Corinne Brusque  
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PREFACE

The widespread distribution of in-vehicle driver information systems on the market and the emergence of advanced driver assistance systems are profoundly changing road transport and more specifically driver environment and driving activity. Through Intelligent Transport Systems, a range of services are indeed offered to the driver with the objective of facilitating the driving task and improving travel safety. Despite the potential benefits on road safety, these developments raise numerous questions about their relevance, usability and acceptability for drivers and their impact on drivers’ behaviour and attitudes. All this contributes to the necessity of encouraging a Human Centred Design approach, in which ITS are designed according to driver needs.

That is the reason why the HUMANIST Network of Excellence decided to organize a conference that would allow the community of Human Factors researchers to gather in order to present and discuss current works on various aspects of Human Centred Design for Intelligent Transport Systems.

The first European conference on Human Centred Design for Intelligent Transport Systems held in Lyon on 3rd & 4th April 2008 was organized by INRETS, the French National Institute for Transport and Safety Research and by ERT, Europe Recherche Transport, with the support of Jean-Pierre Médevielle, the Coordinator of the HUMANIST Network of Excellence.

This volume presents the conference edited proceedings. Thirty three peer-reviewed papers are included and presented in six sessions: “Drivers’ distraction due to ITS use”, “Tools and methodologies for safety and usability”, “Modelling of drivers’ behaviour for ITS design”, “Tools and methodologies for ITS design and drivers awareness”, “Diversity and specificity of road user groups” and “Drivers’ acceptance of assistance functions”. The volume provides an extensive overview of the current developments and trends in Human Centred Design for Intelligent Transport Systems.

The conference scientific committee included Corinne Brusque (INRETS, France), Martin Baumann (DLR, Germany), Guy Boy (EURISCO, France), Emilio Davila-Gonzalez (DG-INFSO, European Commission), John Golias (NTUA, Greece), Josef F. Krems (Chemnitz TU, Germany), José Manuel Menendez (UPM, Spain), Merja Penttinen (Nokia, US), Pirkko Rama (VTT, Finland), Ralf Risser (FACTUM, Austria), Alan Stevens (TRL, UK), Divera Twisk (SWOV, The Netherlands), Mark Vollrath (Braunschweig TU, Germany).
I wish to express my gratitude towards the scientific committee members and the following researchers who actively participated in peer-review process: Angelos Amditis (ICCS, Greece), Angelos Bekiaris (CERTH/HIT, Greece), Thierry Bellet (INRETS, France), José Carvalhais (UTL, Portugal), André Chapon (INRETS, France), Michael Falkenstein ((IfADo, Germany), Alexandra Fort (INRETS, France), Christhard Gelau (BASt, Germany), Richard van der Horst (TNO, The Netherlands), Roberto Montanari (UNIMORE, Italy), José Pardillo Mayora (UPM, Spain), Michael Regan (INRETS / MUARC, Australia), Karel Schmeidler (CDV, Czech Republic), Anabela Simoes (ISEC, Portugal), Mark Tant (IBSR, Belgium) and Truls Vaa (TOI, Norway).

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SESSION 1: DRIVERS’ DISTRACTION DUE TO ITS USE
ABSTRACT: Numerous studies demonstrate the negative effects of cognitively loading secondary tasks on driving performance. We assume that this effect is caused by interference between these secondary tasks and central executive functions of working memory that serve to keep the driver’s situation model of the current traffic situation updated. In this experiment 48 drivers had to drive in a high fidelity driving simulator on a rural road while performing no secondary task, or a working memory task (auditive monitoring) that should not interfere with situation awareness, or a working memory task (memory updating) that should interfere with the comprehension and prediction function of situation awareness. While driving, participants had to react to events that were either announced by a warning signal or not. We hypothesized that participants will benefit least from the warning signal when they had to perform the memory updating task. The results generally support this hypothesis indicating that central executive functions of working memory are highly involved in situation awareness processes.

1 Introduction

There are numerous studies demonstrating the negative effects of cognitive tasks on driving performance (e.g., [1-9]). These studies generally find an increase in response latencies of drivers performing cognitively loading tasks, a decrement in lane keeping performance, or a loss of situation awareness. But these studies seldom link their findings to underlying cognitive processes. The aim of this experiment is to examine whether the effect of cognitively loading tasks on driving behaviour can be partly attributed to interference between the loading task and situation awareness processes. According to [10] situation awareness serves three functions: the perception of elements of a situation, the comprehension of these elements and their relation to the situation as a whole, and the prediction of the future development of the situation. Especially the comprehension and the prediction function draw on working memory resources. To accomplish these functions perceived information has to be associated with information stored in long-term memory to construct a knowledge network that represents the meaning of the current situation, the situation model. We will use this term synonymously to situation awareness. For this construction process knowledge has to be retrieved from long-term memory in order to be available for the associative processes. [11] assume that the prediction function is integrated within this comprehension process as in most cases a given situation is not only connected to knowledge that determines its meaning but also to
expectations about its future development. These expectations are also retrieved and become part of the situation model. In non-routine situations additional attention-demanding processes are necessary to make predictions about the further development of the situation. In this case information has to be kept in working memory to be available for these processes.

Imposing cognitive load on the driver withdraws resources necessary for the comprehension of the current situation and the prediction of future development of the situation. The looked-but-did-not-see phenomenon [12] is an example of the interference of cognitive load with situation awareness. In this case the cognitive load by an additional task leads to an incomplete comprehension of one or more situation elements. This then might lead to an inappropriate action selection of the driver.

According to [13, 14] working memory is not a single structure but consists of different parts: a phonological buffer with an articulatory loop, a visuo-spatial buffer, and the central executive. Recent studies [14-16] indicate that the central executive serves different functions that seem to be highly relevant for the comprehension and projection processes of situation awareness as described above. One of these central executive functions is the retrieval of information from memory, a process essential in the comprehension process of situation awareness. Another is the maintenance of information in a non-modality specific buffer, the episodic buffer, and the control of working memory contents. We assume that the effect of cognitive loading tasks on driving is at least in part due to the interference of these tasks with these central executive processes. The specific aim of this experiment is to test whether specific kinds of cognitive load that are designed to interfere with specific central executive processes interfere especially with the prediction function of situation awareness.

Therefore the participants in this experiment drove through a scenario that contained both predictable and non-predictable events. These events were designed to be exactly equivalent besides that in the predictable version a warning sign warned the driver of the upcoming event. The reaction to the event when the participant was warned was compared to the reaction when the driver was not warned.

While driving the participants had to perform (i) an auditory monitoring task that should not load on the comprehension functions of the central executive, or (ii) a running memory task that should heavily load on those central executive functions that are involved in the comprehension and prediction function of situation awareness, or (iii) no secondary task. In the monitoring task participants had to react as fast as possible to an auditory signal that was presented with either after a long or a short time interval after the previous signal. By using only two randomly presented interstimulus intervals this tasks induces a strong tendency for rhythmic responding leading to errors, mainly too early responses. To avoid these errors one has to constantly suppress rhythmic tapping. According to [17] this task should tap the monitoring function of the central executive. But as this function should not be strongly involved in the construction process of situation awareness this task should interfere less with the construction of a situation model. Therefore the monitoring task should interfere less with the prediction of events in traffic than the running memory task.
In the running memory task [18] participants are presented with a constant stream of items and they have to remember the last items, for example the last three items. As the participants do not know when the stream ends and therefore do not know when they are asked to recall the last presented items, this task requires that the set of items kept in working memory is constantly updated. That is, each time a new item is presented it has to be encoded in working memory and the “oldest” item has to be removed from working memory. Performing this task directly involves those central executive functions that control working memory content, i.e. those functions that should also be highly involved in maintaining and updating a proper situation model. Therefore, this task should interfere with situation awareness processes and especially with the prediction function of situation awareness. We assume therefore that this updating of working memory is highly interfering with the comprehension and the projection function of situation awareness.

To summarize, we assumed that participants driving the scenario without performing a secondary task should clearly benefit from the warning signs in the predictable events. The benefit from warning signs should be reduced when participants had to perform an additional task while driving. And the reduction of this benefit should be greater when participants had to perform the running memory task than when they had to perform the monitoring task, as the memory task should interfere more with the comprehension and prediction function of situation awareness than the monitoring task.

2 Method

2.1 Participants

48 participants took part in this experiment. Their age ranged from 21 to 58 with a mean of 36.9 years (SD = 12.1). Of these participants 29 were male. All participants possessed a valid driving licence at least for one year and drove at least 10000 km per year.

2.2 Driving scenario

The experiment was run in the high fidelity driving simulator of TNO in Soesterberg, Netherlands. The driving scenario consisted of driving on a rural road with an approximate speed of 80 km/h. Each drive took about 20 min. During a drive each participant encountered four critical events. In all of these events the participant’s lane was blocked by an obstacle, for example by a construction site. In two of these events the driver was given information to predict the obstacle, for example a warning sign next to the road; in the other two the driver did not receive such warning information. Each participant drove the scenario only once.
Fig.1. Sketch of the basic layout of the critical events; left side non-predictable obstacle on the lane as no warning sign was presented, right predictable obstacle with warning sign (marked by triangle)

2.3 Secondary tasks

In each secondary task condition participants had to perform several trials of the respective task. The trials lasted between 20 and 40 sec, and were followed by a no secondary task phase (where participants only had to drive) also lasting between 20 and 40 sec. Start and the end of a secondary task trial were triggered when the participant passed a certain position on the road. Therefore it was guaranteed that the participants in the secondary task conditions encountered the critical events while performing the respective secondary task.

2.3.1 The monitoring task

In the monitoring task participants had to react as fast as possible to an acoustical signal consisting of a short, clearly audible sound. As response device a finger switch was used that was applied to the index finger of the participant’s dominant hand. The time interval between two successive signals was either 1 or 2 sec, randomly chosen. We measured the participants’ response times and the numbers of errors, predominantly early responses.

2.3.2 The running memory task

In the running memory task participants were presented an audio stream of 13 possible letters, presented with a frequency of 1 letter per 2 sec. The participants’ task was to repeat the current last three letters each time a new letter was presented. For example, assume the letters “S”, “P”, and “Q” were already presented and the next letter was “G”, the participant had to repeat loudly “P Q G”, after presentation of “G”, and after the next letter “M”, the participant had to repeat “Q G M”, and so on. After a variable amount of time (20 to 40 sec) an acoustical signal was presented to inform the participant about the end of the current trial. After that the last repeated triple of letters was taken as the participant’s response in this trial. This response was taken to measure the participant’s accuracy in this task.

2.4 Design

In this experiment two independent variables were manipulated: the type of secondary task (no secondary, monitoring task, running memory task) and the predictability of the critical event (predictable, non-predictable). The secondary task factor was manipulated as between-subjects factor. Therefore the whole
sample of 48 participants was divided into three groups with 16 participants each. The predictability factor was manipulated as within-subjects factor. Each of the participants encountered both predictable and non-predictable events during his/her drive. This results in a 3 (secondary task) x 2 (predictability) mixed factorial design.

As dependent measures we used different aspects of the driving performance to characterize participants’ reaction to the critical events, such as Time to Collision at the time of response begin or maximum brake pressure after the obstacle became visible. Also, driving performance in phases without critical events was recorded to allow for the assessment of the effects of the secondary task performance on normal driving. Additionally, the participants were asked to rate their workload when performing each task while driving using the Rating Scale for Mental Effort (RSME, [19]). We also measured the participants’ secondary task performance and eye movement behaviour but describing the analysis of these measures is beyond the scope of this paper.

3 Results and Discussion

We will only present an overview of some critical results of this experiment. These results focus on the driver’s reaction to the obstacle on the lane after it became visible to the driver (see Table 1). After this moment there should be a clear difference in drivers’ reaction between drivers that were warned of the obstacle before and were able to correctly comprehend and integrate its meaning into their situation model compared to drivers that were either not warned or not able to fully comprehend the warning signal and therefore were not able to predict the obstacle on the lane. Therefore the difference in the respective measures of drivers’ reactions to events with warning signal and to the corresponding events without warning signal reflect how effective the participants in the different secondary task conditions could integrate the warning signal into their situation model and prepare themselves for the upcoming obstacle. According to our hypothesis we assume that this difference should be greatest in the no secondary task condition and smallest in the memory updating condition.

Table 1. Mean values of various performance measures

<table>
<thead>
<tr>
<th></th>
<th>no secondary task</th>
<th>monitoring task</th>
<th>memory updating task</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TTC</strong> at first throttle release after roadblock is visible in sec</td>
<td>no sign</td>
<td>3.69</td>
<td>3.75</td>
</tr>
<tr>
<td></td>
<td>sign</td>
<td>5.26</td>
<td>4.55</td>
</tr>
<tr>
<td><strong>Speed</strong> at first throttle release after roadblock is visible in kph</td>
<td>no sign</td>
<td>70.23</td>
<td>68.77</td>
</tr>
<tr>
<td></td>
<td>sign</td>
<td>57.62</td>
<td>62.86</td>
</tr>
</tbody>
</table>

The first measure is the Time to Collision (TTC) at the moment the driver released the throttle to brake after passing the location where the obstacle first became visible. As participants being prepared to the obstacle should have already reduced their speed after seeing the warning signal and should brake earlier than participants that did not comprehend the warning signal fully, TTC for prepared participants should be larger than for unprepared. And as stated above this difference should be greatest in the no secondary task condition and
lowest in the updating memory condition. As shown in the first row in Table 1 the results confirm this prediction. Whereas the difference between the predictable and the non-predictable obstacle is 1.6 sec in the no secondary task condition, it is 0.8 sec in the monitoring task condition and 0.6 sec in the memory updating condition. This picture is confirmed in a 3 (secondary task) x 2 (predictability) mixed ANOVA. TTC is significantly greater for predictable events, $F(1, 45) = 40.78, p < .001$. And very important the interaction between secondary task condition and predictability is significant, $F(2, 45) = 3.86, p = .028$, reflecting the reduction in the difference between predictable and non-predictable events from no secondary task to monitoring task to running memory task condition. The main effect of secondary task condition did not reach significance, $F(2, 45) = 1.95, p = .15$.

The same picture emerges when one looks at the speed of the participants when they release the throttle to brake in front of the obstacle. First, there is not much of a difference in speed between the no secondary task condition and the two secondary task conditions in case of a non-predictable obstacle, indicating the validity of the experimental design. But there is a clear difference in speed between these conditions in case of a predictable obstacle. Participants in the secondary task conditions were driving faster when they started to brake than participants in the no secondary task condition, indicating that these participants were less prepared to the obstacle despite the warning sign. Looking at the speed difference between predictable and non-predictable obstacles the same pattern can be found as for TTC. The greatest difference in speed could be found in the no secondary task condition, 12.6 km/h, a medium difference in the monitoring condition, 5.9 km/h, and the smallest in the memory updating condition, 4.8 km/h. Again this indicates that participants in the memory updating condition had the greatest difficulties to comprehend, integrate, and react to the warning sign. A 3 (secondary task) x 2 (predictability) mixed ANOVA revealed a significant main effect of predictability, $F(1, 45) = 43.63, p < .001$, indicating that speed was significantly higher in non-predictable events at the time of the begin of the brake reaction. As for TTC the interaction between secondary task condition and predictability for speed as dependent measure was significant, $F(2, 45) = 4.35, p = .019$, confirming the reduced benefit from the warning signal from no secondary task to monitoring task to running memory task condition.

A basic problem with this kind of analysis is that the interpretation of the effects of the secondary tasks on driving performance as being due to structural differences between the secondary tasks rests on the precondition that task difficulty can be excluded as alternative cause. More specific, the greater interference between the memory updating task and the construction of the situation model should not be a result of a memory updating task that is simply more difficult than the monitoring task. Instead, the greater interference should be due to the different working memory functions both tasks involve. This argument cannot be made straightforward and easily because of the necessary differences between both tasks, especially with regard to the different performance measures – number of trials with correctly updated memory set for the memory updating task vs. number of wrong taps in the monitoring task. But there are some indications that support the interpretation of the results in terms of the structural task differences. First, we analysed lane keeping performance
in curves. Previous studies demonstrated the sensitivity of this driving performance aspect to driver's cognitive load [2, 5]. As the driving task is especially difficult in curves, driving performance should be especially sensitive to differences in task difficulty between the secondary tasks. We found no differences between the tasks both with regard to standard deviation of lane position and number of lane exceedances. A second indication that both tasks were of comparable task difficulty stems from the participants' RSME ratings of workload when performing each task while driving. There was no difference in the ratings between the tasks.

These results cannot completely exclude the alternative interpretation that the greater interference between the memory updating task and the situation model construction is due to the greater difficulty of the updating task. But these results support the interpretation that structural differences between the tasks are the reason for the differential effects on situation awareness.

4 Conclusions

The aim of this experiment was to test one hypothesis about the cognitive foundation of negative effects of cognitively distracting tasks on driving performance. We assumed that such tasks load on working memory and especially on central executive functions of working memory that are also highly involved in maintaining and updating a proper situation model of the current traffic situation. Such functions are the control of working memory content, involving updating the content and removing irrelevant information from working memory, and the retrieval of information from long-term memory to comprehend encoded information in working memory. These functions are necessary to keep the situation model current and to integrate all relevant implications of observed situation elements into the situation model. If additional tasks interfere with these functions as they also require them then the risk is that some elements of the traffic situation are not fully comprehended and their implications are not integrated into the situation model. This should clearly impair the prediction function of situation awareness, that is cognitively distracted drivers should be less able to predict the future development of the current traffic situation and therefore should be less prepared to these developments.

We tested this prediction in a driving simulator experiment where participants encountered predictable and non-predictable events while driving and performing secondary tasks that specifically tapped relevant central executive functions of working memory. The results confirm our hypothesis that the central executive function of controlling working memory content is highly involved in the construction of situation awareness. Interfering with this function by a secondary task leads to a detrimental effect in the driver's ability to predict the future development of a traffic situation. This results help to clarify the cognitive mechanisms that underly situation awareness.
5 Acknowledgments

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6 References


NEURAL BASIS FOR SOME COGNITIVE RISK OF USING MOBILE PHONES DURING DRIVING

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ABSTRACT: Two studies have been conducted on some cognitive risks of using mobile phones during driving. Our previous study showed that voices received by a mobile phone in a car are often interrupted and replaced by silence due to transmission errors. We found with magnetoencephalography (MEG) that such interruptions of voices activate the right parietal cortex, which suggests that auditory attention can not be fully allocated for driving at moments of the interruptions. Secondly, base on evidence that the dorsal part of the visual system treats ‘where’ aspects of information and the ventral ‘what’ aspects, we assumed that driving in a situation is predominated by either of the subsystems. Besides, hearing through a mobile phone was assumed to induce visual imageries which are predominated in a situation by either of the subsystems. Subjects thereby concurrently carried out simplified visual and auditory tasks, each with either ‘where’ or ‘what’ aspects. Reaction times were found to be longer when aspects in the auditory task were the same as those in the visual task than when different.

1 General introduction

Uses of mobile phones during driving are often risky [1-8]. As a matter of fact, if a hand is used for manipulating a mobile phone, it can not be used for driving; If the eyes gaze at the phone, they can not be directed to the scene in front of the car; If the cognitive resources are used for communicating with a mobile phone, they can not be fully allocated for driving. Thus, the risks of using mobile phones during driving are composed of manual, ocular and cognitive factors. Although the cognitive factors are obviously based on neural activities in the brain, they are only rarely studied from the point of neuroscience.

We studied the neural basis for some of the cognitive factors. Firstly, based on the evidence that voices through mobile phones are often interrupted and replaced by silence in a moving car [9], we asked how the interrupted voices would burden the listener’s brain [10]. Secondly, a dichotomy of the visual system that the dorsal subsystem in the parietal cortex treats spatial or ‘where’ aspect of visual information and the ventral in the inferior temporal cortex for ‘what’ aspect such as colors and shapes [11, 12] was applied for elucidating one of the cognitive factors. Our assumptions were that driving in a situation would be predominated by either ‘where’ or ‘what’ aspects and that hearing through a mobile phone would induce visual imageries which would also be predominated in a situation by either of the two aspects.
2 Brain activities to interrupted voices

2.1 Introduction

As we experience ourselves, voices through mobile phones are sometimes difficult to be heard. We previously found that this is because the voices are often contaminated by 3 types of noises: delay of transmission, distraction of their spectral structure and silent interruptions [9]. These noises are characterized in common by their sudden starts and sudden ends, and by their durations of several hundreds ms, which presumably result from occasional drops or distortion of packets (compressed segments) of voices while processed digitally [14-16]. We previously found that long voices (vowel) transmitted to a mobile phone in a car were interrupted more frequently, if the car was moving (6.4 times per minutes on average) than at rest (4.8 times per minutes on average); The average of their durations was 424 ms when the car was moving [9]. We asked how these interruptions of voices affect the human brain. We thereby used magnetoencephalography (MEG), which allows to record the magnetic counterpart of the electrical activity in the brain and has spatial and temporal resolutions finer than those in other measures such as behavioural outputs and heart rates.

2.2 Methods

Eleven right-handed subjects listened to voices or pure tones, some parts of which were interrupted and replaced by silence for either 200, 500 or 1000 ms at 10 times a minute on average (Fig.1a). Their brain activities were measured with MEG, whose signals were averaged with respect to starts of the interruptions and then analyzed with multiple-dipole model [17].
2.3 Results and discussion

The interruptions of voices elicited neural activities after starts and ends of, but not during, the interruptions. The activities after the starts could be explained by three dipoles in the brain: One in each of the left and right temporal (auditory) cortices (T) and one in the parietal cortex (P) of the right hemisphere (Fig.1b). Ends of the interruptions elicited T’s in the temporal cortices, but not P in the right parietal cortex. Interruptions of pure tones also elicited T’s, but not P. Thus, T’s could be due to offsets or onsets of acoustic energy, while P due to offsets of semantic flow. Previous studies [18, 19] related the right parietal cortex to auditory attention. Since the dipole P was activated after starts of the interruptions, but neither during nor after the interruptions, we hypothesize that auditory attention is solicited by sudden stops of semantic flow, rather than by waiting or by attempts to fill the message etc.

