), "distraction" (26.5%), drowsiness (4.6%) and anger (3.1%). Therefrom, this research focused driver's distraction, drowsiness and anger states as higher potential risks in traffic accidents. According previous research [11] [12], changes in heart beat and eye movement are often identified as alternative characteristics of driver's distraction. Also, facial expression is identified as alternative characteristics of drowsiness and anger.

Signal processing may be indispensable technology to detect driver's non-normal physiological states. In order to classify driver's cognitive distraction states, this research used mock-up type driving simulator.

Monitor lead method which includes standard limb lead (II) and measurement with 3 chest electrodes was introduced, which can detect ECG waveform. Data was acquired every 5 seconds, and data set was sampled at 60 Hz. Heart rate and heart rate RRI (HR-RRI) as one of alternative of driver's cognitive distraction were calculated by measuring an interval of R waves (RRI) in an ECG waveform.

Eye movement as well as head movement were tracked by two camera system which is called "faceLAB (Australian make)". This research adopted standard deviations (hereinafter; SD) of gaze angle as well as head rotation angle as alternative of driver's cognitive distraction [13] [14] [15]. Candidate physiological signals were validated by confirming differences between ordinary driving and cognitive loads which were conversation and arithmetic. According previous study [13] [14], frontal focal points of eye sight were scattered widely to peripheral area during ordinary driving, frontal focal points were concentrated within a narrower range when cognitive loads were imposed. Average value of SD of gaze angle decreased by 12.2% by cognitive loads compared with ordinary driving. This agreed with the trend of previous research [13] [14] [15]. However, SD of head rotation angle in cognitive loads condition decreased by 62.8% compared with ordinary driving. From the results SD of gaze angle and head rotation angle were judged as available as features to classify cognitive distraction. When cognitive loads of arithmetic and/or conversation were imposed to the participants, pupil dilated by acceleration of the autonomic nerve. Average value of pupil diameter by cognitive loads increased by 14.1% compared with ordinary driving. From results of SD of combined gaze angle and head rotation angle and pupil diameter were concluded as available for features to classify cognitive distraction. Average heart rate increased approximately by seven beats per minute when cognitive loads were imposed. The order of this result agreed with previous research [11] [12]. Average heart rate RRI imposed by cognitive loads decreased by 9.5% compared with ordinary driving. This change is believed to be a result of higher heart rate caused by cognitive loads. From the above results, average value of heart rate RRI was concluded as available as a feature to classify cognitive distraction. From the above validation, this research selected SD of gage angle and head rotation angle, pupil diameter and heart rate RRI (HR-RRI) as features to classify driver's cognitive distraction.

This research adopted AdaBoost to classify a state of driver's cognitive distraction, which may have advantages of high classification performance, rapid recognition process time and expandability of recognition features. Learning by AdaBoost makes different classifiers while continuously weighting of the learning data. After weighted majority decision is executed, multiple classifiers create final function of classification. Those individual classifiers is called as weak classifier, while final classifier is called as strong classifier. By using SD of gaze angle and SD of head rotation angle, average value of pupil diameter, and, average value of HR-RRI as input data for AdaBoost, this research executed learning and evaluation of classification of driver's cognitive distraction. From calculation by means of using AdaBoost algorithm, classification performance showed that top common result in average accuracy was 91.5 percent in arithmetic load, which classification features were combination of all three features of Visual Information (SD of gaze angle and head rotation angel) plus PD (Pupil Diameter) plus HR-RRI. Second top common in average accuracy was 91.0 percent in conversation load of all three features. From the results, combination of all three features by using AdaBoost with arithmetic loads showed the highest classification performance. Therefrom pattern recognition method called AdaBoost may be applicable to identify driver's cognitive distraction.

In order to identify Driver's drowsiness and anger states, this research adopted Kohonen neural network [16] [17] [18], which uses self-organizing map. This research tried to utilize facial expressions of driver to classify driver's drowsiness and anger. According previous research [19], human emotion may be represented by six facial expressions, which are "ordinary", "drowsiness," "anger", "sorrow", "delight" and "surprise". Therefrom, this research adopted two types of facial expression as alternative characteristics to identify both driver's drowsiness and anger by using KNN, and defined six types of facial expression as self-organized map. Normalization of orientation and size of face was done by using coordination of eyes and nose. This research took 6 pictures for 6 facial expressions per one participant. 240 out of 288 pictures of facial expression was selected. 40 facial expressions were allocated for each facial expression. Then classification experiment by means of using KNN was executed. At the same time, subjective evaluation for six facial expressions was executed by the same participant. As one of improved method, this research introduced classification by Mahalanobis' distance [20].