Although vision is essential for driving, audition is also required for driving. As an example, the in-vehicle information systems often utilize auditory cues for navigation and alerting [20, 21]. Audition is also constantly required for the drivers to estimate the vehicle speed [22] and to detect events back of the car. If
a driver listens to voices through a mobile phone during driving, a part of his resource for auditory attention should be used by the listening to the phone. The remaining part of the resource should be further reduced at moments when voices through a mobile phone are interrupted, which could become a risk for driving.

3 Concurrent visual and auditory tasks with ‘where’ and ‘what’ aspects

3.1 Introduction

Although driving tasks are complex which require both of the dorsal and the ventral visual subsystems (Fig.2), there should be a predominance from one to the other according to a particular situation. For example, the dorsal subsystem would be predominantly used for having the car within the lane or keeping the distance between the cars, i.e. for controlling the car based on locations of visual objects. In other situations, the ventral subsystem would be predominated for identifying obstacles or colors of traffic signals. Besides, hearing through a mobile phone could sometimes induce visual imagery which would again predominantly use either of the visual subsystems depending on situations. For instance, if a partner of the phone explains the place of Institut Lumière by saying "For reaching there, you start from the station Part-Dieu, go straight two blocks, turn to the right and then to the left...", the listener should then mentally image the visual map of the route; The dorsal visual subsystem would then be activated [23]. In another situation, if the partner of the phone says “Her dress yesterday was beautiful, wasn't it?”, the listener should then visually image its colors; The ventral visual subsystem would then be activated [24]. Thus, the concurrent driving and hearing through a mobile phone in a situation would be schematically reduced to neural activations in one of the four combinations, i.e. two (dorsal or ventral) through vision multiplied by two (dorsal or ventral) through audition. We asked which of the combinations would be more dangerous than the others.

Fig.2. Dorsal (D) and ventral (V) visual subsystem. A: auditory cortex, PV: primary visual cortex.
3.2 Methods

Subjects (n=7) concurrently carried out visual and auditory tasks (Fig.3), while their MEG were recorded. A spot light was presented either as red or green at the center of the visual field in the visual color task (vC), whereas at the left or the right position in the visual location task (vL). They differentially pushed one of the two buttons according to the aspects of the visual stimuli with a finger of his right hand (the left button to green or left spots and the right button to red or right spots). Reaction times (RTs) of pushing the buttons were recorded. In a trial of the auditory color task (aC), they heard the name of a colored object, such as "apple" and "cabbage", and had to push a button with his left hand if the object was red, but not if green. In the first trial of the auditory location task (aL), they visually imaged a pointer at the center of a 3x3 imaged matrix. In each of the trials, they heard a direction word, "left", "right", "up" or "down", and accordingly moved the pointer for one step in the matrix. If the pointer exceeded the matrix, they pushed the button with a finger of his left hand and the trials were reset. Otherwise they only memorized the location of the pointer in the matrix for the next trial.

![Fig.3. Time sequences of the audiovisual tasks](image)

In an experimental session, one of the auditory tasks (aC or aL) and one of the visual tasks (vC or vL) were combined. Onsets of the former with respect to the latter (t_{AV}) were randomly varied between -500 and -250 ms from trial to trial in a session. The subjects carried out the visual tasks with priority over the auditory tasks. Two further sessions only with visual stimuli (vL or vC) were carried out as the controls. More than 250 trials were repeated in a session. Errors in pushing the buttons occurred in trials less than 5%; RTs in such trials were excluded from analysis. RTs at t_{AV} of -500 and -250 in a session of a subject were combined and finally grand-averaged across the subjects, which were statistically compared among the different sessions.

3.3 Results and discussion

Since MEG signals were too complicated to be analysed, only behavioral results are described. Fig.4a shows that RTs in the audiovisual sessions were always longer than that in the control, which suggests that concurrent hearing is
dangerous for driving. RTs in aLvL and RTs in aCvL were subtracted by RT in vL in each of the subject. The results represent to what extent RTs in vL were increased by the concurrent auditory tasks (aL or aC) in the subject. These increased amounts were named RT*(aLvL) and RT*(aCvL) of the subject, respectively. Similarly, RTs in aLvC and RTs in aCvC were subtracted by RT in vC, and each of the results was named RT*(aLvC) and RT*(aCvC) of the subject. Grand-averages of these increased amounts are represented by two pairs of two bars (Fig.4b). The figure shows that RT*(aLvL) are significantly longer than RT*(aLvC) (312 ms vs 192 ms, respectively; p<0.05), and RT*(aCvC) are also significantly longer than RT*(aCvL) (152 ms vs 64 ms, respectively; p<0.01).

Fig.4.a: Grand-averaged RTs in different sessions. Error bars indicate SD. Two bars connected by a horizontal line have statistically different heights. **: p<0.01, *: p<0.05. b: Grad-averaged RTs in the audiovisual sessions subtracted by RT in the corresponding control session. Others are the same as in a.

In summary, RTs in the visual tasks were more elongated when the concurrent auditory task had the same aspect as the visual task than when different. The dichotomy of the human visual system can account for these results (Fig.5). As an example, since both the tasks in aLvL are supposed to use the dorsal subsystem, the subsystem could not be fully allocated for the visual task vL. In contrast, in the session of aLvC, since the auditory task aL is supposed to use the dorsal subsystem and the visual task vC the ventral, the ventral subsystem could be fully allocated for the visual task vC. These considerations could explain why RTs were more increased by addition of the auditory task in aLvL than in aLvC. Similar arguments apply for the difference of RTs between the sessions of aCvC and aCvL. The results implicate that hearing through a mobile phone during driving would be more dangerous when aspects of information with which hearing and driving should deal are the same than when different.
4 General discussion

Two studies tried to elucidate cognitive risks of using mobile phones during driving from the point of neuroscience. The first study used MEG to assess the impact of phone communication interruptions to the brain. The results showed that the right parietal cortex was activated after starts of the interruptions, which suggests that the neural resource for auditory attention could then be less allocated for driving. Behavioral experiments in realistic situations are required for validating this hypothesis. The second study was based on the dichotomy of the human visual system: dorsal subsystem for “where” aspects of information and ventral for “what” aspects, as a new type of the multiple resource models [25]. The experiments used reaction times to assess the possible interference on visual tasks by visual imagery induced by the auditory communication. The results implicate that concurrent driving and hearing through a mobile phone could be more dangerous if aspects of information with which driving and visual imagery induced by hearing should deal are of the same type, i.e. both of color or both of location, than when different.

In the first experiment, brain activities to the interruptions were successfully described by dipoles. However, MEG signals in the second study were too complicated to be analyzed, presumably because the experimental setup was not simple enough. Neural studies have advantages that they have finer spatial and temporal resolutions than behavioral or psychophysiological studies, but have disadvantages that they generally require simplified, not realistic, setups. Thus, these different types of studies have to be combined for fully analyzing cognitive risks of using mobile phones during driving.
5 References


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EFFECTS OF VISUAL SEARCH TASK COMPLEXITY ON LANE CHANGE TASK PERFORMANCE

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ABSTRACT: Driver assistance systems are increasingly implemented in motor vehicles. However, it is unclear whether the secondary tasks introduced by these systems affect driving performance and whether they cause safety risks to the driver and road traffic. In this study the effect of secondary task complexity on driving performance is manipulated using different complexity manipulations of a visual search task. The lane-change task [19] was used as the primary task to simulate driving. Results showed that participants (n=12) were unable to maintain their baseline driving performance when the secondary task had to be performed. Moreover, they showed further dual task decrements with increasing visual search complexity. The results show adverse effects on simulated driving depending on the complexity of an additional task.

1 Introduction

The most frequently implemented in-vehicle information systems (IVIS) nowadays are the In-Vehicle Routing and Navigation Systems (IRANS) that provide drivers information about the route from one destination to another [4]. Research has shown that under some circumstances dual task decrement can affect driving performance [5, 6, 14, 15, 23]. However, people are engaged in concurrent tasks on a daily basis, like drinking coffee while watching the news. Most of these tasks are highly practised and are therefore highly automated [22]. People are fairly good at performing multiple tasks at the same time provided at least one of them is (highly) automated, and in case the execution of a task threatens to fail, people have a large range of coping mechanisms available. There are at least three ways in which drivers can adapt their behaviour to cope with higher task demand [3, 13]. These are: investment of more effort, changing working strategy and neglecting subsidiary information. In a study of Dingus et al. [9] IRANS with the highest visual demand were associated with the lowest driving speed. Thus drivers adapted their working strategies and made the driving task less demanding by lowering their speed [see also 12]. It is expected that driver will adjust their strategies to deal with this additional task demand and reach what can be described as homeostasis or an optimum level of accepted risk or task difficulty [11, 12, 27]. For instance, Pohlmann and Traenkle [21] also found speed reductions and a deterioration in lateral control with high visual demand of IRANS. They found this effect particularly near intersections. Drivers reduce speed to allow time to drive safely and were highly motivated to check the IRAN system, even in difficult traffic situations. Unfortunately, it is especially near intersections which are complex traffic situations that the need for route information is high [8]. So this could be a
situation where task demands are higher than normal and possibly cause dual task decrement. As long as the driving task is self-paced and compensating strategies can be executed the interference of secondary tasks will be limited. However, driving can also be paced by the environment. For instance driving 30 km/h on the highway can be done theoretically, but is certainly more hazardous than missing the highway exit. In that case compensating by considerably reducing speed would hardly be possible. So there are situations in which compensating strategies are not sufficient or can not be executed, and when this is the case and task demand is high, driving performance is likely to suffer.

1.1 Visual search

Using a digital map requires searching and detecting relevant information. If the system is well-designed this search for relevant information is efficient, requiring the driver to take the eyes off the road for a minimum amount of time. Complex colouring, multiple signs and long text messages in displays make the search for information demanding and inefficient, and require multiple glances. Factors that influence the search time of a display have been widely studied using all kinds of visual search paradigms. Visual search is easier when the target can be defined by one feature such as colour, e.g. the target colour (blue) is different from its distractor (red). Within the Feature Integration Theory [25] this type of feature search is called pop-out. When a target is defined by a conjunction of two or more features, for instance the target is a blue letter ‘A’ between distractors consisting of blue ‘T’s and red ‘A’s, search for a target is slower. The time needed to search for a conjunction target becomes slower as a function of the set size (the number of elements in a search display) while search for a pop-out target will be relatively independent of set size. Theories on attention try to explain this difference in reaction times [18] between searching for conjunction versus pop-out targets. The fundamental nature of this attentive selection process is still under debate to date [10, 17, 25], but clear is that there is not such a clear dichotomy in visual search as described by Treisman, therefore Wolfe [28] suggested to use the term “efficiency” to describe the continuum of search complexity. The efficiency of visual search depends for instance on the number of distractors and on the number of features in the display (e.g. form and colour). A typical finding is that more distractors and more equality between distractors and targets makes the visual search less efficient, slower and less accurate [24, 29]. Interesting research has been conducted in the HASTE project [20] in which a visual search task is used as a surrogate IVIS. The visual search task was performed both in isolation and concurrently with a laboratory driving task, in a driving simulator and while actually driving on the road. The visual surrogate IVIS task of HASTE consisted of a choice-reaction task with three difficulty levels as shown in figure 1. Each display contained a mixture of pop-out and conjunction displays i.e. of the different classes of search requirements. Results showed that the difficulty of the visual task had a pronounced effect on steering (a higher steering reversal rate) and lateral behaviour (higher standard deviation of the lateral position). Also the increased secondary tasks load led to speed reduction and increase in headway.
Drivers’ distraction due to ITS use

Difficulty level 1

Difficulty level 2

Difficulty level 3

Fig.1. Example displays of the surrogate IVIS displays. Within each difficulty level there are in fact different types of displays. For instance in difficulty level 2 one fourth of the displays are pop-out displays (the upward pointing target arrow ‘pops out’ in left display). And the other part of displays require conjunction search.

1.2 Aim of the study

The aim of the present study is to extend the previous research by focusing on the effect of search difficulty (pop-out versus conjunction) and the effect of set size. Another factor that differentiates the present study from the HASTE experiments is that driving speed was fixed at 60 km/hour. Thus participants were unable to compensate for the task demand by decreasing their speed. In the present study the effect of secondary, visual search complexity on driving performance is evaluated, using a visual search task as a surrogate IVIS and the lane-change task as the primary task to simulate driving [19]. Both tasks were performed separately to acquire the baseline values of each participant, and are then compared to the performance of the two tasks in a dual task situation. In this dual task situation the lane-change task was defined as the primary task which is instructed to be given the highest priority. It was expected that in the dual task situation the performance of the visual search task would decrease and the secondary task may have a possible negative effect on the simulated driving task if the participants are unable to fully prioritise the LCT-task or compensate for the dual task demand. We expect this effect to be larger with increasing set size and with conjunction search displays.
2 Method

2.1 Participants

Twelve female participants aged between 20 and 22 years (M=20.3 (±0.6)) participated in an experimental session in exchange for a partial course credit.1 All participants had their driver's licence for at least 2 years and had normal or corrected to normal vision. The experimental procedure consisted of three different parts. The first part was a simulated driving task called the lane change task [19]. The second part was a visual search task. The sequence of these two parts was counterbalanced across participants. The final part of the experiment combined the simulated driving and the visual search task. Each part started with a training block. In total participants received about half an hour of training. The training of the visual search task continued until the participants reached a minimum of 80% correct trials. Each part was followed by a short break.

2.2 Primary simulated driving task

The simulated track consisted of a straight three-lane road. With the gas pedal pressed maximally the participant drove a constant 60 km/h. This resulted in a total driving time per track of about 3 minutes. There were 18 signs along each track indicating the lane the participant had to change to as soon as the sign was identified. Signs were present with a mean distance of 150 m (min. 140 and max. 188 metres, exponentially distributed). Each of the 6 possible lane changes occurred three times during one track. The performance on six different tracks was measured of which the first two were considered training. Data were continually sampled with a scan rate of 130 Hz, namely the lateral and longitudinal position, speed (as a control) and steering angle. As a measure of driving performance the deviation between a normative model and the participants' actual course on the track was calculated [19].

2.3 Secondary visual search task

In the visual search task each experimental trial began with the presentation of a fixation cross, which remained on screen for 1000 ms. The fixation cross was followed by the presentation of a visual search display for 3000 ms. The display types consisted of a complexity manipulation pop-out/conjunction and a set size manipulation (4 versus 9 items). The four types of display were blocked and randomly presented to the participants. Participants were presented with 8 blocks, each consisting of 40 trials. The target stimulus was either an upward green arrow or a right-pointing red arrow, only one target was present per trial with a 50% change. The target appeared on a random location. The non-targets were all other combinations of green or red arrows with orientation to the left, to

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1 Since this experiment was part of an university course, therefore participants were not divided equally across gender. Adam [1] showed that female spatial choice-RTs were about 34 ms slower than those of male participants and different strategies were adopted per gender group, effects like this should be considered when determining the external validity of the study.
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the right, up or down. The participant had to indicate by a button press whether the target was present or not. They were instructed to react as quickly and accurately as possible. In the pop-out displays the target was distinguishable from the non-target either by colour or orientation. Thus there were two possible situations: distractor arrows all pointed in the vertical direction when the target was a red right-pointing arrow or when the target was a green upward arrow, all distractors were red. In conjunction displays the non-targets pointed in all directions and the amount of red and green arrows was equal.

Fig. 2. Four example displays with the two different target arrows (displays are described from left to right): The two left displays are the pop-out search displays; participants can discriminate target arrows from distractor arrows by looking at direction or colour. In display 1: a red arrow (= grey) pointing to the right or in display 2: a green (= white) upward pointing arrow. The displays on the right side are the conjunction search displays, where both features colour and direction have to be determined to find the target. The same targets are presented in display 3: a red arrow pointing to the right and display 4: a green upward pointing arrow.

2.4 Dual task

In the dual task the instructions and conditions for driving as well as for the visual search task were kept equal and the participant was instructed to give first priority to the driving task. The constant, required driving speed of 60 km/h made it impossible to compensate for secondary task difficulty by reducing speed. In each of the eight blocks one of the four visual search conditions was presented. Each condition was thus presented twice and the order was random.

2.5 Equipment and analysis

For tracking a simple Logitech gaming steering wheel was used with gas and brake pedals. The visual search task was displayed on a small LCD screen at a distance of 1.45 m with a visual angle of 18°. This LCD screen was positioned in front of the main screen (distance 1.96 cm, visual angle 38° x 29°) without blocking the sight on the road. For stimulus presentation E-prime was used (Psychology Software Tools, Inc., Pittsburgh, USA) the small set size was visible within 1°, the large set size within 1.6°. Two of the original response buttons behind the steering wheel were adapted to make accurate RT acquisition possible using the printer port. Data were subjected to ANOVA repeated measurement analyses of SPSS 13.0, except for training blocks. In case of sphericity violation the Greenhouse-Geiser modification was used. Within-subjects factors were complexity (pop-out/conjunction), set size (4/9 items) and single versus dual task performance. For the behavioural results of
the visual search task target and non-target reactions are combined in the analysis.

3 Results

3.1 Visual Search

The analysis of the RT showed that participants took on average 86 ms longer to react in the dual task situation ($F(1,11)=4.3$, $p=.063$; see table 1). RTs were about 1000 ms slower for conjunction displays where participants had to search for a target looking at its two features colour and rotation ($F(1,11)=425.8$, $p<.001$; see figure 3a). Participants were reacting on average 260 ms slower for the large (nine elements) displays then for the small (four elements) displays ($F(1,11)=194.1$, $p<.001$). Also the expected interaction between complexity and set size of the visual search task reached significance ($F(1,11)=110.0$, $p<.001$) showing a larger increase of RTs with set size when the displays were conjunction displays.

![Figure 3](image)

Fig.3. A) Reaction times of the visual search task in the dual task condition (averaged over target and non-target displays) for the conditions set size and efficiency. B) Errors in percentage of the visual search task in single and dual task condition (averaged over number of false alarms and misses). The increase of the percentage of errors with dual task can be attributed to the increase in the number of misses.

Participants hardly made any errors with pop-out displays, i.e. 0.2% compared to 16.5% with conjunction displays ($F(1,11)=96.6$, $p<.001$). Also with larger set size the amount of errors increased ($F(1,11)=19.2$, $p<.001$). And the interaction between set size and the complexity of search was significant showing the same direction as RTs, i.e. the amount of errors increased more with set size when the displays were conjunction ($F(1,11)=13.1$, $p<.004$). Participants made significantly more errors in the dual task condition; 8.5% in single task performance versus 10.6% when performing the visual search task together.
Drivers' distraction due to ITS use

with the lane change task ($F(1,11)=6.2$, $p<.030$). Within the dual task the number of errors increased for display complexity ($F(1,11)=12.2$, $p<.005$), set size ($F(1,11)=16.0$, $p<.002$) and also the interaction between complexity and set size was significant ($F(1,11)=24.8$, $p<.001$). This interaction showed that when the visual task is performed as a dual task the number of errors increases and the errors increase more drastically for conjunction displays with a large set size. When looking at the type of error (false alarms and misses see table 1) in the dual task situation, there is no significant difference in the false alarms, so the effect can be attributed to an increase in the number of misses in the dual task condition.

3.2 Primary task

The mean deviation from the ideal lane keeping (the normative model) showed an effect of dual task ($F(4,44)=11.9$, $p<.001$). It showed that even in the most simple dual task condition drivers were unable to perform the lane change task at baseline level ($F(1,11)=7.5$, $p<.019$). The complexity of the search ($F(1,11)=12.5$, $p<.005$) and display size ($F(1,11)=5.7$, $p<.036$) reached significance as well as the interaction between the two conditions ($F(1,11)=9.0$, $p<.012$). Effects showed an increase of the deviation of the ideal lane keeping with increased set size and conjunction search (see figure 4). The variance of steering wheel angle is reduced as an effect of dual task but this measure showed no significant effects of the visual search manipulations. Participants were able to keep a constant speed of 60 km/h during the whole experiment.

![Fig.4. Mean deviation from the normative model for single task baseline driving and driving with different visual search conditions.](image)

Table 1. Performance measures of the visual search task

<table>
<thead>
<tr>
<th></th>
<th>Dual Task</th>
<th>Dual-Single difference</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT (ms)</td>
<td>1359 (39.3)</td>
<td>85.9 (37.0)</td>
<td>.063</td>
</tr>
<tr>
<td>Error (%)</td>
<td>10.6 (1.1)</td>
<td>2.1 (0.8)</td>
<td>.030</td>
</tr>
<tr>
<td>Misses</td>
<td>13.4 (2.7)</td>
<td>9.1 (2.1)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>False alarms</td>
<td>20.4 (3.4)</td>
<td>-1.3 (2.6)</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

Note: Displayed are the mean and standard error. Performance measures on dual task minus single task are given and the paired t-test of this dual vs. single task difference.

4 Discussion

People are fairly good at performing multiple task at the same time when one of the task is automated or highly trained or when coping mechanisms can be applied when task performance is threatened. One of the common adaptations seen while driving is to reduce the speed to allow more time for decision making [9, 12, 21, 27]. Because the speed in the experiment was fixed there was no
possibility to compensate for high task demand by reducing the speed. The results of this experiment showed that drivers were unable to continue performing the driving task adequately at baseline level in the dual task condition. Apparently they could not or at least did not sufficiently prioritise the lane change task. Like in the HASTE studies [20] where higher complexity of the visual search task resulted in a large deviation of the lateral positioning on the road, the performance on the lane change task decreased, as was shown in the mean deviation from the normative model. The driving decrement was found even for the most simple search displays containing only four elements with a pop-out target based on colour or orientation. The visual search task performance showed was in accordance with the literature [7, 24, 25, 29], i.e. almost no increase in RT or errors for pop-out displays when set size increases, but a large increase of RT and errors with set size for conjunction displays. The visual search task also affected the mean deviation of the driving task. Participants were unable to perform the secondary, visual search task at baseline level while driving making substantially more errors. Although there was only a trend (p<.063) showing that reaction time increased in the dual task condition, the number of errors increased most strongly with large conjunction displays. The amount of errors could be attributed to the increase of the number of misses. A likely explanation for the number of errors is that the participants did not have enough time to inspect the visual display for the target.

Although it is not directly verifiable it could be the case that the larger mean deviation from the ideal driving track resulted from participants spending a larger amount of their time looking at the visual search display or taking a long time switching between the two tasks. To minimize the physical switching distances between two objects of visual attention, head-up displays (HUDs) have been introduced into the modern automobile. The benefit of this technology is that it decreases eyes-off-the-road and accommodation time [16], although there are also some concerns about the cluttering of information [26]. A follow-up of the present experiment is currently being performed to investigate the use of a HUD to verify if the performance decrease in the driving task can be attributed to the time that the participants spend looking on the display as opposed to divided attention. Another follow up on this study will focus on the elderly driver because they could be especially vulnerable to dual task interference, having motoric perceptual and cognitive functions decline due to normal ageing which affects driving [2, 20].

When using a laboratory driving task to measure the driving performance it should be considered that this environment is artificial and can give a false impression of driving performance. Further results can not be assumed to transfer exactly to driving on the road. It can be concluded that when participants can not adapt their speed, dual task performance decreases when displays require conjunction search and a large number of elements are displayed. Displays with conjunction features forcing inefficient search should be avoided, because reaction time increases and in the dual task situation the amount of errors increases drastically, and at least simulated driving performance is worsened.
5 Acknowledgments

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6 References


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EFFECTS OF SIMULTANEOUS MULTI-MODAL WARNINGS AND TRAFFIC INFORMATION ON DRIVER BEHAVIOUR

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ABSTRACT: It is expected that the number of in-vehicle telematic systems will increase rapidly over the next years, leading to an increased amount of information a driver has to deal with. In the scope of the research project LIVES\(^1\), the organisations CURE and FACTUM OHG have investigated how these systems could be used optimally to improve the safety on the road. To be able to answer the research questions formulated by FACTUM OHG, CURE developed a driving simulator specifically tuned to these questions. The driving simulator made it possible to investigate the effects on the driving behaviour using different modalities for information and the effects of simultaneously submitted information. The results of these experiments were used to formulated guidelines to increase safety. These guidelines focus on the optimal use of auditory, visual and haptic information for the driver as well as on the simultaneous communication of more than one system.

1 Starting point

It is expected that the number of in-vehicle telematic systems will increase rapidly over the next few years. This will lead to an increased amount of information a driver has to deal with besides the primary task of driving. The main advantages of telematic systems are or should be the ability to increase both the safety and the comfort of the driving task. These advantages, however, might be compensated by additional perceptual and cognitive load, as the driving task is extended with the task of reacting correctly on the information, directions and warnings that these systems provide. This will especially be the case when the driver receives different information simultaneously from these systems.

The research institutes CURE (Center for Usability Research & Engineering) and FACTUM OHG (Transport- and Social Analyses) investigated in the year 2006 in the Austrian study LIVES how the human machine interface (HMI) of different telematic in-vehicle systems should be designed in order to guarantee an optimal use of diverse systems [1]. It dealt with the integration of disjunctly developed systems, that are not a priori matched to one another. Thus, the driver may run the risk of being distracted by unimportant or interfering information during possibly critical situations.

\(^{1}\) German title: LIVES - LenkerInnenInteraktion mit VERkehrstelematischen Systemen
2 Development of hypotheses

One main focus of the project was the identification of new requirements to drivers which might appear through the implementation of telematic systems into cars. Especially the effects on the driver and his/her behaviour while he/she gets simultaneous information from two systems were tested. Another focus was on the search for the optimum modality in which information should be submitted to the drivers.

Based on a literature study several telematic in-vehicle systems and situations, where systems submit either information (traffic news) or warnings (too little distance to the car ahead etc.) to the driver, which suited the project objectives best were selected. These information and warnings have different priorities with regard to the driving task and the driver's reaction in different situations. Three priority levels were defined:

1. Warnings which need an immediate reaction by the driver
2. Latent instruction – no immediate reaction of the driver is needed
3. General information – no immediate relevance for the driving task

One of the main questions was: "What is the best way and the best modality to submit information or warnings in order not to distract or to overload the driver?"

Based on literature the following matrix was established, in which the priority levels are set in contrast to the three modalities acoustic, visual and haptic.

<table>
<thead>
<tr>
<th>type of information</th>
<th>acoustic</th>
<th>visual</th>
<th>haptic</th>
</tr>
</thead>
<tbody>
<tr>
<td>warnings, high priority</td>
<td>suited well, it can be instinctively handled. Speech is not adequate [2]</td>
<td>not adequate, modality is to slow to transfer the information in critical situation</td>
<td>hardly any literature, short breaking impulses could lead to an erroneous interpretation of the driver</td>
</tr>
<tr>
<td>medium priority</td>
<td>acoustic signals are experienced as hindering and therefore should not be used for this level</td>
<td>suitable. Drivers can partially decide themselves when they want to receive the information</td>
<td>pedal-Feedback or vibration on the steering wheel helps the driver to adopt to the speed limit without nerving [3]</td>
</tr>
<tr>
<td>general information, low priority</td>
<td>possible, but not optimal, driver is distracted from the driving situation</td>
<td>adequate, distract driver not directly. Driver can decide himself if and when he wants to receive information</td>
<td>hardly any literature available</td>
</tr>
</tbody>
</table>

For the first level, the warnings, it becomes clear that acoustic signals (with the exception of speech) are the most appropriate ones. The driver can handle the signal instinctively. Visual as well as haptic signals are not adequate for this priority level, because they are either interpreted too slowly or lead to misunderstandings [4].

For the medium priority level the visual information is seen as the best solution, because messages of this type are not too penetrating (like acoustical signals). Haptic feedback, like it is used for example for ISA (Intelligent Speed

<table>
<thead>
<tr>
<th>modality</th>
<th>type of information</th>
<th>acoustic</th>
<th>visual</th>
<th>haptic</th>
</tr>
</thead>
<tbody>
<tr>
<td>warnings, high priority</td>
<td>suited well, it can be instinctively handled. Speech is not adequate [2]</td>
<td>not adequate, modality is to slow to transfer the information in critical situation</td>
<td>hardly any literature, short breaking impulses could lead to an erroneous interpretation of the driver</td>
<td></td>
</tr>
<tr>
<td>medium priority</td>
<td>acoustic signals are experienced as hindering and therefore should not be used for this level</td>
<td>suitable. Drivers can partially decide themselves when they want to receive the information</td>
<td>pedal-Feedback or vibration on the steering wheel helps the driver to adopt to the speed limit without nerving [3]</td>
<td></td>
</tr>
<tr>
<td>general information, low priority</td>
<td>possible, but not optimal, driver is distracted from the driving situation</td>
<td>adequate, distract driver not directly. Driver can decide himself if and when he wants to receive information</td>
<td>hardly any literature available</td>
<td></td>
</tr>
</tbody>
</table>
Adaptation) systems, is also seen as adequate. If the driver is speeding above the limit the accelerator pedal gives a counter pressure which informs the driver about his/her erroneous behaviour [5].

For the general information on the third priority level it looks as if the visual information were the most appropriate one. The reason for this is that the driver could decide him/herself when he/she wants to receive the information. Also acoustic signals are adequate, but have to be announced in some way in order not to distract the driver from the driving task. No literature was found for the haptic signals on this level.

Based on the matrix above the following hypotheses for the systems which were tested were formulated:

- If level 1 warnings are submitted acoustically, than they have less negative effect on the driving behaviour than if they are submitted visually.
- Latent instructions of level 2 have less negative effect on the driving behaviour if they are submitted via the haptic channel than if they are submitted acoustically.
- General information of level 3 has less negative influence on the driving behaviour if it is given visually than if it is submitted acoustically.

In order to test these general hypotheses five scenarios, which represent typical situation in real traffic, were developed. For these scenarios the driving task was defined as "primary task" while the secondary task consisted of the tasks given by the different telematic systems. In every scenario two systems submitted information/warnings/instructions to the test persons. The task of the test persons was to react correctly to these information/warnings/instructions. In order to test the hypotheses the test persons drove through the test track twice while the modality in which the information in the different scenarios were submitted changed.

In the following, an overview about the scenarios and the systems which were used.
Table 2. Overview of the experimental design of the simulation test

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Course A</th>
<th>Course B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test situation 1 &amp; 2</td>
<td>Control Situation</td>
</tr>
<tr>
<td>1</td>
<td>Route Guidance</td>
<td>acoustic</td>
</tr>
<tr>
<td></td>
<td>Information priority level 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traffic news</td>
<td>acoustic</td>
</tr>
<tr>
<td></td>
<td>Information priority level 3</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>ISA</td>
<td>haptic</td>
</tr>
<tr>
<td></td>
<td>Information priority level 1-2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traffic news</td>
<td>acoustic</td>
</tr>
<tr>
<td></td>
<td>Information priority level 3</td>
<td>acoustic</td>
</tr>
<tr>
<td>3</td>
<td>Parking information</td>
<td>acoustic</td>
</tr>
<tr>
<td></td>
<td>Information priority level 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Additional parking information</td>
<td>visual</td>
</tr>
<tr>
<td></td>
<td>Information priority level 3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Pedestrian warning</td>
<td>visual</td>
</tr>
<tr>
<td></td>
<td>Information priority level 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Route Guidance</td>
<td>acoustic</td>
</tr>
<tr>
<td></td>
<td>Information priority level 2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Distance warning</td>
<td>visual</td>
</tr>
<tr>
<td></td>
<td>Information priority level 1-2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traffic news</td>
<td>acoustic</td>
</tr>
</tbody>
</table>

3 Simulator set-up

In order to give answers to the formulated research questions and hypotheses a driving simulator based on a 3D development environment (BLENDER – open source) was developed.

The test track consisted of roads within build up area and rural roads. Traffic signs were virtualised in order to guide the test person through the course, and speed limits as well as overtaking bans were announced. The general speed limit was 50 km/h but on certain parts of the test track there was a 30 km/h limit. Random generated traffic volumes but also virtualised cars and pedestrians based on the behaviour of the test person appeared during the test rides.

The duration of one drive through the whole test track was about 15 minutes. Altogether, including a five to ten minutes adaptation phase before each test drive, the duration of the test was about 45 to 50 minutes.

A customary steering wheel for racing games was used as well as two pedals (acceleration and breaking pedal as in a car with automatic gearing). A simple engine noise reflecting the driven speed was heard.

The picture of the test track was projected with two beamers on a white wall. The test person sat approximately two meters away from the wall.
Data about deviation from the optimum driving line, control of pedals (speed) and steering wheel movements (deviation from the zero position) were logged during the whole test ride. In addition, all test rides were filmed with two video cameras.

The haptic information was given by two vibrating electro-motors which were put on the left and right side of the test persons seat. For the haptic route guidance only the motor on the side in which the test person should go vibrated, for the ISA warning both motors were vibrating when the test person drove above the allowed speed limit.

4 Evaluation

The sample was distributed in the following way. Eleven men and eight women participated in the simulator tests: The test persons had a mean age of 37.5 years with a standard deviation of 11.8:

<table>
<thead>
<tr>
<th>Table 3. Sampling distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>Under 30 years</td>
</tr>
<tr>
<td>between 30 and 49 years</td>
</tr>
<tr>
<td>50 years and above</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

The yearly driving performance showed that eight test persons drove less than 5.000 kilometres the year before, six drove between 5.000 and 10.000 kilometres, three between 10.000 and 20.000 and finally two test persons had a yearly driving performance of more than 20.000 kilometres.

Four test persons stated that they had experience with computer racing games while 15 test persons answered that they did have not. Seven test persons did not have any experience with the warning and information systems used in the simulator study while twelve participants said that they already had used one of the systems at least sometimes.

Two evaluation methods were applied:

4.1 Statistical evaluation for speed and steering wheel movements

In order to make the data of the test persons and for each situation comparable only the data logged ten seconds before and after each scenario (test situation and control situation) was taken for the statistical evaluation. Mean speeds for the various situations and standard deviations of the steering wheel movements were used to calculate significance's between the control situation and the two test situations and within the test situations (Mann Whitney U-Test).
4.2 Behaviour observation with the help of the video recording

In order to evaluate differences in the behaviour of the test persons in each situation the recorded material was seen through with the help of a standardised observation sheets. In these sheets specific criteria were defined which cannot be identified in the logged data, e.g. overtaking where the test persons were not allowed to overtake, conflicts with other road users, etc. The observed driving behaviour in each test situation was compared between the control situation and the two test situations and within the test situations. The aim was to evaluate possible differences of the effect of the modalities in which the information/warning was given, on the driving behaviour. Furthermore, on the three parking places the test subjects were asked about the traffic news which they received during the test- and control-situations, and answers were also evaluated.

5 Results

In the following some basic results for each scenario are presented:

Scenario 1: The driven speed was significantly higher in the first test situation in comparison to the control situation (46,73 km/h to 34,83 km/h, p=0,026). Also the standard deviation of the steering wheel movement in both test situations (acoustic route guidance/acoustic traffic information & haptic route guidance/acoustic traffic information) was significantly higher than the one in the respective control situations (32,71 to 26,22, p=0,000 & 32,25 to 24,90, p=0,008), Additionally the behaviour observation showed that with haptic route guidance three test persons did not follow the correct route.

Scenario 2: The standard deviation of the steering wheel movement was significantly stronger in the situation were acoustic/visual ISA-warning was used in combination with simultaneous acoustic traffic news than in situations were a haptic ISA system was tested in combination with simultaneous acoustic traffic news (17,2 to 14,9, p=0,011). The behaviour observation showed no differences in the driving behaviour between the two test drives.

Scenario 3: No significant differences in speed and standard deviation of the steering wheel movement between the two test drives. More erroneous turns on the parking place were observed while using the visual route guidance in combination with the additional acoustic information where to park, in comparison with the situation in which an acoustic route guidance was tested in combination with additional visual information.

Scenario 4: The standard deviation of the steering wheel movement was significantly lower in the situation were acoustic pedestrian warning was tested in combination with simultaneous haptic route guidance in comparison to the situation where a visual warning system was used in combination with simultaneous acoustic route guidance (29,7 to 32,1, p=0,040). The behaviour observation showed that the visual warning was detected later and that it was also more often ignored by the test persons.
Scenario 5: The standard deviation of the steering wheel movement was significantly higher in the situation where an acoustic distance warning system was tested in combination with simultaneous acoustic traffic news in comparison to the situation were a visual distance warning system was used in combination with acoustic traffic news (22.9 to 20.7, \(p=0.045\)). The behaviour observation showed that the participants ignored the acoustic warning more often than the visual one.

The results of hypotheses tests were transferred back to the matrix in which the information given on different priority levels was combined with the three modalities. The following table gives an overview about the comparison between the literature results and the results of the simulator study.

<table>
<thead>
<tr>
<th>modality priority levels</th>
<th>acoustic</th>
<th>visual</th>
<th>haptic</th>
</tr>
</thead>
<tbody>
<tr>
<td>warnings, high priority</td>
<td>Confirmed by the results of the simulator study</td>
<td>Confirmed by the results of the simulator study</td>
<td>Was not tested within these project</td>
</tr>
<tr>
<td>medium priority</td>
<td>Confirmed by the results of the simulator study</td>
<td>Confirmed by the results of the simulator study</td>
<td>Confirmed by the results of the simulator study</td>
</tr>
<tr>
<td>general information, low priority</td>
<td>Confirmed by the results of the simulator study</td>
<td>Was not tested within these project</td>
<td>Results of the simulator study are not clear in this respect</td>
</tr>
</tbody>
</table>

Additionally, general results show that

- None of the test persons could accomplish all tasks or reacted correctly to all given information
- None of the test persons could answer all question concerning the traffic news correctly

This underlined that simultaneous communication should be avoided whenever possible, as it may lead to an overload situation for the driver. Hence, it is recommended to delay the communication of less important information until a higher-priority warning has been resolved.

6 Workshop and resulting guidelines

The results were presented to Austrian telematic experts during a one-day workshop. Additionally to the comments which were collected with respect to the results also feedback about the matrix, future trends and recommendations for the formulation of the guidelines were obtained.

Finally, the results from the literature study at the beginning of the project, the results of the simulator study and the recommendations produced by the experts were used to formulate guidelines for the optimum use of in-vehicle telematic systems. These guidelines were compared to international guidelines [6-8] so that at the end several LIVES-recommendations were the outcome of the project:
Information and warnings have to be as simple as possible; they should include clear instructions for the drivers, what kind of actions have to be taken; it has to be clear for the driver what he/she has to do.

### Table 5. Recommendations classified into priority levels and modalities

<table>
<thead>
<tr>
<th>modality</th>
<th>priority level</th>
<th>acoustic</th>
<th>visual</th>
<th>haptic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>warnings, high priority</strong></td>
<td></td>
<td>sounds earcons and analogue signals(^2), but no speech</td>
<td></td>
<td>can be exceptionally used; for instance related to exceeding of limits (speed, distance to the car ahead)</td>
</tr>
<tr>
<td><strong>medium priority</strong></td>
<td></td>
<td>symbols and pictures in the direct visual field of the driver</td>
<td></td>
<td>user should train the handling of the haptic signal before using it in real traffic</td>
</tr>
<tr>
<td><strong>general information, low priority</strong></td>
<td></td>
<td>sounds and speech (also if much information has to be submitted to the driver)</td>
<td>symbols, pictures, text and maps; information should be understood within two seconds</td>
<td></td>
</tr>
</tbody>
</table>

**Submitting simultaneous information:**

- There should be the possibility that priority level 3 information can be turned off in order not to interfere with information of higher priority.
- The simultaneous submission of information to the driver should, if possible, generally be avoided. The possibility to receive information from two different sources is limited and distract the driver from the driving task.
- For certain priority level 3 information speech could be used. But one should not submit more messages from this area simultaneously. Priorities have to be set, submission should happen consecutively.
- Information with lower priority should be submitted in such a way that information/warnings of higher level priority can be understood without any problems.

It is possible to submit the information with the same content multi-modal so that two or more modalities are used and strengthen the information. This can reduce the reaction time of the driver.

- The use of different modalities, especially acoustic and visual, for the simultaneous submission of the same information is possible without disadvantages.

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\(^2\) Sounds - noises, tones: random mapping, the signal has no direct link to the content of the information

Earcons - mnemonic mapping, the signal has a semantic link to the content of the information

Analogue signals - analogue mapping, the signal is according to the information modified along a dimension
• The use of acoustic and visual information in combination with haptic submission of the same information is possible for priority level 2 warnings. There, the acoustic and visual signals support the understanding of the haptic signal

7 Conclusion

The aim of this project was on the one hand to give recommendations for which modality should be used to submit information to the driver while considering the priority level of the content. On the other hand, the goal was to look how simultaneous information submitted to the driver influences his/her driving behaviour. This was done in the light of the fact that more and more in-vehicle telematic systems are today implemented in cars in order to inform, warn and help the driver. Conclusions were drawn as a result of simulator tests as well as from comments by experts in different settings.

Research work in this project provided indications for what modalities should be used for different kinds of information and warnings in order to address the driver in the best way, without interfering too much with the driving task. Acoustic information can be used when low priority information is submitted, as it is usually not too much disturbing. However, this modality also should be used when the driver should (urgently) be warned, because information forwarded via this channel is interpreted very fast. Visual information should mainly be used for low and medium priority information. Like for the acoustic modality it is essential to consider how visual information should be prepared for the driver. Low-priority information can be presented in detail (like maps). The higher the priority becomes the more simple the information should become (symbols). The haptic modality can with advantage be used for the medium priority level.

Simultaneous submission of information should be avoided unless two different modalities are used to submit the same information. If different types of information become relevant simultaneously a "workload manager" or "dialogue manager" could help, that "decides" what information should be presented to the driver first and what information could be suppressed for the moment and provided later, under better preconditions. Although such technical solutions are much sought for, their development must be based on socio-scientific findings, such as the guidelines described in this project. With the help of this research, solutions for both individual systems and combinations of systems can be developed.

The clear advantages in using a simulator was that with the help of this approach many different information and warning systems could be tested (which would be rather complicated in real traffic). Especially for the warnings of priority level 1 the controlled setting of the simulator would not have been achieved in real traffic. The approach allowed to gain basic results concerning the research questions in a cheap and easy way. The sample size was rather small but the statistical evaluation nevertheless showed significant differences between the used modalities and systems. Moreover, the results of the simulation study were discussed with experts and compared with the actual literature in order to validate both the outcomes and the final product, namely the guidelines.
However, more research within this field has to be done. For instance, there is hardly any literature according to haptic information which may be seen as a good possibility for in-vehicle telematics, as this channel is not used so far. More information also has to be gathered about technical solutions to avoid simultaneous submission of information (“dialogue manager”). Furthermore, recommendations and directives for HMI application should be continuously adjusted. Not least, clear instructions for the use of telematic systems, and for training for their use, should be given.