Classification accuracy of drowsiness 93.8% which was second top in common among 6 facial expressions. However, amount of subjective evaluation of drowsiness was 81.3% which was fourth top in common. Classification accuracy of anger was 83.3%, which was fourth top in common among 6 facial expressions. Amount of subjective evaluation of anger was 91.7%, which was third top in common. Therefore, this examination by means of using Kohonen neural network was said as practical to classify states of both drowsiness and anger.

Accordingly, this examination adopted two kinds of classification accuracy between facial expression and subjective evaluation for states of drowsiness and anger. This method of classifying both driver's drowsiness and anger states may be applicable to driver's physiological states adaptive driving support safety function which should be included one of contents of artificial intelligence (AI) unit for autonomous driving in near future.

This research reviewed driver's non-normal physiological states by analyzing real world traffic incidents data collected by Internet survey. This research introduced two types of signal processing method to identify classification accuracy of driver's cognitive distraction and drowsiness as well as anger states, which algorithm were AdaBoost and Kohonen neural network. Classification accuracy of these two methods indicated higher amount which could be incorporated into driver's physiological states adaptive driving support safety function in cooperation with artificial intelligence for autonomous driving.

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Keeping drivers engaged in automated driving through maneuver control - effects on perceived control and responsibility

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Keywords: automated driving; automotive HMI; individual automation; maneuver control

Background

Highly automated driving is projected to change the global transportation system in the future, taking the human driver out of the control loop of vehicles [1]. However, systems employed today still require a human to monitor the automation, changing a driver's task from actively controlling the vehicle to a monitoring role [2]. Research shows that drivers frequently engage in secondary tasks and do not fulfil the required monitoring role [3][4]. This distraction from drivers' monitoring task leads to decreased detection of automation failures and a lack of situation awareness in takeover situations [5][6]. Vehicle manufacturers have implemented systems that aim to ensure continuous monitoring, e.g. through requiring the driver to have regular contact with the steering-wheel or through monitoring the driver's attention and turning of the automation if inattention is registered [7][8]. Existing safety systems penalize inattention, but do not increase drivers' engagement in the monitoring task.

A relatively new field of study in the area of automated driving has been the implementation of *shared control* or *maneuver control* [9][10][11]. Under this proposed control scheme, the basic driving task, i.e. control of speed and trajectory of the vehicle, is controlled by the automation. Advanced driving parameters, such as following distances, lane choice, and targeted maximum speed can be controlled by the driver through a human-machine interface (HMI). Shared control allows the driver to influence the driving style of the automation and to initiate driving maneuvers without taking over complete control of the vehicle. In theory, the concept encourages drivers to stay engaged in the driving task, although the vehicle automation is activated. A first implementation of this concept is Tesla's lane change assist, which allows drivers to initiate a lane change maneuver during highly automated driving [12].

In this driving simulator study, we investigated how the ability to adjust driving parameters and initiate driving maneuvers in highly automated driving influences the subjective experience of drivers when compared to driving a completely automated vehicle without maneuver control, and self-driving without any form of automation. We hypothesized that drivers' perceived level of control and perceived responsibility for potential crashes would be significantly increased through the implementation of maneuver control when compared to automated driving without maneuver control. We further hypothesized that drivers would use maneuver control to adjust the vehicle's following distances to a value that correlates with their preferred following distance in self-driving.

Method

A convenience sample of 42 participants (28 female) was recruited from the Leuphana University Lüneburg. Participants were on average *M* = 22.36 years old (*SD* = 3.36), had an average driving experience of *M* = 4.5 years (*SD* = 2.9) and had driven an average of *M* = 30,378 kilometers since acquiring their license. The study was conducted in a fixed-base driving simulator with a projected field of view of 110°x30° (3072x768 pixels), running version 1.4 of the SCANeR Studio driving simulator software from Oktal. A joystick with a 3D-printed top was installed in the center console of the simulator as the HMI that allowed participants to initiate maneuvers and adjust driving parameters.

In a within-subject repeated measures design, the level of control that participants had over the vehicle was varied threefold. Participants either had complete control over the vehicle (full control), were driving highly automated but could use the joystick to adjust driving parameters or initiate maneuvers (maneuver control), or had no control over the vehicle as it was driving fully automated (no control). Participants were presented with 18 traffic situations on city-, rural-, and highway-roads. 12 of these situations were designed to allow participants to either conduct a driving maneuver themselves (full control condition), initiate a maneuver through use of the joystick HMI, or monitor a driving maneuver conducted by the automation (no control). Driving maneuvers in these 12 situations consisted of lane changes and take-over maneuvers in different traffic environments. In 6 more situations, participants were following another vehicle and could either adjust their following distance through the use of the brake and gas pedal (full control), through using the joystick HMI (maneuver control), or monitor the following distance without the possibility to adjust it (no control). All 18 traffic situations were presented in one block for each condition (full control vs. maneuver control vs. no control), while the sequence of the blocks was randomized. After each block of 18 traffic situations, participants rated their subjective experience during the block on the disco-scale (Table 1) which measures discomfort in automated driving through 15 items on a 5-point Likert scale [13]. Furthermore, time headway following distances were registered for the full control and maneuver control block of the experiment. Time headway following distances in the no control condition were fixed to 3 seconds for all participants.