8 Acknowledgement

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9 References


NATURALISTIC DRIVING OBSERVATIONS TO INVESTIGATE DISTRACTION EXPOSURE AND IVIS PATTERNS OF USE: INTERESTS AND CONSTRAINTS OF THE APPROACH

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arnaud.bonnard@inrets.fr

ABSTRACT: With the development of communication and information technologies, driver's distraction linked to In-Vehicle Information Systems has become a key issue for road safety. Despite ten years of investigation on IVIS impacts on driving behaviour, several research issues remain to be addressed. By observing in an unobtrusive way the behaviour of drivers, at the wheel of their own vehicle, during their daily journeys, naturalistic driving observations seem an interesting approach to investigate the link between driver distraction and critical situations occurrence, driver exposure to distraction related or not to IVIS and IVIS patterns of use. Despite the current technological offer permits their implementation, these studies raise some constraints, in terms of ethical issues, participants’ selection, servicing processes, data coding and statistical analysis. Nevertheless, even if the issues to address are various, the outcomes of naturalistic driving observations in term of knowledge about IVIS integration in everyday life driving deserve the challenge.

1 Introduction

With the development of communication and information technologies and their deployment in the field of road transport, In-Vehicle Information Systems (IVIS) is becoming a common feature of the car environment. IVIS provide various functions and services to the driver. They may deliver information related to the trip management (e.g. navigation, traffic or weather information) but also completely unrelated to the driving activity (e.g. phone calls, e-mails…).

However, driver's distraction linked to the use of these electronic devices has become a key issue for road safety. Indeed, even if it is expected that IVIS can increase driving comfort when supporting the driver adequately in his or her driving task, it has been demonstrated that IVIS handling or checking can have negative side effects, such as distraction, mental workload increase, lapses of attention, reaction delays and inadequate situation awareness.

Since the nineties, numerous researches have been carried out, using various experimental contexts (driving simulators, test tracks or real traffic conditions) to estimate driver's demand while performing this kind of secondary task and to evaluate how this workload increase interferes on the driving performances [1-3]. In parallel, some authors showed that drivers engaged in secondary tasks have an increase risk of being involved in a crash or near-crash, whatever the solicitation modality (auditory, visual or manual) [4-6]. Accident analysis databases have also been analyzed to identify the part of distraction on crashes [7-8]. Aware of this issue, the European Commission, through the edition of European Statement of Principles on the design of Human Machine Interaction, decided to disseminate widely the best practices for the design of IVIS and their
in-vehicle installation [9-10]. Their objective was to limit the risk that poorly designed interfaces introduce unnecessary driver’s distraction. From a few years, driver’s distraction due to IVIS use has become a major topic of interest for researchers, authorities and designers. Despite this interest and the efforts achieved, some issues remain unresolved.

We assume that naturalistic driving observations offer the opportunity to fill in these research gaps. Indeed, it will be a challenging approach to investigate drivers’ distraction exposure and patterns of use of IVIS in everyday driving. In this paper, we present the main characteristics of naturalistic driving observations. Then, we highlight the research issues they can address and we describe the observations that can be carried out with this approach according to the current technological supply. However, the interests of these new possibilities of investigation must be balanced with their constraints. Thus, the different methodological questions raised by this approach are presented and discussed.

2 Naturalistic driving observations

2.1 Definition

Naturalistic driving studies consist in observing, in an unobtrusive way, drivers’ behaviour in naturalistic settings - that is, during their everyday life driving - out of experimental context [11-13]. Indeed, participants just drive where and when they want to, at the wheel of their own car. Participant cars are equipped with an instrumentation package, in order to record different information. Thus, it is possible to collect data related to the driver’s state, to his or her driving behaviour, to the vehicle dynamics, to the infrastructure or to the environment surrounding the car. These data are recorded non-stop during all the observation period. After the observation, they permit an in-depth analysis of drivers’ behaviour by researchers. Recorded and analyzed drivers’ behaviours can concerns standard driving situations but also critical or accidental situations.

Thus, conducting naturalistic driving observations seems a relevant method to collect information on the way drivers use IVIS in everyday driving, in addition to traditional crash investigation or experimental studies.

2.2 Research issues that can be addressed

Despite ten years of investigation on drivers’ distraction and IVIS impacts on driving behaviour, several major issues of research remain to be addressed. However, this missing knowledge can be largely investigated by naturalistic driving observations under the three following aspects at least: the link between driver distraction and critical situations occurrence, the drivers’ exposure to distraction related or not to IVIS and the patterns of use of IVIS.

Researchers that attempt to investigate the part of distraction on road accidents are confronted with the weakness of police reports and crash investigations regarding information on driver’s distraction or inattention at the moment of the crash [7-8]. Indeed, this distraction or inattention information is only issued from self-report of drivers involved in crash, or eyewitness accounts. But drivers
generally try to hide some details of what really occurred for fear of prosecution. Furthermore, it is difficult for the crash eyewitness to establish if the driver was running a secondary task just before the accident. At last, the recording of distraction or inattention information is not currently generalized in all accident databases. For example, in spite of the high media coverage of the risk linked to mobile phone use while driving, this information is not systemically available. And the solution retained by Redelmeier [4] to match the crash information given by the police reports to the phone activity of the drivers few minutes before the crash given by their telecommunication company is also spoilt by mistakes due to the inaccuracy of the collision time. For these reasons, naturalistic driving observations offer an efficient way to evaluate objectively the part of distraction on accidents with a possible in-depth analysis of crash and near-crash events recorded during the observation period [6].

Moreover, there is a lack of knowledge concerning the driver exposure to distraction. Authorities focus on the distraction risk due to electronic devices handling or checking, but the relative part of this specific kind of distraction amongst all the other potential distraction sources needs to be investigated. For example, what are the driver’s exposures to adjusting ordinary vehicle controls as climate control or radio, to locating or reaching objects inside the vehicle, to being distracted by car passengers, to being distracted by billboards along roads or to being lost in thoughts? And what is the actual exposure to handling or checking IVIS? If questionnaire-based surveys permit to distinguish clearly drivers that decide to use IVIS or not while driving, they are less relevant to evaluate accurately the frequency of IVIS use and the characteristic of the drivers that are more likely to use them. This information is necessary for an accurate exposure analysis and can be provided by naturalistic driving observations [11].

Beyond frequency of IVIS use, it is important to identify the patterns of use of IVIS in everyday driving. Under experimental conditions, subjects are instructed to pay maximum attention to the driving task, but they are still in a position to run a secondary task at the experimenter’ request. We assume that in the everyday driving, some drivers decide to minimize the risk due to electronic devices handling or checking by choosing carefully the driving context for their use. For example, they can decide to perform some interactions only when their vehicle is stopped. They can also decide to limit IVIS use according to the type of road or the traffic condition. They can also defer some interactions waiting for a more suitable driving context. Finally, they can slow down in order to keep safety margin thresholds at an acceptable level. Thus, it is interesting to highlight the detailed modalities of driver interactions with IVIS. Furthermore, IVIS are designed for a reference use that is defined by the objectives of the systems and the conditions in which it should be operated. We assume that some drivers might misuse their systems, using them for objectives or in conditions that were not anticipated by their designers. For example, a driver could activate the cruise control system in order to be more available to read the SMS message he has just received on his cell phone. This unexpected uses of systems, called misuses, have to be evaluated and quantified. Finally, when providing drivers with driving-related information, IVIS can modify driving behaviour at strategic, tactical or operational levels. The way drivers really use all the available IVIS information, the related modifications of their travel pattern and the long term effects on their driving behaviour are still unknown. These
three different aspects of patterns of IVIS use could be evaluated thanks to naturalistic driving observations.

Some North-American researches attempted to answer these questions [11-13]. Nevertheless, their outcomes can not be applied straight away to the European drivers because of major differences on vehicle models, on road network characteristics and on available technologies on the market. European countries also present cultural, institutional and economic differences that can explain various levels of IVIS availability or different drivers’ willingness to use IVIS. All this argues to launch naturalistic driving observations in Europe in order to address all these unresolved research issues, all the more so since the technological offer permits nowadays their setting-up on a large scale.

2.3 Available technology

Nowadays, actual technological equipments enable us to easily and efficiently equip the participants’ personal car and to collect several hours of data and video. Basically, a simple video recording system would be a good basis to study naturalistic driving behaviours, by filming what happens inside and around the vehicle [11]. However, a broad range of sensors can come in addition to this system [13]. Various vehicle parameters, like speed, steering wheel angle or indicator use can be collected via the E-OBD interface, by scanning the CAN bus of the vehicle or via specific additional sensors. The instrumentation package could also include a GPS to collect information on the vehicle whereabouts or several accelerometers to collect the lateral and longitudinal acceleration of the vehicle. We can even imagine the integration of advanced perception sensors like lane tracking systems or radars to know the position of the car on the road, and the surrounding traffic. However, these sensors are still expensive and their relevance is yet to be determined, as some of this information can be computed a posteriori from the video with image processing algorithms. Furthermore, given the constantly increasing size of the hard disk drives in computers, such a hardware data collection system could collect hours and hours of continuous driving data.

Obviously, it is easily possible to use many different sensors for the data collection with the only constraints of cost and of available space. However, to perform an in-depth investigation of driving behaviours, the recorded parameters will have to be carefully analysed.

To ease this analysis, the large amount of collected data can be automatically processed with the objective to find models that may deliver interesting behavioural information. For example, triggers can be set in order to select the near-accident sequences [13] or other potentially interesting sequences. To do so, the recorded parameters must include data that might act as triggers to indicate interesting sequences (e.g. beginning of a phone call, entering of a destination…). Even if the relevance of these sequences still has to be validated by an expert, it will facilitate and optimize the analysis work. However, some behavioural information can only be found manually by experts. This implies that they will have to check cautiously most of the collected data and videos, in order to code relevant behavioural information, which is very time-consuming.

Finally, technological choices must be a compromise. A simple data collection system offers a higher reliability and will be simpler and faster to equip in the
participants’ cars. However, due to the complexity and the cost of naturalistic driving observations, the instrumentation should still be rich and open enough to allow future exploitations.

Even if naturalistic driving observations are promising in terms of research issues to address and in terms of instrumentation development, the implementation of this kind of studies raises a set of additional constraints.

3 Constraints of Naturalistic driving observations

3.1 Ethical issues

First of all, from the ethical point of view, it is important to respect the privacy of the drivers and of the potential passengers. Indeed, data protection is a fundamental human right that must be guaranteed by experimenters, even if data protection laws may differ from a country to another.

Thus, experimenters must ask participants to sign an informed consent form. This consent form explains the purpose and the constraints of the study. It also explains that the confidentiality of the personal data is guaranteed and that their personal data will be anonymous. Finally, it offers them the possibility to withdraw from the study at anytime. When signing the consent form, participants fully agree to be involved in this study and that their personal data will be analysed by experimenters for the research needs. The difficulty is that the instrumented vehicle can be driven by secondary drivers and drivers can also carry some passengers, adults but also children and teenagers. Experimenters could then have difficulties for collecting consent forms of these casual secondary drivers or passengers.

Moreover, the respect of personal data protection can have a major impact on the kind of data that can be recorded during naturalistic driving observations, and especially concerning the video and audio recording systems. Different technical solutions can address this issue. The inside camera could only capture the driver’s face and not the entire vehicle cabin to guarantee the anonymity of potential passengers. Also, the audio information could not be recorded with the video to respect participants’ private life [13]. This kind of restrictions was used during previous studies, even if it considerably decreases the quality of dual task situations analysis. Indeed, with such recording conditions, it is hard to distinguish if the driver is talking with a passenger or if he/she conversing on a hands-free phone. It would also be difficult to identify which IVIS is handled by the driver [13].

To guarantee an accurate analysis of dual task situations, it seems preferable not to restrict the collected parameters, but to allow the participants to stop the data recording when they want to, with the only constraint to inform the experimenters of the reason of their decision. Thus, when participants take part in long observation period, they are able to preserve their private life when exceptionally needed, with only little impact on the final analysis.
3.2 Definition & representativeness of the driver’s sample

The correct definition of the sample of drivers involved in a naturalistic driving study and the capacity to generalize its results to the entire population are also major issues.

For experimental studies, the subjects are usually selected according to their gender and their age class. But in the case of a naturalistic driving study investigating the patterns of IVIS use, the participants’ sample should not be only constituted according to these two criteria [11] and other parameters should be taken into account.

In order to avoid any biased results, it is necessary to check if the devices at the disposal of the participants are sufficiently representative of the market. Indeed, the commercial offer for IVIS is diversified between the OEM systems, the after market ones and the nomadic devices. The human machine interfaces of the systems are also varied. They can be based on a visual/manual or on a vocal interface; the navigation in the menus can be more or less complex and so on. As these interaction modalities can have a direct and strong effect on the impact of IVIS on drivers’ behaviour, they have to be selected very carefully.

Of course, the fact that drivers are regular or irregular IVIS users must also be considered. In order to detect significant associations between IVIS use and driver’s behaviours, and even more to detect associations between IVIS use and crash or pre-crash situations, it is necessary to collect various patterns of IVIS use in sufficient quantities. However, even if it is practically preferable to use a sample with intensive IVIS users in order to clearly highlight typical patterns of use and to limit the necessary observation period, the possibility to generalise the results should be balanced. Indeed, drivers’ population is composed of individuals with very heterogeneous IVIS handling habits and irregular users also have to be taken into account.

Finally, the sample has also to take into account the various travel patterns of the population in order to highlight different patterns of use of IVIS and different conditions of distraction exposure. For example, concerning distraction, we assume that a commuter will probably be easily distracted by a phone call but maybe won’t be aware of outside distractions like special road signs. On the opposite, a couple with children that mainly drive to the countryside on the week ends will be more likely distracted by a navigation system (or by their children!). It will be necessary to control the participants’ sample in terms of numbers of driven kilometres, of road networks taken and of travels purposes.

As a conclusion, it is important to control the characteristics of the sample, not only in terms of gender and age. Even if we try to obtain a representative sample, a correction of the exposure data will still be necessary to extend accurately the results to the entire population.

3.3 Suitable servicing processes setup

Another major issue is to guarantee the quality and the consistency of the data collected during the whole observation period. First of all, this can be achieved by focusing on the simplicity and on the robustness of the data recording system [13], as it is a good solution to prevent potential hardware or software failures. However, it is also important to have additional processes to detect any
Drivers' distraction due to ITS use

possible breakdown. It is necessary to organise suitable servicing processes. This servicing will have to be reactive and mobile, given that the car can be anywhere. It is also important to plan repetitive partial data downloads to minimize the potential risks of data loss [13]. All these processes will permit to fix most of the problems. It will guarantee a maximum quality of the information collected during the whole experimentation. However, to limit the workload and the journeys of the servicing team, a periodic remote monitoring of functioning of the technical equipments installed in the participants’ car can be assured. For example, the system could send automatic reports via a wireless connection about the functioning status of its different components, but also summary information about the last collected data [14]. Moreover, download could also be done remotely using a wireless connection. Communication strategies will be necessary to keep a connection with the car even when it goes out of network coverage.

3.4 Event selection and data coding issue

As it was briefly presented in part 2.3, the selection of the significant events for the statistical analysis and the additional coding of the selected sequences are crucial issues to obtain relevant results from the naturalistic driving observation.

Indeed, according to the events studied by researchers (phone calls, consulting traffic or navigation information, pre-crashes and incidents) and their occurring frequency while driving, it is necessary to observe drivers and to collect data continuously during more or less long periods (a few weeks, several months or even a year). Amongst this huge amount of collected data, only a small subset of sequences is significant for the statistical analysis. Different kinds of procedures can be used to select these sequences. First, events can consist of few-seconds or few-minutes period of time selected randomly. This procedure has been used to evaluate drivers’ distractions exposure [11-12]. Events can also be selected from event triggers. For example, for the identification of pre-crashes or incidents, a set of variables measuring vehicle kinematics with a set of associated trigger criteria have been used to pre-select applicant events, selections are later strengthened by watching the corresponding video clip [13][15]. We can also dream up to conceive event triggers that identify the moments when drivers are using their electronic devices, with an analysis of video or audio data, or with specific sensors of devices running. This latter solution will be easier to set up when the instrumented vehicles are lent to subjects and then experimenters can control IVIS present in the vehicle.

All in all, this reduction process is necessary to reduce the effort for the following step, the data coding. Indeed, this part of the study is very time-consuming, but the accuracy of this work has a direct impact on the quality of the outcomes of the research. Video data plays a major part in the data coding process. Video clips permit first to evaluate if the driver is attentive or distracted and in the case of distraction to evaluate the distraction source. It permits also to code information about the driving environment like road characteristics, traffic, light conditions and so on. At last, the driving task under way can only be described in detail by watching video. Moreover, the coding of video data has a subjective nature and because of the amount of data, several people could be involved in this activity during several months. For that, they must be trained,
and the quality of their must be controlled on a regular basis with the objective to increase inter and intra reliability [13].

3.5 Statistical analysis constraints

The last major issue raised by naturalistic driving observations concerns the statistical analyses and their constraints that differ according to the research objectives. For example, for researches that attempt to evaluate drivers’ distraction exposure, the challenge is to extend the results obtained for the subjects’ sample to the whole population. We have already tackled the constraints raised by such an analysis in section 3.2, so we don’t broach this topic again and we prefer to focus on the case of researches attempting to evaluate the impact of IVIS on driver’s behaviour.

Statistical approaches have already been tested to analyse data collected during naturalistic driving studies. However, they have to be applied carefully. For example, an approach consists in selecting random driving sequences in order to assess drivers’ distraction status, according to the fact that the driver is distracted or not, and according to the nature of the distraction [12]. Then, these authors evaluate the impact of distraction on drivers’ behaviour by aggregating all the sequences with the same distraction status and by looking for significant differences on driving performance among them. However, this aggregating process doesn’t into account the heterogeneous driving context of the selected sequences, which can mask specific dual task effects.

Indeed, in the case of naturalistic observation, unlike experimental research, all the situations of dual task studied for each participant are unique, in terms of secondary task nature and also in terms of driving context. Here, it is not possible to isolate the effect of dual task by controlling all the interfering variables by the experimental design. A possible solution would be to realize matched-paired comparison. For that, each driver is considered as his/her own control and each situation of dual task must be matched with a baseline situation. The baseline situation must be as similar as possible to the dual task situation in terms of driving context. For example, a dual task situation can be matched with a sequence of the same duration, randomly selected just before, or just after, the studied sequence and during which the driver must be not distracted by any source of distraction. It is also possible to identify sequences with similar characteristics, like manoeuvre, traffic condition and road infrastructure, using advanced mathematical modelling like hidden Markov modelling [16]. This new approach would bring interesting information about the impact of IVIS use while driving.

Nevertheless, the effect of IVIS handling and checking on drivers’ behaviours at operational level must be certainly hard to evaluate. Indeed, the experimental studies on mobile phone use while driving show with a clear consensus that performing secondary task increases reaction time [1][3]. Conversely, the results concerning impacts on vehicle control (e.g. speed, headway, lateral position) are divergent [1][3]. And even for the authors who found significant effects, these effects are low. Thus, for naturalistic driving observations in everyday driving, it could be difficult to show effects on vehicle controls specifically due to the dual task situation and not to some variations in the driving context. Furthermore, the setting-up of compensatory processes during dual task situations is linked to the driving context, but it is also linked to
personal characteristics of drivers, like the awareness of the risks taken to handle or to check an IVIS, or the driving style.

The statistical approach retained for the data analysis, and its specifics constraints, must be taken into account at an early stage of the design of the naturalistic driving observation in order to make sure to achieve the desired research outcomes.

4 Conclusion

As a conclusion, even if naturalistic driving observations raise issues of different natures, they are still an interesting challenge that promises many visionary outcomes and that will certainly bring us new knowledge and new methodological approaches. Very aware of this interest, European researchers have already tackled this challenge and make strong efforts to implement naturalistic driving observations, with the support of their government and of the European Commission. We can assume that in a near future, large scale naturalistic driving observations will be launched in Europe and will complete the knowledge brought by American studies.

5 References


SESSION 2:
TOOLS AND METHODOLOGIES
FOR SAFETY AND USABILITY
DEVELOPMENT OF INNOVATIVE METHODOLOGIES TO EVALUATE ITS SAFETY AND USABILITY: HUMANIST TF E

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ABSTRACT: During the HUMANIST project Task the aim of Task Force E (TF E) was to develop innovative methodologies to evaluate ITS safety and usability. A matrix of methods for the assessment of ADAS and IVIS was developed and subsequently a proposed model for integration of these methodologies was proposed. A number of methods for the assessment of driver appropriation of ITS over time were also established and another model was proposed for the integration of these methods into one integrated methodology.

1 Introduction

In-vehicle information and communication systems (IVIS) are increasingly the standard equipment of modern cars. Advanced Driver Assistance Systems (ADAS) are also increasing, but the boundaries between the definition of IVIS and ADAS systems are blurred. Despite the obvious benefits of IVIS and ADAS there are also concerns that their use while driving may cause safety problems due to distraction and increased workload. Thereby it is assumed that it depends mainly on the user-friendly design of the Human-Machine-Interface (HMI) if the use of IVIS is compatible with the primary task of driving. In Europe recent efforts to develop and evaluate a catalogue of design goals for the in-vehicle HMI of IVIS, the so called “European Statement of Principles” (ESoP), reflect this approach. Nevertheless, the character of the ESoP is generic, i.e. defining no criteria to assess if the design goals have been achieved by a certain HMI solution. From all this it follows that there is an urgent need for methods to evaluate the effects of IVIS on driver workload and behaviour in order to assess potential problems for traffic safety and to improve HMI design [1]. It is also vital that researchers start to understand how drivers learn to use IVIS and ADAS and how this affects their driving performance over time as they become more familiar with particular systems.