Table 1 Disco-scale

Items (Answered on a 5-point Likert scale (“strongly disagree” “strongly agree”))
1. I can move unconcerned using the system.
2. I feel endangered by the system.
3. With more clearance distance my journey would be more comfortable.
4. I felt that I could always intervene in time.
5. Using the system is unpleasant.
6. The system relieves me as a driver.
7. I was always in control of the situation.
8. I felt safe during the drive.
9. I felt the situation was risky.
10. There was enough safety clearance to travel comfortable.
11. I found the driving situation to be uncomfortable.
12. If an accident happens I am responsible.
13. The system is an added burden.
14. In my opinion the system increases safety.
15. I perceive driving myself as less strenuous.

Results

While the disco-scale consists of 15 items, only the results on perceived ability to control the vehicle (item 7), ability to intervene in time (item 4), and potential responsibility in case of a crash (item 12) are presented in this extended abstract. When asked to rate their ability to control the vehicle on a 5-point Likert-scale (1 to 5), the full control condition was rated highest for controllability (M = 3.48, SD = 1.11), followed by the maneuver control condition (M = 2.50, SD = 1.33), and the no control condition (M = 1.52, SD = 0.94). A repeated measures ANOVA was calculated to test the effect of level of the independent variable on the perceived level of control. As Mauchly's Test revealed a violation of the assumption of sphericity for the main effect of control ($\chi^2(2) = 9.51$, $p < .01$), Greenhouse-Geisser corrected degrees of freedom were used ($\varepsilon = .83$). Control conditions were rated as significantly different on the perceived control item ($F_{(1.65, 67.68)} = 38.18$; $p < .01$; $\eta_p^2 = .48$). Post-hoc tests using Bonferroni correction for multiple comparisons revealed significant differences between all levels of control (all $p < .01$).

Participants further rated if they thought they could intervene in time during the traffic situation. Perceived ability to intervene was again highest in the full control condition (M = 3.62, SD = 1.17), followed by rating in the maneuver control (M = 2.29, SD = 1.24), and no control condition (M = 1.76, SD = 1.27). A repeated measures ANOVA revealed significant differences between perceived ability to intervene ($F_{(2, 82)} = 26.24$; $p < .01$; $\eta_p^2 = .39$) depending on the level of control. Bonferroni corrected post-hoc tests revealed that there is a significant difference in the level of perceived ability to intervene between the full control and the maneuver control condition ($p < .01$), as well as the full control and the no control condition ($p < .01$). There was no difference in perceived ability to intervene between the maneuver control and no control condition (p = .069).

When asked if they would feel responsible for a potential crash with the vehicle, participants felt most responsible in the full control condition (M = 3.45, SD = 1.12), followed by the maneuver control (M = 3.14, SD = 1.10), and no control condition (M = 2.12, SD = 1.31). A repeated measures ANOVA revealed significant differences between conditions $F_{(2, 82)} = 20.51$; $p < .01$; $\eta_p^2 = .33$). Post-hoc test with Bonferroni correction revealed that perceived responsibility in case of a crash differs between the full control and the no control condition, as well as between the maneuver control and the no control condition (both $p < .01$). There was no significant difference in perceived responsibility between the full control and maneuver control condition.

Time headways from traffic situations in which the following distance to a lead vehicle could be adjusted were found to correlate significantly between the full control and maneuver control conditions (r = .38 to .72, all $p < .05$).

Conclusion

The ability to adjust driving parameters and initiate maneuvers in highly automated driving has positive effects on the subjective experience of drivers. Participants in this study felt more in control of the vehicle in driving situations with maneuver control when compared to highly automated driving without this ability. Furthermore, maneuver control increased the perceived level of responsibility in case of a crash, to levels that do not significantly differ from self-driving (full control condition). This high level of perceived responsibility could help to keep drivers of highly automated vehicles engaged in the driving task. While our results on drivers' perceived ability to intervene indicate that they do not perceive the joystick HMI as a tool to use in case of safety critical intervention, the effect of maneuver control on take-over behavior needs to be researched in future studies. The results of a significant correlation between following distances in self-driving (full control) and adjusted following distances in maneuver control conditions indicates that drivers use the ability to adjust driving parameters to individualize the driving style of the automated vehicle to align with their own preference in self-driving.

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