One of the main objectives of HUMANIST Task Force E (TF E) was to exchange through the network, the knowledge and experience of projects which have applied or developed methodologies for the evaluation of on-board and off-board ITS; assessing systems both in terms of safety and usability. The Task force was required to consider the integration of various methods into comprehensive methodologies and then to consider the investigation of driver appropriation processes overtime.
2 Innovative methodologies to evaluate its safety and usability

The TF took a decision early in the project that the development of a matrix of methods would assist in the conception and confrontation of methods and procedures for usability and safety evaluations of ITS. The purpose of the matrix was to identify and categorise existing and proposed methods for usability and safety evaluation of ITS. When assessing usability and safety, different metrics (or measures) are used. These metrics are collected using specific techniques and often require specific tools, such as cameras or questionnaires. The metrics are collected in one or more physical environments. The following measures were collated for each method identified:

- Metric: Measure used to assess safety and usability of ITS e.g. brake response time.
- Technique: Details how the metric is determined e.g. deviation in distance between the vehicle centre and the road centre line
- Tool: Equipment needed to use the metric e.g. video camera, adjusted speedometer
- Environment: Environment in which the test is carried out. e.g. Instrumented vehicle
- Aspect of the system/human investigated: Describes how the metric assesses ITS safety and/or usability
- Type of data: Objective, subjective or observed (expert opinion)
- Effectiveness: How useful the measure is
- Practical issues: Issues to consider when using metric e.g. time, expense
- Organisation: Organisation which submitted or had experience of the metric

The combination of metric/technique/tool/ environment is what is referred to as a method. The Task force held two workshops to discuss different metrics and the formation of a matrix. A summary of some presentations can be seen in HUMANIST Deliverable D.2/E.2 [2]. To populate the matrix information was collated through these workshops as well as through scientific literature and experience of the HUMANIST partners. The measures were categories into nine groups; lateral control measures; longitudinal control measures (speed, vehicle following); steering wheel movement measures; eye tracking measures; physiological measures; situation awareness measures; task orientated measures; subjective mental workload measures; incident analysis measures. Initially only IVIS were considered then later in the task force a final category of ADAS measures was included in the matrix.

That matrix contains 130 methods. Partners were asked to indicate their ‘favourite’ method. Favourite meaning those most frequently used or most useful to the HUMAIST network partners. There are 22 favourites identified and the range of favourites is very broad, demonstrating the variety of methods available and that the methods used depend heavily on the objectives of a
study. The ‘favourites’ were categorised at 3 levels according to the number of partners selecting the method (level 1 being the most popular favourites and level 3 being the least popular favourite). There were two ‘level 1’ favourites: lane standard deviation and minimum following distance (closest longitudinal approach). The ‘Level 2’ favourites were: occlusion, glance frequency, glance duration, brake response time, time headway and time to line crossing. The full matrix can be found in the HUMANIST deliverable E.4 [3].

The matrix summarises important information and experience about each method based on scientific literature and experience of the HUMANIST partners. This information includes the type of data obtained (e.g. objective, subjective, observational or expert opinion); the effectiveness of the method expressed in terms of the validity, reliability and sensitivity; and practical issues of application including time, cost and training requirements. Where possible, the matrix provides scientific references and lists the HUMANIST partners with experience or knowledge of the methods. From developing the matrix it is clear that partners are doing substantial research into the impact of IVIS on driver workload and behaviour and that a large variety of ITS assessment methods are used.

3 ADAS and IVIS

An ‘In Vehicle Information System’ (IVIS) and an ‘Advanced Driver Assistance System’ ADAS are both obviously defined as systems. All systems perform functions, such as obtaining an address from the driver, warning of a collision or adjusting headway. Additionally some systems may include information functions, warning functions and assistance functions (and also in-built stability functions such as ABS). IVIS focuses on informing while ADAS focuses on warning and assisting. The table below demonstrates the issues associated with each of the four functions, hence distinguishing the difference between each of the functions. A detailed explanation and definition can be found in HUMANIST Deliverable E.4 [3]. An integrated methodology needs to address all of the safety issues listed in the diagram.

<table>
<thead>
<tr>
<th>FUNCTION ISSUE</th>
<th>In-built</th>
<th>Informing</th>
<th>Warning</th>
<th>Assisting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example</td>
<td>ABS ASC</td>
<td>Route guidance Mobile phone</td>
<td>LDWS ISA Advisory</td>
<td>ACC</td>
</tr>
<tr>
<td>Focus</td>
<td>Vehicle stability</td>
<td>Information to the driver</td>
<td>Warming the driver</td>
<td>Aspects of longitudinal and lateral control</td>
</tr>
<tr>
<td>Driver’s locus of control</td>
<td>None</td>
<td>Full</td>
<td>Depends</td>
<td>Overrideable</td>
</tr>
<tr>
<td>System supplier</td>
<td>OEM</td>
<td>OEM aftermarket Nomadic</td>
<td>OEM aftermarket</td>
<td>OEM</td>
</tr>
<tr>
<td>Safety issue</td>
<td>Technical</td>
<td>Distraction</td>
<td>Understandability</td>
<td>Controllability</td>
</tr>
<tr>
<td>Typical human interface</td>
<td>None (or via existing controls)</td>
<td>Screen + Audio</td>
<td>Buzzer, Symbol</td>
<td>Button Small display Existing controls</td>
</tr>
</tbody>
</table>

Fig.1. IVIS and ADAS function matrix
4 Integration of Methods

Humanist partners had several meetings and an internal workshop to discuss the process of developing an integrated methodology. The main objective of the workshop was to collate and review existing knowledge concerning the integration of individual methods into a more holistic approach to assessing safety and usability. A detailed report is in HUMANIST Deliverable E.3 [4]. An Integrated methodology was defined by HUMANIST TF E as:

“Structured human factors evaluation (of a system or function) that combines evidence from multiple assessments of different aspects of driver-vehicle interaction within a conceptual framework”

Developing an integrated methodology is a complex task and TF E have made some significant advances. From the first workshop it was clear that there remains a research gap concerning how to combine individual methods into an overall integrated methodology. The partners had a general common understanding of safety and risk, but there was a need to identify and use a common conceptual framework of driver information processing and risk. The next challenge was to find a conceptual model.

An integrated methodology should help to:

1. Understand the system being studied
2. Identify behaviours and communication aspects that could have influence on traffic safety
3. Formulate hypotheses concerning how (in what direction, in what aspects) behaviour and communication might be influenced
4. Decide how the effects can be measured in principle
5. Design and undertake appropriate assessments & analysis
6. Combine and present results

There are several reasons why a conceptual framework is needed in context of Integrated Methodologies. First, as a “theoretical backbone” it should offer some “guidance” through the process of HMI assessment. Second, it should represent relevant aspects of driver-vehicle interaction (with IVIS/ADAS), and third, it should make meaningful predictions for user tests. From this point of view it was obvious to clarify in a first step if some ideas could be derived from the work on driver models performed by HUMANIST (Task Force C) at the “International Workshop On Modelling Driver Behaviour In Automotive Environments”. The model proposed by Oliver Carsten [5] was considered worth further examination.

The group formed a view that the application of this model for the development of an Integrated Methodology can be described as a top down approach. On the other hand the question was raised in the discussion if such an approach would be really viable in practice and it was suggested that a bottom up approach which is driven by the actual demands of the system(s) under investigation might be more appropriate. This is, of course, a strong point in particular because the “Carsten-Model” is purely descriptive and does not specify how the relationships described are moderated by IVIS and ADAS. As a result an agreement on a conceptual model as specified in the definition of Integrated
Methodologies could not be achieved within HUMANIST, however work continued on integrated methodology.

The International Standards Organisation (ISO) have developed a suitability standard. Additionally the RESPONSE [6] and ADVISORS [7] projects have suggested methodologies which the HUMANIST group considered as a framework for integration.

The aim of this part of the HUMANIST work was to merge all the methods described in “The Matrix” towards one “Integrated Methodology” as a guide to the assessment process.

A proposal of how an integrated methodology could be developed into a model is shown below where available tools have been related to the different phases of the process. The HUMANIST Group then applied their knowledge of what is possible from current research, to establish where we are in the process of developing an integrated methodology. The diagram below shows the model that the HUMIST partners have generated.

As can be seen from the figure there are three phases in the process (IVIS/ADAS description, selection of measurement methods, measurement and analysis) where it is possible to refer to available inventories of methods as e.g. the “HUMANIST Matrix”. The most critical item seems to be the Multi-Criteria-Analysis or other combination/analysis tool at the end of the process where it has to be concluded that suitable tools do not exist. Of course, some related work has been done within the European projects ADVISORS and RESPONSE but these were developed for different purposes. This does not mean to say that an Integrated Methodology following this definition is incompatible with these developments. Rather, the approach followed here aims at a stronger microscopic or scientific level bridging the knowledge gaps between system functions, driving behaviour and accident risk.

![Diagram of HUMANIST TFE model of the stages and tools required for an integrated methodology](image-url)

As can be further concluded from the figure above, there are two phases in the process (identification of potential behaviours, generation of hypotheses) where at least some ideas on necessary tools exist but the state-of-the-art is far from...
satisfying. The discussions within TF E on conceptual models and frameworks [3] open research issues and reflect the need for a specific, meaningful, empirically validated but also parsimonious conceptual model. The continued review of models of driving behaviour might provide further input. However, it also became very clear during the discussions that these are too general to have more than a heuristic value. This means that we might now be at a stage where as well as practical tests assessments, deliberate theorising and careful experimentation are necessary in order to convert the orange and red fields in the Figure above into green ones.

A joint AIDE/HUMANIST workshop took place in March 2006. The Humanist integrated methodology model was presented to AIDE and it received positive approval.

Overall the work on Integrated Methodology has been useful at two levels. At the more immediate practical level the work has provided support for assessment by summarising the features of specific approaches. In addition the conceptual work has allowed a dis-aggregation of the complex issue of integrated methodology into a number of separate components that appear to be amendable to further research.

5 Driver appropriation of its over time

TF E was required to investigate methodologies to evaluate the safety and usability of ITS systems. One group of such methodologies includes methods to assess driver appropriation of IVIS and ADAS systems. Therefore the next aim of the HUMANIST work was to consider methods for the investigation of driver appropriation processes over time. In this paper ‘appropriation’ is considered as a specific case for integration into the general topic of methodologies (as depicted in Figure 2). The entirety of behavioural changes in response to a safety measure is generally referred to as ‘behavioural adaptation’ [8] [9]. An Organisation for Economic Co-operation and Development (OECD) report states that “Behavioural adaptations are those behaviours which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change. Behavioural adaptations occur as road users respond to changes in the road transport system such that their personal needs are achieved as a result. The adaptations create a continuum of effects ranging from positive increase in safety to a decrease in safety” [10]. TF E contributors agreed that appropriation does not only include observable behavioural changes, but also changes in cognitive, regulatory and motivational processes that underlie those observable behaviours. TF E contributors agreed therefore to adopt a wider view regarding the nature of the adaptation processes.

A workshop was held and several presentations from partners were given providing different methods. A review of the workshop presentations and discussions can be found in HUMANIST Deliverable E.5 [11]. In addition the next deliverable, E.6, [12] provides a detailed description of 12 methods that can be used to assess driver appropriation of ITS over time. Additionally brief descriptions of a further 10 methods are provided with advantages, disadvantages and comments on how the method is linked to driver
appropriation. The TF has developed a main body of the deliverable that provides an overview of driver appropriation processes and a discussion of scope for an integrated methodology for appropriation measurement informed by an underlying model of driver appropriation processes.

Starting from a number of presentations explaining possible methods to measure driver appropriation, the TF built a better understanding of different aspects of appropriation. This led to a deeper understanding and a better definition of appropriation. Task Force E aimed to develop an 'integration model' to conceptualise integrated driver appropriation methods. The HUMANIST task force agreed on the following definition of driver appropriation:

“Acquisition of knowledge, skills and attitudes underlying short term and long term changes in behaviour”

As stated in this definition, driver appropriation in response to ADAS may occur directly after introducing a new system into the vehicle (e.g. short-term changes in workload), as well as after a certain period of time of driving with the system. Furthermore, the definition emphasises the different nature of causes underlying driver appropriation, which are knowledge (e.g. of how a system works in different conditions), skills (e.g. in using/driving with the system), and attitudes (e.g. trust in the system).

In order to conceptualise driver appropriation it was regarded as useful to view different aspects of appropriation in relation to the three levels of the driving task as proposed by hierarchical control models of driving (Michon, 1985).

Fig.3. A diagram to show the different levels of driver appropriation

Appropriation on the ‘operational level’ of the driving task is mainly concerned with skill acquisition in how to operate a system. Decisions and skill in how to use or to apply a system in particular situations and driving manoeuvres (overtaking, lane changing) primarily affect driving on the ‘tactical level’. Overall, behavioural adaptation in response to ITS is observable on the tactical level of the driving task. Changes in drivers’ knowledge, attitudes and motives (e.g. overall risk taking, trust in a system) will mostly affect the ‘strategic level’ of the driving task, and thereby influence control on the lower levels. As the three hierarchical levels do interact with each other, adaptation at one level of driver control has influence on the other levels as well.

A number of factors influence drivers’ response to ITS. HUMANIST TF E focused on appropriation processes in response to IVIS and ADAS that are
influenced by three interacting factors: system characteristics, situation characteristics and driver characteristics.

A conceptual model of driver appropriation has been developed (By Anke Mogilka of CUT forming part of the PhD studies). The model together with a detailed description can be found in HUMANIST Deliverable E.6 [10]. The model aims to draw attention to relevant variables and their interdependences in influencing driver appropriation. The model includes several processes, including behavioural adaptation, risk compensation, and changes in information processing in response to the introduction of ADAS.

According to this model, driver appropriation develops in response to changes in the driving task due to driver assistance systems. The systems’ characteristics have a direct impact on driver's information processing. The degree of assistance offered by the system, i.e. the level of automation and the systems feedback mediated by the HMI are believed to have an impact on driver’s situational awareness and mental workload. Feedback from the system about its current state and behaviour is necessary to build up a comprehensive situation model that governs behaviour in unforeseen situations. Driver’s workload is thought to have an influence on alertness and vigilance in such a way that vigilance decreases to a greater extent over time when workload is below or above a medium optimal level.

6 Integration of appropriation methods

Within the work of TF E, a concept was developed concerning possible integration of methods based on the theoretical background and processes of appropriation. In order to develop the concept/model the integrated methodology model presented in a previous deliverable [3] was used as a ‘baseline’ approach. There were several issues raised and discussed. It should be noted that previous work of TF E has been more concerned with methods that relate to skill acquisition and driver behaviour measurement. The new and wider perspective requires methods that have not hitherto received as much attention including: elicitation of attitudes and knowledge by “soft” means; extended field trials and naturalistic measurements; measurement of system use/ non-use and measurement of changes in use of vehicles. A very important issue is the need to be able to identify loss of ‘manual driving’ skills caused by new technical system and the potential impacts of this skill loss e.g. during system malfunction or failure.

The HUMANIST TF E proposed integration of driver appropriation model is shown below. It is considered a working model that requires further research and validation:
7 Conclusions and future work

HUMANIST TFE has made a significant research contribution through the development of a matrix of methods and advances towards an integrated methodology. The work on Integrated Methodology has been useful at two levels. At the more immediate practical level the work has provided support for assessment by summarising the features of specific approaches. In addition the conceptual work has allowed a dis-aggregation of the complex issue of integrated methodology into a number of separate components that appear to be amendable to further research. It is therefore a challenge for future projects to make progress in these target areas.

Discussion within TF E on driver appropriation has helped to understand the requirement for future work in the research area. Starting from a “flat” list of possible methods to measure driver appropriation, a better understanding of different aspects of appropriation was built and a three-level characterisation developed. This led to a deeper understanding and a better definition of appropriation based on common understanding. Because driver appropriation and the integration of appropriation methods is such a new work area more questions have been raised than answers provided. The next phase of work in this area should focus on further developing the conceptual model of driver appropriation and the appropriation integrated methods model. In developing these models further it will be important to resolve detailed issues. For example:

- How can we measure transfer of learning from other environments?
- How do differences in intelligence or educational background affect appropriation?
What intervals should be measured to detect important adaptive changes?

How can we quantify driver distraction (internal and external) and its impacts?

What are the driver appropriation processes for IVIS and ADAS and their impact on safety?

The work of TF E has been very productive with some thought-provoking contributions in this relatively new scientific area. These considerations led to a better understanding of the development of innovative methodologies to evaluate ITS safety and usability.

8 Acknowledgement

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9 References


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EVALUATING DRIVER MENTAL WORKLOAD USING THE DRIVING ACTIVITY LOAD INDEX (DALI)

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ABSTRACT: Methodologies are required to support the user-centred design and evaluation of in-vehicle Information and Communication Technology (ICT). This paper reports the outcomes of three on-road experiments conducted to assess the usability of mobile phone and guidance/navigation systems. These utilized a method for evaluating drivers’ mental workload: the Driving Activity Load Index (DALI). For the guidance situation, functions were tested for two systems corresponding to two levels of technology maturity. Outputs of the DALI were used to identify which aspects of the old generation system had to be improved, and how the new generation could be designed to be more usable by drivers.

1 Introduction

Many research studies have been conducted to investigate the road safety consequences of deploying Information and Communication Technology (ICT) in vehicles [1],[2]. The objective is to create a balance between the potential interference induced by these systems versus the potential benefits that can be derived from them in supporting the driving task.

To evaluate these systems, it is necessary to have an efficient methodology that is applied according to the type of function, the type of system and the context in which the system is used [3]. A quite exhaustive overview of available methodologies, tools and techniques has been conducted within the framework of the network of Excellence HUMANIST [4]. Classically, the parameters that have been taken into consideration for safety evaluation have been related to the vehicle; for example, deviations from vehicle trajectories deriving from system use [5]. Other parameters include drivers' visual strategies, visual demand deriving from use of on-board screens [6], general driver behaviors [7],[8] and overall driver workload according to the situation [9].

The assessment of workload is coupled with the difficulty of the task experienced by the individual [10], because several reactions to task demands are possible. The individual can adapt his behaviour to increased demand, leading to a higher investment of effort but no perceptible effect on performance; or, on the contrary, he can decide to change his strategy with a lower level of performance. Then, moderate increases in task difficulty may produce few observable changes in error rate, as the driver attempts to keep performance constant by allocating more resources to the task [11]. Furthermore, inter-individual strategies are variable; some individuals develop more effective strategies which require less effort to reach a level of performance than do others. So, for all these reasons, objective performance measures, which directly measure performance, are not sufficient by themselves to evaluate the overall demands of a given situation.
Mental workload is a variable difficult to assess, in comparison with other variables. Several methods have been developed to measure mental workload [12]: measurements of physiological parameters, such as heart rate [13]; the dual-task method [14]; and methods that elicit drivers’ subjective judgments about the workload they have experienced. The latter include S.W.A.T (Subjective Workload Assessment Technique; 15) and the NASA TLX - Task Load Index [16]. Subjective measures are often used in practice because they have many practical advantages over objective measures [17],[18],[19].

The next section of this paper discusses subjective methods for the evaluation of drivers’ mental workload.

2 Subjective evaluation of drivers’ mental workload

2.1 Methods for subjective evaluation of mental workload

The subjective method allows for the evaluation rather than the measurement of mental workload by comparing the perception of workload between situations. It can therefore be regarded as a global, and even a "crude", criterion. Subjective evaluation is often conducted in association with other workload measurement techniques [20].

The SWAT is a sophisticated workload assessment tool, composed of a two-step process: in a scale development phase, data necessary to develop a workload scale are obtained from individuals; during an event scoring phase, people rate the workload associated with a particular task [21]. The primary assumption of SWAT is that workload is function of three dimensions: time load, mental effort load and psychological stress, each dimension having three possible levels. All possible combinations of the three levels of each dimension yield a 27-cell, three dimensional, matrix to represent workload.

The NASA TLX method assumes that workload is influenced by mental demand, physical demand, temporal demand, performance, frustration level and effort. After assessing the magnitude of each of these six factors on a scale, the individual performs pairwise comparisons between these six factors, in order to determine the higher source of workload factor for each pair. A composite note quantifying the level of workload is set up by using both factor rating and relative weights computed from the comparison phase.

The NASA-TLX has been tested and used by the army; being considered as superior in terms of sensitivity than other methods and well accepted by the operator [22].

The DALI (Driving Activity Load Index) is a revised version of the NASA-TLX, adapted to the driving task [23]. As previously mentioned, mental workload is multidimensional and, among other things, depends upon the type of loading task. The NASA TLX was originally designed to assess pilot workload in the aviation domain.

The basic principle of DALI is the same as that for the TLX. There is a scale rating procedure for six pre-defined factors, followed by a weighting procedure in order to combine the six individual scales into a global score. The main difference lies in the choice of the main factors composing the workload score.
For the NASA TLX, one of the factors to be rated is called the Physical Demand component and is usually defined in the following terms: "How much physical activity was required? - pushing, pulling, turning, controlling, activating,..." It appears that this question would not be very relevant when considering the driving activity where the control of the vehicle is quite automatic for an experienced driver, and where maneuvers are not supposed to be physically demanding in modern cars.

Another example is the Mental Demand component defined in the TLX as follows "How much Mental and perceptual activity was required? - thinking, deciding, calculating, remembering, looking, searching,...". This statement covers both perceptual and cognitive aspects of workload, and we think it would be interesting in the context of the driving task to be able to identify these various modalities.

Finally, the evaluation of the Performance factor can be made using objective data. The subjective rating of a good performance by the driver can show discrepancies with the measured one, but this difference might be due to many factors other than the mental workload itself - low or high self-esteem, motivations to fit to the standard performance,...-

DALI was derived principally by asking various experts involved in driving task studies to define which were, in their opinion, the main factors inducing mental workload for people driving a vehicle equipped with an on-board system (car phone, driving aid system, radio,...). This investigation led to the development of six workload dimensions for DALI: Effort of attention, Visual demand, Auditory demand, Temporal demand, Interference and Situational stress.

Key results of previous and recent studies using the DALI tool are summarized in the following paragraph. An overview is provided of the advantages and the limits of this task load index according to the purposes of the investigation and the various contexts in which it is used.

2.2 Evaluation of driver’s workload using Hand-Free mobile Phone

Using a mobile phone while driving raises the issue of road safety. Unlike other Information and Communication technology developed to support the driving task, the activity of phoning is disconnected from the driving task itself. There is then no benefit of this function in terms of enhancement of the driving task process for the driver. Use of the mobile phone while driving would induce a high probability of interference in terms of attentional demand for the driver [24],[25].

Nevertheless, some diversified findings are encountered in the literature, linked to the modalities of experimental conditions. In order to test the load of conversation, one author [26] used secondary verbal task techniques to assess mental load while driving. According to this author, drivers showed no significant changes in their driving performance while verbalizing, which made him assume that the driving task priority was maintained as intended. Brown, Tickner & Simmonds [27] used a verbal reasoning task based on grammatical transformation in order to assess the effect of phoning while driving. Results indicated increased errors in judgment of gaps, decreased skill in steering...
through narrow gaps and decreased speed. Drory [28] measured driver behaviour when using a mobile phone in a driving simulator. No serious performance decrement was found concerning the driving activity, except when the subjects actually dialed the number. Mikkonen & Backman [29] studied the influence of phone conversation on driving performance in a familiar urban environment. In this case, drivers paid more attention to their task, increasing their alertness and their anticipation behavior. Tokunaga & col. [30] showed the negative impact of the complexity of the phone conversation on reaction time and on NASA-TLX values, both for young and older drivers.

In order to evaluate the efficiency of the DALI as a tool for the assessment of mobile phone use, an experiment was carried out in a real road context (see Pauzié & Pachiaudi [31] for detail of the experimental protocol and results). The objective was to investigate evaluation of perceptual and cognitive load for the driver in this phoning condition, knowing that specific factors of the DALI were dedicated to these aspects. Results indicated that the global value of mental load increased significantly when phoning and driving in comparison with the reference situation corresponding to no system use. The load index was significantly high for “auditory” and “interference” factors, in addition to “stress”. The effort of “attention”, although higher than during a simple driving task, does not increase significantly. So, in terms of subjective evaluation of the workload, drivers identified the disturbance induced by phoning, through the perceptive channel of audition, on managing the driving task, which induced stress. Through this example, it is possible to illustrate how a tool based upon subjective evaluation and driver awareness can allow for the understanding of mental workload and cost of the task.

![Fig.1. Factors and Global Value of the DALI for hand-free mobile phone use.](image)

**Advantages:** Allow to better understand how the implementation of a system in a vehicle can be experienced by driver (in this example, the most significant factor was “interference” due to phoning while driving).
2.3 Evaluation of driver’s workload using Navigation/Guidance function

Navigation and guidance functions have been developed to support drivers at the strategic level of the driving task, by supporting the navigation process. They also support driving at the operational level, by supporting drivers to anticipate upcoming maneuvers. Theoretically, driver reliance on auditory and visual instructions to support their way finding decisions should decrease mental workload and reduce driving errors. However, this objective can only be reached if the system is correctly designed, that is to say avoiding misconception, with correct timing for displayed messages, not too soon and not too late, and clear, legible and visible visual information. Evaluation of drivers’ mental workload, in addition to driving errors, is necessary to enhance the effectiveness, usability and acceptability of systems developed to support these functions [32],[33].

Two experiments conducted with a 9-year time lapse [34] are especially revealing about the importance of making a distinction between the “benefit of the function”, such as “instructions to guide the driver”, and “design of the system for this function” such as “modalities of displayed instructions, timing of auditory messages, legibility and understandability of messages”. The first experiment described was testing the first generation GPS-based system; the second was conducted using a new-generation version of the system, both implemented by the same car manufacturer.

2.3.1 Drivers’ workload for old-generation guidance system

It was proposed that this system provide the option of auditory guidance instructions or an electronic map display. The experiment was conducted in a real road context and the purpose of it was to compare drivers’ workload for these two options with a reference situation (that is, no system but a paper map; Pauzié & Pachiaudi, 1997).

According to the DALI “global” score, use of the system corresponded to a significantly higher workload for the driver in comparison with the “reference” situation (guidance or electronic map). The DALI factors, “auditory” and “temporal” demands were both critical factors, rather than “visual” load, with high values for “stress” and “attention”. Based upon this data, it was possible to determine that the messages displayed by this specific system, whatever the option of guidance (display of arrows) or navigation (display of electronic map), has a poor timing when delivering auditory instructions to the driver. These results showed also that the navigation option induced a high rate of interference, in comparison with the two other contexts of guidance and reference situations.
Advantages: Allow to identify the weakness of the design characteristics that induced workload for the driver (in this example, poor timing of the auditory messages)

Limits: Necessity to analyze objective variables such as driving errors to complete the investigation (in this example, the value of driving errors could modulate the conclusions regarding reference situation versus guidance situation; it can be costly to use the system for the driver but it can induce less driving errors).

2.3.2 Driver’s workload and new-generation of guidance system

Diversified contexts of orientation processes have been set up, varying according to their level of workload for the driver, in order to test the validity of the method DALI. Overall, 4 situations were identified, from HIGH to LOW demand: “complex system” requiring cognitive and perceptive attentional demand, “paper map” with no system, “guidance system” correctly designed and “human co-pilot” giving instructions to the driver. The four situations have been processed in real road contexts in a turnover order between drivers to avoid effect of practice and learning [34].

According to the DALI global score, there is a significant difference between the 4 experimental sessions (Wilcoxon, $Z= 3,007$, $p=0,003$; $Z= 2,224$, $p=0,026$, $Z= 2,539$, $p=0,011$; $Z= 3,923$, $p<0,001$). More precisely, contrary to the previous experiment, “use of guidance instructions” induced generally a lower workload than “use of a paper map”, identified as “reference” in the previous paragraph. Looking at the detail of the DALI factors, it appears that support of the system for the driver is in terms of “stress”, “interference between driving and finding his route”, “temporal”, “visual” and “attentional” demand, with significant differences. Of course, “auditory” demand was not rated by the driver in the context of the paper map use.
Hence, these results demonstrate that a guidance system correctly design in terms of visual and auditory messages (timing, loudness, content) is an added value for the driver by making the orientation task lighter in terms of cognitive and perceptive processes. Furthermore, the DALI results showed that there is a higher level of workload while using the system in comparison with relying on the human co-pilot. Hypothesis can be made that this system could require a phase of training longer than the timing of this experiment, in order for the driver to be fully comfortable with the system. Additional testing with a longer training phase could indicate if the system can be equivalent to a human co-pilot or not. At least, the DALI results indicated that this system is superior to a paper map.

Fig.3. Factors and Global Value of the DALI for Guidance and Navigation.

New generation system

**Advantages:** Allow identifying correctly design functions of in-vehicle system, able to support driving task, in comparison with situation with no system (in this example, driving with a well-designed guidance system in terms of visual and auditory messages (timing, loudness, content) induced less workload for the following factors “attention”, “visual”, “temporal”, “interference”, “stress” in comparison with the situation of paper map use).

**Limits:** Necessity to set up several contexts to be able to use this tool (reference situation versus tested situation or several tested systems), as it allows relative and not absolute results.

2.3.3 **Driver’s workload and maturity of technology**

The two previous experiments illustrated evolution of the design characteristics of a system for a given function in relation to the improvement of the technology. They highlighted the need to keep in mind, while testing in-vehicle ICT, that both functions and system design can have an impact on usability and safety, but at a different level. At this stage, and based upon literature investigations, it can be considered that the guidance function by itself has a positive impact on the driving task (less driving errors and hazardous behavior,
less workload in comparison with paper map use) as long as the guidance instructions are correctly designed. Indeed, in this experiment, a specific care on the HMI design of the guidance instructions was applied: enhanced contrast, simplified visual display, well-paced auditory message. The objective was to evaluate the added value brought by the guidance functions in an optimized context of HMI design. The chosen HMI design was not the only solution, but avoid poor interface such as monochrome screen (example: mobile phone on the left of the figure 4) or complex map display.

To summarize, the use of the DALI can support the designer in identifying which aspects of the driver-vehicle interface are inducing perceptual and cognitive demand for the driver due to poor design of the system, and to improve next generation of prototypes, allowing also to take into account the quick evolution of the technology in this domain through the iterative processes of design and evaluation (figure 4: examples of two successive generations of mobile phones HMI).

Fig.4. Old and new generation of mobile phone giving guidance information to the driver

3 Conclusion
The measurement of driver workload complements other workload metrics in bringing additional information and allowing broader understanding about the complex interactions between drivers and the systems they use while driving. DALI, as a subjective workload evaluation tool, allowed for the gathering of data that was usable by the designer in improving his system prototype. It allowed enabled identification of the impact of a given system implementation by comparing results with a reference situation with no system. One of the main advantages of this tool is that it makes it possible to identify the origins of driver workload, allowing for corrective action at the identified level (e.g., high interference and visual load indicate that an in-vehicle system has a demanding visual display). The possible design improvement would be to add factors linked to specific aspects of the driving task useful to evaluate the impact of ADAS functions (e.g. level of stress to keep distance with the vehicle ahead, in the case of a system having an impact on this specificity of the driving task). It is planned to conduct further investigations to improve this method by varying these types of situations. The “DALI tool kit”, comprising the detailed method and procedures for the automatic computation of statistics and the display of
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graphical outputs, will soon be available on the INRETS web site (www.inrets.fr), allowing any researcher to use it in his/her scientific context.

4 References


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COMPARISON OF SUBJECTIVE WORKLOAD RATINGS AND PERFORMANCE MEASURES OF A REFERENCE IVIS TASK

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ABSTRACT: The aim of this study was to establish subjective workload ratings (NASA-TLX) for the ADAM surrogate reference task (SURT) and compare them to ratings of a test battery of real IVIS tasks while participants performed a surrogate of the driving task (Lane Change Task). The results indicated that subjective workload ratings were comparable for both the real and reference tasks, performance measures were significantly correlated with measures of subjective workload and that performance of the secondary reference task declined as task difficulty increased. Reasons for the pattern of results are discussed.

1 Introduction

Traditionally car drivers have operated a number of ‘additional’ devices in the driving environment including; radios, heating, ventilation and air conditioning systems. Quite often these systems are controlled in addition to the primary task of driving. Technological advances have facilitated the development more sophisticated driver information systems intended to make travel more efficient and less arduous [1]. The major concern with the introduction of new IVIS is that they may introduce driver distraction sufficient to interrupt the primary driving task [2].

Workload is a hypothetical construct [3] that represents the cost incurred by a human operator in achieving a particular level of performance. It can be viewed as the proportion of resources required to meet task demands. If the demands of the task exceed the resources available to the skilled operator performance will inevitably decline [4, 5]. Subjective workload ratings are the most common method of obtaining estimates of the workload associated with a variety of tasks and are an important consideration in the evaluation of performance. If operators consider the workload of a task to be excessive they may behave as though they are overloaded, even though the task demands are objectively low. In such cases participants may report that the task was hard, but then perform just as well as if undertaking a low workload task [6, 7].

A central theme in the development of IVIS is the evaluation of the user’s ability to complete two or more tasks concurrently [8]. The primary aim of any evaluation of IVIS is to ascertain whether drivers are able to perform the system tasks in the dynamic and sometimes difficult circumstances that can be expected during performance of the driving task. For these tests the primary task does not necessarily have to be driving a car. It is only necessary to present a primary task which demands an equivalent level of continuous
attention from the participant while operating a secondary task (the interface). The dual task approach purposely divides the attention of the subject in order to define the limits of their processing capabilities.

The rationale behind the use of reference tasks is that an IVIS device will produce a particular pattern of behaviour and if a reference task produces the same pattern of behaviour we can conclude that the reference is a suitable surrogate. Reference tasks are intentionally generic in nature allowing the impact of IVIS tasks to be assessed in a context independent fashion. A good secondary reference task should be analogous to IVIS devices, complex enough to illicit the same responses as a real IVIS yet, simple enough as to be analogous to all IVIS. The ‘trade off’ in using reference tasks is between the loss of ecological validity (real tasks), compared with the advantages of being able to compare the results of studies more readily (standard tasks).

A robust secondary reference task was developed as part of the ADAM project. The visual search task requires participants to report whether or not a pre-specified target is embedded in a multi-item display. In this instance the specified target is a circle that is distinguishable from other items (also circles) within the display by size. Non-target items are designed to act as distracters.

![Fig.1. Screen shot of the surrogate reference task (SURT).](image)

Figure 1 illustrates how visual complexity of the task can be manipulated by altering the size of the target, the thickness of the line and the number of distracters present. The size of the target is always 44 arc minutes. In the left image distracters are 22 arc minutes in which the target is easy to find, in the centre image distracters are 35 arc minutes finding the target is moderately difficult and in the right hand image the distracter size is 40 arc minutes, in this instance the target is very difficult to distinguish. Task difficulty can therefore be adjusted to match the difficulty (in terms of visual search) of a wide range of real IVIS tasks.

The key aim of the current study was establish the subjective workload ratings for an established reference task and a test battery of real tasks and then consider these ratings with respect to the participant’s performance on the Lane Change Task. This would then establish the utility of reference tasks as a suitable surrogate for real tasks in the investigation of performance.
2 Method

2.1 Participants

16 participants (2 Female, 14 Male) were selected at random from staff and students at Loughborough University. Participants were required to have a full United Kingdom driving licence and normal or corrected vision. They had an average age of 35 years and 6 months and had held a driving license for an average of 15 years and 7 months, self report estimate of annual mileage was an average of 10,464 miles.

2.2 Design

A within subjects ‘repeated measures’ design was used wherein each subject completed each of the conditions. The trial design was counterbalanced so that learning effects could be controlled for in the statistical analysis.

2.3 Lane Change Task

The Lane change Task is a laboratory control and event detection metric based on the dual task paradigm. The dual task paradigm posits that primary task performance will degrade with the introduction of a secondary task. In this case LCT performance can be viewed as the primary task and it is designed to be analogous to the driving task. It was developed as part of the ADAM project (Advanced Driver Assistance Metrics [10].

Fig.2. Screen shot from the LCT. In this instance the driver has to change from the centre lane to the right lane.

The LCT requires participants to negotiate a 3000m long section of three lane highway. Participants are instructed by signs on the roadside (150m apart) to perform a lane change manoeuvre (see figure 2). While completing the LCT participants are required to perform a specific secondary task. To avoid speed confounding the results it is controlled by the program and is kept at a constant 60kmph. The illumination reflects daytime driving with a constant light level. Simulated low level engine noise is also provided. Visual information is
presented using an egocentric (front) view; no visual information is presented regarding side or rear views.

The vehicle dynamics are such that the simulated car will behave as a standard passenger car. Participants are required to change lane when instructed, when not performing a lane change manoeuvre they are required to maintain a central position within the lane. Performance of the lane change task by itself is used as a measure of baseline performance for comparison with performance of the LCT and a secondary task. During a LCT trial the LCT program automatically records data to the computer on which it is running. From this data the LCT analysis program can calculate a number of performance measures. These include; mean deviation from the normative model, standard deviation from the normative model, mean steering angle, as well as time course and distance information to allow for standardisation of experimental runs. The normative model is an ‘ideal’ vehicle path.

Mean deviation from the normative model is the major variable of interest. It is a measure of the effect of secondary-task demand and refers to the deviation between the normative model and the actual driving course of the participant along the track (see Figure 3 for a symbolic example of the normative model and driving data). This deviation measure covers important aspects of the driver’s performance; namely his/her perception (late perception of the sign or missing a sign), quality of the manoeuvre (slow lane change results in larger deviation) and lane keeping quality, which all result in an increased deviation.

### 2.4 In-Vehicle Information Systems

The IVIS used in this experiment was a Tom-Tom satellite navigation system running under windows on a HP iPAQ (PDA). The ADAM SURT task was presented on an 8 Inch TFT LCD Monitor produced by LinITX. Using this equipment participants were required to complete seven LCT trials. Each of these trials was dedicated to one of seven IVIS tasks (see Table 1) which have been applied in previous research [10, 11].


Table 1. List of Tasks

| Task 1: | PDA POI – entering a destination by selecting a “point of interest” using the PDA |
| Task 2: | PDA address – entering a destination by “address” function using the PDA |
| Task 3: | Shares short – searching for a share price from a single scrolling column of text using an LCD screen |
| Task 4: | Shares long – searching for a share price from three scrolling columns of text using an LCD screen |
| Task 5: | SURT circles task easy: - distracters are 22 arc minutes⁴ in which the target is easy to find. |
| Task 6: | SURT circles task average: - distracters are 35 arc minutes finding the target is moderately difficult. |
| Task 7: | SURT circles task difficult: - distracter size is 40 arc minutes; in this instance the target is very difficult. |

2.5 NASA Task Load Index (NASA-TLX)

The NASA-TLX [12] is a multidimensional tool for the measurement of workload. It identifies a number of subjective factors that are relevant to workload [13]. It has been extensively tested and widely used in the study of human performance [14]. It provides an overall workload score based on a weighted average of ratings on six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration.

2.6 Procedure

Informed consent was sought from participants prior to commencement of the experiment. Participants were informed of their right to withdraw at any time, for any reason without penalty. Participants were invited to complete a practice session (a block of 5 LCT trials lasting 15 minutes, instructions for the LCT were provided) in order to familiarise themselves with the operation of the LCT. Upon satisfactory performance of the practice task participants completed the experimental trials. In the IVIS condition participants were required to complete 7 LCT trials, one for each task under dual task conditions. The order of these trials was counterbalanced. The seven IVIS tasks are detailed in table 1. After completion of each dual task participants were required to complete the NASA-TLX.

3 Results

Mean deviations from the normative model and participants NASA-TLX ratings for the SURT tasks were significantly correlated ($r (48) = .424, p< .01$). There was not a significant correlation between NASA-TLX ratings and tasks 1-4 (Real). A one-way repeated measures ANOVA was calculated for mean deviation from the normative model on the LCT across the seven conditions (PDA POI, PDA Address, Shares short, Shares long, SURT easy, SURT difficult).

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⁴ The size of the target is always 44 arc minutes.
average and SURT difficult). The main effect was not significant \[F (6, 15) = 1.029, P>0.05\].

![Fig.4. Average NASA-TLX rating and average mean deviation from the normative model by condition](image)

A repeated measures ANOVA was calculated for mean un-weighted NASA-TLX score across the seven conditions (PDA POI, PDA Address, Shares short, Shares long, SURT easy, SURT average and SURT difficult). The main effect was significant \[F (6, 15) = 14.421, P<0.05\]. The subjective nature of workload is illustrated in a significant test of between-subjects effects \[F (1, 15) = 193.206, P<0.005\].

### 3.1 Secondary task performance

![Fig.5. Mean number of responses and task time by SURT condition](image)

A repeated measures ANOVA was calculated for mean number of responses in the three SURT conditions (Easy, Average, and Hard). There was a significant difference between the three conditions \[F (2, 47) = 36.150, P< 0.005\]. Similar results were observed for total task time \[F (2, 47) = 63.467, P< 0.005\], mean
reaction time \[F (2, 47) = 13.388, P< 0.005\], and errors \[F (2, 47) = 14.302, P< 0.005\]. The difference between number of key presses required to complete the tasks and actual number of presses by participants was not significant \[F (2, 47) = 1.755, P> 0.05\].

4 Discussion

Performance measures were significantly correlated with measures of subjective workload as evidenced by the significant correlation between NASA-TLX rating and mean deviation from the normative model; this was the case for the SURT tasks, but not the real tasks. Subjective workload ratings were comparable for both the real and reference tasks. There were similarities in the NASA-TLX profiles of the real and reference tasks. Figure 4 shows that the subjective workload ratings obtained on the NASA-TLX for the reference tasks were an approximate replication of the patterns observed in the battery of real tasks. The ratings for the SURT easy task were similar to those for the shares short task, the SURT average task rating was similar to ratings for the shares long and PDA POI conditions and the SURT difficult rating reflected the rating for the address entry condition. This suggests that the amount of workload generated by the SURT tasks is reflective of the workload that would be generated by a real task. The subjective nature of workload is illustrated by a significant test of between-subjects effects. This result strongly suggests that the ratings for each of the seven tasks were different for each participant.

These results reflected the hypothesised difficulty levels of these tasks at their original conception. [11] evaluated the four real tasks (PDA POI, PDA Address, Shares Short, Shares Long) used here using expert opinion and a key stroke analysis. The panel of experts consisted of members of staff from TRL, Nottingham University (UK) and the Chemnitz University of Technology (Germany). The tasks were assessed on four criteria; input (how the driver enters information), task (what needs to be done), display (what information is presented), and output (what results are displayed by the system). The negative, neutral and positive factors of each task were identified. All the tasks were primarily visual however it was hypothesised that the Shares Short task would be the easiest as it contained the least amount of visual information. The Shares Long task contained only a small increment in visual demand (three columns instead of one) therefore we would expect a similar increase in workload rating. The PDA POI task contains an added element in that a physical response is required therefore we would expect a further increase and finally a further increment for the PDA address entry task which is more demanding both visually and physically.

However, the performance measures do not support this. Scores for the mean deviation from the normative model were not significantly different. We can however examine the pattern of results with reference to [11]. What is surprising are the scores for the mean deviation from the normative model for the real tasks. In both the PDA and scrolling shares tasks the mean deviation was higher than expected for the task rated as easier (PDA POI and Shares short) in the expert review. We would have expected a smaller deviation from the normative model in these conditions and therefore a significant difference.
However, there is a plausible explanation for this pattern of results. [15] demonstrate task adaptation in which participants performance in a dual task setting was shown to improve due to participants applying more effort to these tasks and relaxing when performing the driving task alone. A similar effect may be observed here in that participants may be mobilising more resources and increasing effort in the more difficult conditions and/or relaxing and decreasing effort while completing the easier tasks.

This possible explanation is particularly relevant in an examination of the SURT tasks. As the difficulty of the SURT tasks increases so does the subjective workload ratings of participants as illustrated by an increase in the mean NASA-TLX rating. In conjunction with this increase there is a decrease in the mean deviation from the normative model. This is surprising given that this would be indicative of good performance of the LCT. However, this point is clarified in an analysis of the participants’ performance on the secondary task.

Data regarding performance of the secondary task suggests that as the difficulty of the task increases participant’s performance declines. This is illustrated in Figure 5 which shows that as the difficulty of the SURT task increases the number of responses declines and the time taken to make these responses increases. The results also imply that the SURT difficult task is too difficult for participants and those participants disengage from the task; secondary task performance is sacrificed to maintain what the participant perceives to be an acceptable level of primary task performance. These results are in line with the theory of compensatory effort [16] which states that when faced with a difficult task participants will either mobilise more effort in order to achieve performance goals (with an associated increase in physiological and behavioural costs) or reduce their performance goals to avoid such costs. [6] imply that people are aware of their task performance and that their estimates of subjective workload are based on their perceptions of performance. It is reasonable to suggest that in this instance participants are basing their estimates of workload on their success at completing the SURT task and not on their performance of the LCT. It is important to note that the SURT difficult task is still useful in performance evaluation as it is representative of tasks that should probably not be undertaken while driving.

5 Conclusion

The original aim of this study was to establish the subjective workload ratings (NASA-TLX) for the SURT reference task and compare them to ratings of a test battery of real IVIS tasks while participants perform a surrogate driving task (LCT). The results of this study support the conclusions that subjective workload ratings are comparable for both the real and reference tasks. Performance measures suggest that participants trade-off secondary task performance in order to maintain LCT performance at their perceived level of acceptable performance.
6 References


IMPAIRMENT OF LANE CHANGE PERFORMANCE DUE TO DISTRACTION: EFFECT OF EXPERIMENTAL CONTEXTS

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ABSTRACT: This paper aims to evaluate the consistency and sensitivity of the Lane Change Test (LCT), which is subject of a proposed ISO standard. The method aims at estimating driving demand while a secondary task is being performed, by measuring performance degradation on a primary driving-like task. An experiment was conducted in two experimental contexts, a driving simulator and a Personal Computer (including pedals and steering wheel), and with two auditory and two visual-manual secondary tasks. Three performance measures were calculated: mean deviation adapted, correct lane change ratio and lane change initiation. The effect of experimental context was significant. The trajectory, measured by adapted mean deviation, was of better quality on the simulator, while lane changes were initiated earlier on the PC. This difference may be explained by the greater immersion of the driver in the driving scene, which led to easier control of the trajectory in the simulator. Conversely, participants initiated quicker responses to signs when using the PC, to the detriment of trajectory control. The LCT was proven to be sensitive enough to evaluate the driving performance impairment due to the simultaneous performance of various secondary tasks.

1 Introduction

The handling and the use of In-Vehicle Information Systems (IVIS) while driving induces dual-task situations that can lead to driver distraction. Distraction occurs when a driver is delayed “in the recognition of the necessary information to safely maintain the lateral and longitudinal control of the vehicle due to some event, activity, object or person, within or outside the vehicle that compels or tends to induce the driver’s shifting attention away from fundamental driving tasks” [1].

Experimental studies point out differentiated impairment of driver performance for auditory and visual-manual secondary tasks. Performing auditory tasks while driving alters the ability to detect an event, to respond to it correctly and quickly [2-5]. In the case of visual-manual tasks, the ability to control a vehicle is also altered and lane keeping becomes more difficult [6-8].

Distraction has also been shown to increase the risk of having an accident. The National Highway Traffic Safety Administration estimates that at least 25% of police-reported crashes involve some form of driver inattention [9]. For Stutts et al. [10], drivers were distracted at the moment of the crash in 8.3% of the police-reports they analyzed. In-vehicle distraction is also reported as a contributory factor in nearly 2% of the police fatal accident reports investigated by Stevens and Minton [11]. However, these studies certainly underestimate IVIS
distraction as the reports are somewhat dated (1995-1999 [10], 1985-1995 [11]). More recently, in the US 100-car naturalistic driving study, Klauser et al. [12] showed that drivers engaged in visually and/or manually complex secondary tasks have a three-times higher near-crash and crash risk than attentive drivers. Epidemiological studies confirm the negative impact of distraction on road safety, showing that conversing by phone while driving (with a hands-free or hand-held phone) is associated with a fourfold increase in crash risk [13-14].

The risk of distraction generated by poorly designed device interfaces is thus of main concern for authorities, designers and researchers. The challenge is to develop simple and low-cost methods to assess the distraction of the Human-Machine Interface at the early stages of the IVIS design process.

The Lane Change Task (LCT) meets these requirements. This method was developed for in-vehicle information systems evaluation in the German project ADAM (Advanced Driver Attention Metrics) [15]. It aims at estimating driver demand while a secondary task is being performed, by measuring performance degradation on a primary driving-like task. This method is currently being discussed in ISO working group TC22/SC13/WG8 as the basis of a standard to access driver demand [16]. The LCT display can be implemented in different experimental contexts (laboratory, driving simulator, mock-up or complete/production vehicle) and should be applicable to all types of interactions with in-vehicle information.

The aim of this paper is to evaluate the consistency and the sensitivity of the LCT. Two main questions are addressed. Firstly, are the test results consistent from one experimental context to another? Secondly, is the test sufficiently sensitive to evaluate distraction effects of tasks with different characteristics?

To answer these questions, the LCT was implemented on two experimental contexts: a driving simulator and a low-cost simulator (Personal Computer, pedals and wheel) and with four very different secondary tasks: two auditory tasks and two visual-manual tasks.

2 Method

2.1 Participants

Thirty participants were recruited and split into two equivalent groups of 15 drivers (7 males and 8 females in each group). All participants were aged between 26 and 45 years (mean = 33.8; SD = 5.58). All of them had a driving licence and reported driving at least 5,000 kilometres per year. All stated that they drove several times each week.

All participants were used to using a mobile phone in everyday life (for more than 7 years on average; SD = 2.58). Most of them also stated they used their phone while driving, at least occasionally. All but one stated that they often tuned the radio or dealt with a CD player while driving. None of them had previous experience of the LCT.
2.2 Procedure and design

Each group of 15 drivers performed the experiment in two sessions: one on a driving simulator and the other on a Personal Computer (PC). One group began with the PC condition (Order 1: PC 1\textsuperscript{st} – Simulator 2\textsuperscript{nd}) and the other with the driving simulator condition (Order 2: Simulator 1\textsuperscript{st} - PC 2\textsuperscript{nd}). In between the two sessions, there was a two week break.

On arrival, participants filled in a personal data questionnaire. They were then given written instructions explaining the experiment. To begin each session, participants performed a learning phase consisting of four runs without any added task to enable them to become familiar with the LCT. The experiment itself always began and ended with a run without an added task. Such a run was also performed in the middle. These three runs provided the reference data.

Four added tasks were also performed in four different orders to limit potential task order effects. Each task was first executed without the LCT during about 90 seconds, to let participants get acquainted with it. Participants were then asked to estimate its level of difficulty, by using a scale from 0 (no difficulty) to 10 (very difficult). They were then invited to perform the task with the LCT. After a first run, to ensure that the participants had understood the instructions, their performance was registered. At the end, they had to estimate the difficulty level of the task concurrently executed with LCT, using the same scale.

2.2.1 Driving context

For both sessions, the primary task was the LCT simulated driving task, which involved driving along a straight 3-lane road at a constant speed of 60 km/h. Participants were asked to use the steering wheel to maintain the vehicle position in the centre of the indicated lane. Lane change signs appeared on both sides of the simulated road to inform the drivers of the requirement to change lanes. The signs were always visible but blank, until the lane change instruction was given at a distance of 40 m before the sign position. Participants performed 18 changes resulting in a duration of about 180 s per run (3,000 m).

Fig.1. The LCT track
The simulator session was conducted on the INRETS fixed base simulator in Lyon, which had a front screen with a horizontal visual field of 50°. The car body was a Renault Espace with a manual gearbox and all the standard passenger compartment features, displays and controls. Software, conforming to the ISO draft standard, was developed by the INRETS-MSIS team. Checks were carried out in order to ensure a perfect correspondence between this software and the LCT developed in the ADAM project [15].

The same software was used for the PC session, which was carried out on a Personal Computer equipped with a Logitech “Gaming steering wheel and pedals MOMO”. The parameters of the transfer function between wheel and vehicle were adjusted in order to make PC and simulator conditions comparable. However the force feedback steering as well as the size of the wheel remained different. The horizontal visual field was between 29° and 34°. Such a configuration is very simple and not expensive making it possible to set up an experiment very easily.

### 2.2.2 Secondary tasks

Two types of secondary tasks were performed: 2 auditory ones and 2 visual manual ones.

**Auditory tasks:**

The first one (AT1) consisted of a series of statements pronounced by an experimenter. The participants had to listen to each statement, to repeat it, and to answer “Yes” if it was true, and “No” if it was false. For example: “Alice, my mother in law is younger than her mother Martine” to which participants had to respond “Yes”. Each assertion was randomly presented so that each driver had a single series.

The second task (AT2) involved inventing sentences by creating a chain. To begin with, the participants were given a first sentence comparing animals. They then used the last word of the sentence to create the following one. For example: “A horse is taller than a rat”, “a rat is smaller than an elephant”...

**Visual manual tasks:**

To perform the visual-manual tasks a screen was placed on the dashboard (simulator condition) or fixed on the table (PC condition). Position and size recommended by the ISO draft standard were respected for each display. A numeric keypad was laid out under the screen so that the driver could carry out the commands related to the two tasks (Figure 2a and 2b).
The first visual-manual task (VM1) was the Surrogate Reference Task (SuRT). The objective was to look at a screen and to locate a circle among distractors (smaller circles). To select the target, the participants moved a cursor to the relevant zone by using right and left arrows. Then a button allowed them to validate the choice and a new configuration was given by the system. Three levels of difficulty could be activated. All drivers performed the “difficult” level (Figure 3).

The second task (VM2) was the Critical Tracking Test (CTT) designed by Dynamic Research (Figure 4). This task was of interest because the driver did not control its evolution. Participants were faced with a moving black line. To begin with, this line was displayed in the centre of the screen but then went up and down. The objective was to keep it as close as possible to the centre part of the screen, by using the up and down arrows of a keypad. Various difficulty levels could be activated. All drivers performed an easy level (lambda = 1, gain = 20).
2.3 Data analysis

2.3.1 Performance measurement

First, subjective evaluation of the task difficulty was assessed, by asking the participants to estimate on a 0-10 scale the level of difficulty of each task, while performed alone, and then while performed concurrently with the LCT.

Three measures of performance were also calculated:

- **The Mean Deviation Adapted**: as specified in the LCT ISO draft, the driving performance is mainly evaluated by the driver’s mean deviation obtained for each run as compared with a normative trajectory. However, the use of a unique model for all drivers has been discussed and a new model is also being proposed [16-17]. The purpose is to define a reference lane change trajectory for each driver based on his/her baseline runs. This driver-tailored reference was used to calculate the mean deviation adapted.

- **The ratio of correct lane changes** indicated the correctness of the responses to lane change signs. Between two lane change signs an observational zone was defined to determine the lane where the vehicle was most frequently positioned. If this lane corresponded to the sign indication, the lane change was considered as correct [16][18].

- **The lane change initiation** corresponded to the distance between the lane change sign and the distance at which the driver actually initiated it [19]. The calculation only applied to correct lane changes, as determined by the method described above.

2.3.2 Statistical procedure

One-Way Repeated Measures Analyses of Variance ANOVAs were carried out to analyze the data. The experimental design included one between-subjects factor, the Session order (Order 1: PC1st_Simulator2nd; Order 2: Simulator1st_PC2nd) and two within-subjects factors: the Experimental contexts (PC and Simulator) and the Tasks (Reference, AT1, AT2, VM1 and VM2). Paired comparisons were then computed with the Fischer LSD (Least Significant Difference) test. For non-normally distributed data, non-parametric statistics were used for significance testing. For both analyses, a significance threshold of 0.05 was accepted (p < 5%). The statistical procedures were performed with SPSS.

3 Results

3.1 Subjective evaluation of the task difficulty

In terms of subjective evaluation of the task difficulty (Figure 5), no significant difference was found between the two session orders (PC 1st_Simulator 2nd / Simulator 1st-PC 2nd) - neither for the tasks being executed alone [F(1, 

\[1\] Whisker lines on figures 5 to 8 represent the standard deviation of each variable.
28) = 2.049, p = 0.163], nor for the tasks being executed with the LCT [F(1, 28) = 0.728, p = 0.401].

No experimental context effect was found; the subjective evaluation for a given task did not significantly differ from the simulator condition to the PC condition, when the tasks were executed alone [F(1, 28) = 0.041, p = 0.841] and when the tasks were executed with LCT [F(1, 28) = 0.231, p = 0.635].

![Subjective evaluation of the task difficulty executed alone (a) or with LCT (b)](image)

Fig.5. Subjective evaluation of the task difficulty executed alone (a) or with LCT (b)

When executed alone, the task difficulty was not significantly different from one task to another [F(3, 28) = 0.112, p = 0.953]. When performed concurrently with LCT, the tasks appeared to have significantly different subjective levels of difficulty [F(3, 28) = 28.612, p < 0.001]. Paired comparisons computed with the Fischer LSD showed that all tasks differ significantly in terms of level of subjective difficulty given by the participants [p < 0.005]. The tasks can then be sorted, as follows, from the easiest to the most difficult: AT1, AT2, VM1 and VM2.

### 3.2 Mean deviation adapted

For the measure mean deviation adapted (Figure 6), no significant difference was found between the two session orders (PC 1st–Simulator 2nd / Simulator 1st–PC 2nd) [F(1, 28) = 1.053, p = 0.314].

The analysis yielded a global experimental context effect; the mean deviation obtained in the simulator condition was significantly lower than in the PC condition. The trajectory was thus of better quality in the simulator condition [F(1, 28) = 45.217, p < 0.001].
The mean adapted deviation was also significantly different according to the tasks [F(4, 28) = 50.736, p < 0.001]. Paired comparisons computed with the Fischer LSD showed that all tasks except AT2 and VM1 differed significantly in terms of mean deviation [p < 0.005]. The mean deviation for the Reference appeared to be significantly lower than for all other tasks and mean deviation for VM2 was higher than for all other tasks. AT2 and VM1 were in an intermediate position.

However, a significant interaction was registered between experimental contexts and tasks [F(4, 112) = 5.489, p < 0.001], showing the effect of the context on the distractive impact level of the tasks, especially on AT2 and VM1.

### 3.3 Correctness of the lane change

The ratio of correct lane changes was then computed for each task in each experimental context (Figure 7). Since the ratios were not normally distributed, non-parametric statistics were used for significance testing.

No significant difference was found between the two session orders (PC 1st – Simulator 2nd / Simulator 1st - PC 2nd) [U(1, N=30) = 106.5, p = 0.806].

The analysis yielded a significant effect of experimental context, showing ratios were higher in the simulator condition than in the PC condition [Z(1, N=30) = -2.738, p = 0.006].

A Friedman test revealed a significant main effect of the Tasks [$\chi^2(4, N=30) = 72.082, p<.001$]. Differences in terms of lane change correctness were found between tasks except between Reference and AT1, between AT2 and VM1, and between VM1 and VM2.
3.4 Lane change initiation

For the measure lane change initiation, no significant difference was found between the two session orders (PC 1st - Simulator 2nd / Simulator 1st - PC 2nd) \( [F(1, 28) = 2.289, p = 0.142] \). The analysis yielded a global experimental context effect \( [F(1, 28) = 12.670, p = 0.001] \), showing participants took longer to initiate a lane change in the simulator condition than in the PC condition.

Lane change initiation was also significantly different according to the tasks \( [F(4, 28) = 16.977, p < 0.001] \). Paired comparisons computed with the Fischer LSD showed that the reference gave significantly earlier LC initiation than all other tasks while VM2 gave later LC initiation than all other tasks, except AT2. No significant difference was found between AT1, AT2 and VM1.
4 Discussion

As the results did not show a significant effect of session order for the four dependent variables, we shall focus on differences between experimental contexts and tasks.

First, an effect of experimental context was obtained, showing differentiated results according to the variables considered. Lane change performance was better in the simulator than in the PC condition. More precisely, mean deviations were smaller and the ratio of correct lane changes was higher. Santos et al. [20] showed similar results by comparing secondary task impacts on driver’s lateral control registered in a low cost laboratory driving simulator or a fixed-base driving simulator. We can assume that, in the case of the driving simulator, immersion of the participants in the driving scene is greater. The control of the trajectory is thus easier for the drivers due to the increased visual realism. This assumption is consistent with the findings of Kappé et al. [21] which show that lane-keeping performance is improved by increasing the size of the horizontal visual field and by the display of peripheral information. However, the quality of the force feedback steering was also better in the simulator condition, which may have contributed to the easier control of the trajectory registered in this condition. A similar trend is highlighted by Mourant and Sadhu [22], who showed that the feeling of immersion increases with the realism of force feedback steering. Conversely, participants reacted earlier to the lane change signs in the PC than in the simulator conditions, with distances of lane change initiation being longer. In such a condition, participants seemed to pursue quick sign detection and response, to the detriment of the quality of trajectory control. It is possible that subjects behaved as if they were playing a video game in the PC condition, due to the poorer realism of the driving task.

On the other hand, distractive effects of the four secondary tasks have been evaluated with respect to their modalities: auditory or visual-manual and with respect to their nature:

- establishment of comparative judgement (AT1)
- production of comparative sentence (AT2)
- location of target among distractors (VM1)
- realisation of a tracking test (VM2)

If executed alone, the four tasks were evaluated as being of a similarly low level of difficulty; it was not the same in the dual task condition. AT1 was evaluated as being the least distractive task, VM2 as the most distractive one, while AT2 and VM1 were evaluated at an intermediate level. Such a classification was confirmed with the performance measures. The LCT method thus permits the evaluation of the distractive impact of tasks of different characteristics. The method is sensitive enough to evaluate driving performance impairment due to auditory tasks even in the case of an easy one such as AT1. Moreover, if AT1 and AT2 were both concerned with comparative judgements and thus presented some similarities, their reported difficulty and performance impairments were not of the same level. This could be explained by the necessity of producing complex sentences in the case of AT2. The LCT method
also permitted the differentiation of distraction induced by two different visual-manual tasks. Both tasks differed with respect to participants' involvement in the control of their execution. In the case of VM1, the drivers controlled the pace of the display. On the other hand, VM2 consisted of the stabilization of an unstable component. Changes in the task were thus unforeseen and out of their control, then required continuous reactions. These results highlight the joint effect of interface modality and task nature on distraction.

Lastly, this study showed that the three driving performance measures were affected by the experimental context even if the four tasks were organised into a similar hierarchy. This result raises some questions about the possibility of comparing distractive levels obtained in different experimental contexts. It is thus necessary for each experiment to describe the equipment set up and to use a set of reference tasks, in order to be better able to compare experiments.

5 References


CONNECTING BLACK BOX DATA AND DRIVING BEHAVIOUR OBSERVATION FOR BETTER UNDERSTANDING OF DRIVING BEHAVIOUR

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ABSTRACT: This paper presents two studies where the observation method "Viennese Driving Test" (Wiener Fahrprobe) was connected to the data of a Black Box (BB). The "Wiener Fahrprobe" was used to decode these BB data in order to identify special driving behaviour like hard braking, fast acceleration, sharp turning, etc.. Data from observation rides with novice drivers and self reporting test rides on standardised test routes in Brno and Vienna were analysed in this respect. With the help of the results gathered from the evaluation recommendations for future research and future application were established.

1 Introduction

Within two projects “Black Box – Novice Drivers” and “Black Box – Introspection” the observation method “Wiener Fahrprobe” was connected to the data of a Black Box (BB). Nowadays BB are used mainly for crash investigations but not for studying driving behaviour, although it might be a quite easy and cheap way to collect information about the driving style of individuals. The Wiener Fahrprobe should help to decode these BB data in order to define special driving behaviour like hard braking, fast acceleration, sharp turning, etc.. The future goal is to analyse driving behaviour by collecting BB data, understanding those data, and additionally give feedback to the driver or maybe the driving instructor based on the data, to make suggestions about improvements or information and/or training needs. The advantages could be that novice drivers could get a quick check on their driving behaviour by looking at the data of the BB. But not only for novice drivers improvements could be seen. Also while training or testing ITS applications the concrete interpretation of driving behaviour will help to assess the effects on the driving behaviour of such applications.

Several aims were defined at the beginning of the project:

1. Connecting both methods – BB & Wiener Fahrprobe
2. Find out what driving aspects BB data do reflect compared to data of the driving behaviour observation done by human observers
3. Identify special driving behaviour with the help of BB data (for instance fast acceleration, hard braking, fast turning)
4. Give recommendations for future research
5. Future goal: Improve driver education based on BB data that are easy to collect, given that thorough interpretation is possible

6. Future goal: Evaluate differences in the driving style with or without using ITS

To find an answer to all these questions a basic BB was used within the cars which were used for the observation of novice drives and the introspection rides. The BB registered accelerations in three dimensions. In parallel, either the driver should be observed (novice drivers) or he/she should observe himself/herself and note whether he/she remembered significant situations (introspection).

This paper is based on an internal HUMANIST paper [1].

2 Methodology

2.1 Viennese Driving Test (Wiener Fahrprobe)

The Viennese Driving Test [2, 3, 4] is an instrument for behaviour observation of drivers. This method gives researchers the possibility to get a structured impression of the driving behaviour of a person. The observation was done by one observer inside the car, sitting in the back of the vehicle. The observed person was asked to drive along a standardised route of between 17 to 20 km in length which included densely inhabited areas, and to a lesser degree rural roads and motorways. The test route was divided into sections such as intersections, motorway entrances or exits, sections of road between intersections, roundabouts, etc. in order to make the evaluation of the behaviour observation easier.

The behaviour variables were observed both in a standardised and in a non-standardised way: The observer used an observation sheet where erroneous types of behaviour were listed. One sheet per section had to be filled in. But also non-standardised variables like errors, explicit interaction/communication processes and traffic conflicts were noted. For each event a note had to be taken and the number of the sections where the event happened was added.

2.2 Black Box (three axes acceleration recorder)

Acceleration is one of the most accurate indicators for critical driver behavior. Based upon this awareness, CDV (Centrum dopravního výzkumu – Brno, Czech Republic) developed a very basic Black Box (BB) which saves data of acceleration on three axes \{x, y and z\} in relation to the time line.

The heart of the recording device (Black Box) is the Micro Electro Mechanical System (MEMS sensor) that works as a tri-axes digital output linear accelerometer. It includes a sensing element, and an IC interface element able to take the information from the sensing element and to provide the measured acceleration signals to the external world through an I2C/SPI serial interface. The sensing element capable of detecting acceleration is manufactured using a dedicated process called Thick Epi-Poly Layer for Microactuators and Accelerometers (THELMA) to produce inertial sensors and actuators in silicon.
The Integrated Circuit (IC) interface is instead manufactured using a Complementary Metal Oxide Semiconductor (CMOS) process that allows a high level of integration to design, and a dedicated circuit which is factory trimmed to better match the sensing element characteristics.

The MEMS has a full user selectable scale of 2g, 6g and it is capable of measuring accelerations over a maximum bandwidth of 2.0 KHz for the X, Y and Z axis. The device bandwidth may be selected accordingly to the application requirements.

The BB was located below the driver seat. The data were transferred and logged on a Laptop after the rides.

There were different reasons for using "only" a basic BB within the project:

- The project was designed as a pilot study to see if the connection between the two data gathering methods is worthwhile
- The costs of project has to be as low as possible
- The BB has to be easily transferred to different cars which were used in Vienna and Brno

2.3 Procedure of both projects

Both methods which are described here were connected to two projects.

Project Black Box – Novice Drivers:

This project was part of a dissertation carried out in the framework of the NoE HUMANIST [5]. In the frame of the dissertation several novice drivers were observed with the method of the Wiener Fahrprobe while driving a BB equipped car on four different test routes in Brno, Czech Republic and in Vienna, Austria. During these test rides data were registered with help of the BB.

The sample included 24 novice drivers in Brno (43 rides) and 7 novice drivers in Vienna (14 rides). All test rides were done during August and September 2006.

Project Black Box – Introspection:

Additional to the test rides with novice drivers, introspection rides were done in Brno as well as in Vienna. Employees of CDV and FACTUM drove on two of the test routes with a car which was equipped with the BB. The drivers were also observed and after each test ride the drivers recorded all noticeable situations themselves. The aim was, on the one hand, to compare the observations of the observers with the notices of the drivers and, on the other hand, to compare both notices with the data from the BB. This procedure should help to get more knowledge of the character of the BB data and what they mean in terms of actual behaviour in traffic.

Two test rides were carried out in Brno in October 2006 and January 2007 and two test rides were carried out in Vienna in February 2007.
The results and recommendations derived from both projects are reported in the following chapters.

### 3 Results and achievements

According to the aims defined at the beginning of the project, the following results can be reported so far.

#### 3.1 Connecting both methods

To start with, it can be stated, that both methods could easily be connected. The BB only has to be implemented in the car before starting the observation rides. There is no further need for handling the BB since the data are recorded automatically, then. The use of the BB while observing driving behaviour is totally unobtrusive, it does not interfere with the behaviour of the driver, nor the one of the observer. Just the time of the beginning and the time of the entrance in a new section have to be noted by the observer on the observation sheet. This extra effort is necessary in order to make the connection of the BB data with the behaviour observation data possible.

During the project it turned out, that many "manually" registered behaviour aspects could also be identified with the help of the BB data. Types of behaviour recorded with both methods reflect acceleration, braking and turning performances. Additionally, with the BB data the observer receives a simplified impression of the overall driving style. As the observer never notices acceleration, braking and turning behaviour in a such a continuous and differentiated way as the BB can do, the BB reflect more thoroughly whether a person drives smoothly or more in a staccato style. Because of this extra information a more quantitative assessment of the driver is possible.

On the other hand, it is not possible to interpret the BB data without any additional information. E.g., the amplitudes in the graphs (see in next chapter) do not tell whether a person just drove into a curve very fast, or if he/she approached an unexpected object and had to swerve rather quickly.

Thus braking and turning performances that can be observed (Wiener Fahrprobe), can also be identified in the BB data, but BB data do not give any information about circumstances.

#### 3.2 Driving behaviour reflected by the BB data

In relation to what was said above, the first step was to find out the meaning of the BB data, i.e., in which way do the data reflect observable driving behaviour. Graphs of about 15 test drives were produced which display the acceleration in the longitudinal axis (x-values) and lateral acceleration (y-values). The reason for using the data from only 15 test rides was that within the financial and schedule frame of this pilot study only a small sample of the test rides could be evaluated. Furthermore we did not deal with z-values (vertical accelerations, e.g., when driving over a hump) at this stage because of the same reason stated above. The data used for evaluation within the novice driver project was gathered from test rides with only one car.
If the amplitude on the **longitudinal axis** of the values goes up this reflects acceleration, and if goes down this means braking. Of course, also stand-stills can be identified, for instance because of a red traffic light.

With the help of those graphs the first statements about the driving behaviour can be made, for instance whether the acceleration behaviour of a driver is steady or not. If the amplitude goes rather steeply up and down all the time this means that a rather strong acceleration is always followed by a rather sharp braking manoeuvre and vice versa. Behaviour observation can give the additional information that, for instance, a hard braking of the driver occurred due to a red traffic light.

If the amplitude on the **lateral axis** of the values goes up it shows a left turn of the car, if it goes down it reflects a right turn.

The combined graph below shows the x- and y-values and displays the driving behaviour with respect to acceleration and turning.

Two situations could be described with the help of this chart. The **black circle** shows the acceleration and braking behaviour before and after two right turns. First, the driver slows down before the right turn (seconds 33 till 35 – black line) Æ turns right (seconds 35 till 37 – white line) Æ accelerates after the turning manoeuvre (seconds 37 till 42) Æ brakes again for the next turn (seconds 43 till 46) Æ turns again right and accelerates during the turn (seconds 50 till 55).

The second situation describes the behaviour of the driver after a red traffic light, marked with the **white circle**. The driver waits at the traffic light for about 20 seconds (seconds 112 till 132) Æ after the traffic light has turned green the driver starts to accelerate and drives into the intersection (seconds 133 till 136 – blue line) Æ slows down as a preparation for the turn, turns left and accelerates during the turn (seconds 136 till 140).

### Graph 1: Acceleration to the front (x-values) and acceleration to the side (y-values) for 150 seconds

By looking only at the graphs it is of course not clear where on the test route these situations occur. Therefore several self-introspection rides were carried out with employees of the two institutions working within the project. The aim of these rides was to describe the test routes according to turns, intersections,
etc., and the driven time between those sites. Also some hard braking and fast acceleration manoeuvres were carried out on purpose in order to identify how such behaviour is displayed by the BB data. This is necessary in order to be able to interpret the graphs, because it makes clear what the amplitudes mean in reality. With the help of these descriptions the sites that test persons have to drive through can be identified. In this way special events like hard braking or fast acceleration because of, e.g., an error of the driver become better identifiable, by amplitudes on the x- or the y-axes in sections where there should not be any deflections.

In a next step the charts we had received were analysed accordingly. The following graph 3 shows 150 seconds of the test route. Graph 2 below displays acceleration and braking behaviour, and right or left turns. The black circles in both graphs show accelerations and brakings for "special" occasions, while the grey circles show the turning behaviour.

By comparing the graphs derived from the BB data (graph 3), the notes of the driving behaviour observation (table 1), and the map showing the test route (graph 2), turning behaviour at intersections, accelerations and brakings before and after these intersections, and also standstills at traffic lights, can be identified.

Graph 2 & 3: Map of the first part of the test route in Vienna, acceleration in the longitudinal axis (x-values) and lateral acceleration (y-values) for 150 seconds

Source: www.wien.gv.at [6]
3.3 Identification of "special" driving behaviour within the BB data

As said, not only the behaviour before and after turns can be identified, also special situations can be identified when comparing BB data and behaviour observation. For a demonstration, a hard braking manoeuvre was selected. The following graph shows a cut-out of the data from a novice driver and describes a hard braking manoeuvre before a traffic light (black circle). The observer marked this behaviour in her notes as "maladjusted speed before traffic light". Several other situations like the above described were found in the BB data as well as in the observation notes.

Graph 4: Acceleration on the longitudinal axis (x-values) and lateral acceleration (y-values) for 300 seconds
3.4 Problems

Unfortunately, not all graphs can be interpreted that easily, and the comparison with the behaviour observation notes and the street map did not work for all drivers. Also the comparison of different charts of drivers displaying the same section of the route was hard to interpret. The main problem was that the BB used at this moment is only saving acceleration data on three axes and the corresponding time (seconds), but cannot take up and reflect the exact position of the driver. Therefore, from the data it is sometimes not clear where exactly on the route the driver is located, and what the circumstances there are. Thus, the comparison with other drivers becomes complicated because test persons drove with different speeds and therefore arrived at sites at different times. Also the fact that the test persons have to wait at a different number of traffic lights makes comparisons of the graphs difficult. For example, some drivers were at the first left turn within two minutes, while others needed two and a half minutes to get there. The longer the test persons had been driving, the larger the bias became. Without information about the driven meters, or GPS data, this problem cannot be solved.

4 Recommendations for future research

Because of the results of these two projects and with the knowledge gained about how to interpret the BB data with the help of the Wiener Fahrprobe, it became clear that further research is needed. Especially, the preconditions for comparison of the data of different test rides should be improved in the future. The reason for problems there was that no continuous variable which would make the data comparable, such as meters or other positioning parameters, could be included in the BB measurements. Furthermore, there are still some more questions about the correct meaning of the data to be answered. For example: What does the difference between an amplitude which goes up to the value of 2g and an amplitude which goes up to the value of 3g mean? Would only a value of 5g mean that the behaviour was "really" inappropriate? Where does the boarder go?

Because of these questions several recommendations for further research were formulated. The aim of these recommendations is to make the data collection more precise and better comparable in order to be able to interpret the outcome of the data more thoroughly:

Recommendations concerning Data collection

The knowledge of the actual speed will help to interpret the data. Speed is one criterion for the classification into appropriate and inappropriate behaviour.

Similar to speed, also a distance measurement will be needed. As already said comparisons of the graphs were sometimes difficult because some of the test persons drove faster or were waiting at red traffic lights more often than other test drivers. With the knowledge of the driven meters the data of all test rides could be compared more thoroughly and easily. The most efficient, but also the most costly solution would be to include GPS and/or XL-meter data in the data collection of the BB.
• During the analyses it also become obvious that the measuring of data was not well calibrated, also depending on where the BB was put into the car or which car was used. Especially a comparison between the data from the novice driver project and the introspection project, were different cars where used, showed quite different values on the x- and y-axis while driving on the same route. Within the novice driver project it was also tried to put the BB in the trunk which had also an effect on the data collection. A calibrated data collection will also make the resulting data better comparable.

Recommendations concerning interpretation of the data

• More test- and introspection rides have to be carried out in order to gain more knowledge about the meaning of the data – i.e., what different types of behaviour and interaction are reflected in the graphs produced by the BB. And what are the critical values where one can say that they reflect erroneous or dangerous behaviour. This applies for acceleration as well as for the driven speed in curves.

• The behaviour observation has to be better adapted to the content of the test rides with the BB, as well. Many of the behaviour variables which are observed and noted with the help of the Wiener Fahrprobe do not necessarily have to be taken care of at this point of the project. Especially, behaviour which has nothing to do with longitudinal and lateral acceleration can be eliminated from the observation sheet. This means that for instance the use of the indicator does not have to be recorded by the observers, in this phase. On the other hand, better specified notes about speed behaviour in relation to circumstances (acceleration, speed in curves) need to be included.

5 Conclusion

In general it can be said that the behaviour observation and the data collection method with a BB can easily be connected, and that they in principle can be seen as complements of each others. The data of the acceleration on the three axes have been visualised with the help of graphs and compared with the notes of the behaviour observation. With the combined methods it was possible to assess special types of behaviour like full braking at curves as well as other aspects could be identified and better explained and described.

Some difficulties occur when one only relies on BB-data and if one wants to exactly determine the changes in the stimuli for the drivers, and to transform such aspects into readable data that represent realistic conditions. No criteria could be introduced that allowed to interpret exactly when a certain type of acceleration on one of the axes is critical, meaning that an error or dangerous behaviour occurred, like ”really” driving too fast through curves or braking too hard. So it was not possible at this stage of the project to say that one full braking was more dangerous than another one. Only the statement that it was a full braking could be made. To describe such mistakes no secure statements can be given by only looking at the graphs. The connection with the behaviour observation is needed to finally describe, and to understand, the behaviour of the driver.
However, one of the future goals is that the graphs which display the BB data should be used as a stand-alone in order to describe driving behaviour. The aim could be to give driving instructors additional, concrete and demonstrative material in order to assess and explain the driving style of a learner. On the other hand it could be possible to assess the driving style of novice drivers and give further recommendation about his/her driving style. Another possibility for the use of such stand-alone graphs could be to assess the driving style of drivers while driving with and without ITS in the car. As it was shown in the results of this feasibility study two graphs could easily be compared and different behaviour could be evaluated. This would also include the effects on the driving style while using ITS.

To conclude, it has to be stated that the results of these two (pilot) projects are very promising concerning the future goal of improving driver education by "proving" with the help of BB data that erroneous or dangerous driving behaviour really has occurred. However, to achieve this it will be necessary to complete the BB data registration with other measurements, like, e.g. GPS and XL-meter, and to add site descriptions to the acceleration data graphs. This will help to give more detailed, more thorough, and better comparable descriptions of the test rides.

6 References


SESSION 3:
MODELLING OF DRIVERS’
BEHAVIOUR FOR ITS DESIGN
MODELLING DRIVER BEHAVIOUR IN ORDER TO INFER THE INTENTION TO CHANGE LANES

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ABSTRACT: This study focuses on the examination and comparison of selected behavioural and environmental indicators that predict the intention to change lanes. These indicators were chosen from previous driving studies and driver models. The data were gathered in a field study with an instrumented car that can log data from the driver, the car, and the environment. The collected data were analysed and modelled with the help of a "knowledge discovery framework" (Georgeon, Mille, & Bellet, 2006). The first analysis of all lane changes caused by a slow leading vehicle focuses on the following indicators: glance to the left outside mirror, turn signal, and lane crossing. It is shown that the glance to the left outside mirror could serve as a predictor with a high potential to get information about the intention to change lanes in a very early stage. However, it is important to combine this predictor with additional information to avoid a high false alarm rate.

1 Introduction

The increase in the use of Advanced Driver Assistance Systems (ADAS) and In-Vehicle Information Systems (IVIS) in recent years has created the need for information about the driver and the traffic situation. To augment the benefit to road safety and the driver’s acceptance of such systems, these ADAS and IVIS should react according to the traffic situation and according to the driver’s intention. For example, a Lane Departure Warning System (LDW) warns the driver if he/she leaves the current lane. However, if the driver wants to execute a lane change the system should not warn the driver.

A lane change is a ubiquitous driving manoeuvre in common driving environments. It combines many critical features of driving such as low level control, monitoring, and decision making. Lane change is defined by a more or less stable sequence of actions which begins with a motivation to change lanes (for instance a slow leading vehicle), followed by a gathering of information about the surrounding traffic situation, and the decision whether to change lanes or not, e.g. [1].

Several sources of data could be used to infer a driver’s intention to change lanes. First there are car data; for example, using the turn signal could be a valid predictor of the intention to change lanes. However, drivers do not use the turn signal in every lane change situation. In a field study, Olsen [2] reported that drivers tend to indicate a lane change in only 65% of all cases. Other predictors could be steering wheel angle or acceleration [3]. A second source of data is the car’s external environment [4]. The surrounding traffic, the lane...
position, or geographical position can have some indicative power about the intention to change lanes. Third, the driver himself could serve as a source. In particular, eye movement behaviour could be a rich source of information about the current goals and motives of the driver [5].

There have been several attempts to build algorithms to predict a lane change manoeuvre. In a simulator study, Liu and Pentland [3] developed Hidden Markov Models (HMMs) to predict a lane change to the left out of several other driving manoeuvres. Prediction accuracy was 50% 0.5 sec after the onset of the manoeuvre, but increased in accuracy over time. Liu and Pentland [3] only used information about the steering wheel for their models. Oliver and Pentland [6] also used HMMs to predict a lane change manoeuvre to the left among other manoeuvres in real traffic situations. Here, prediction accuracy was 23.5% 0.1 sec before the manoeuvre took place. These authors used car data (speed, acceleration, brake, gear, and steering angle) and gaze information. McCall, Wipf, Trivedi, and Rao [7] used Sparse Bayesian Learning to develop an algorithm to detect the intention to change lanes to the left. Information used in this model was gas pedal position, brake pedal depression, longitudinal acceleration, vehicle speed, steering angle, yaw rate, lateral acceleration, road curvature metric, heading, lateral lane position up to 20 m ahead, and side-to-side and up-down head movement. Real traffic data of only three participants were used, and an accuracy of approximately 95% was achieved, with 5% false alarms. Salvucci [8] proposed a "mind-tracking architecture" based on a cognitive model of driver's behaviour implemented in the ACT-R cognitive architecture [9]. He reported a hit rate of 85% with 4% false alarms by using information from the car, the environment, and the driver in a driving simulator.

All these attempts to build valid algorithms have some limitations. The studies suffer either from a very small sample size or they were conducted in driving simulators. Studies that were performed in real traffic environments with a sufficient number of participants had a low prediction accuracy.

The goal of the present study is to focus on the impact of specific indicators and their position in the lane change sequence. The present article describes in more detail the timeline of the following indicators: slow leading vehicle, glance to the left outside mirror, turn signal, and lane crossing. Those behavioural indicators were chosen according to the Intent Detection Framework proposed by Smith and Zhang [10].

2 Method

2.1 Participants

Data from 22 participants between the ages of 24 to 58 years were recorded (MEAN = 33.8 years, SD = 10.1 years). 10 of them were female, and 12 of them were male. Their driving experience in years ranged between 2 and 39 years (MEAN = 13.4 years, SD = 9.7 years), with an annual quantum of driving from 2,000 to 50,000 km (MEAN = 13,136 km, SD = 10,508 km).
2.2 **Instrumented car**

A Renault Scénic was equipped to record and synchronize sensor data and videos. The synchronization was done by using the time code from the video frame. The logged sensor data came from car dynamics (speed, acceleration, deceleration, yaw rate, and inclination), driver's behaviour (eye movement, steering wheel position, pedal use, and turn signal), and environmental data (distance to car ahead, GPS positioning). Video signals were recorded from five sources: stereo-vision camera with radar for distance estimation to obstacles (top left), the front view (top right), the rear view (down left – upper part), the view from the left outside mirror down to the surface of the road (down left – lower part), and the view to the participant’s head with the indications of the eye-tracker (down right). Figure 1 shows the video logged during the experiment.

Fig.1. Video sources from: stereo-vision camera with radar for distance estimation to obstacles (top left), the front view (top right), the rear view (down left – upper part), the view from the left outside mirror down to the surface of the road (down left – lower part), and the view to the participants head with the glance direction of the eye (down right)

2.3 **Test course**

The field study was conducted in the area of central France around the city of Lyon. The subjects drove on a multi-lane motorway between Bron and the Lyon International Airport (Saint Exupéry) in both directions. The total length of this course was about 50 km. The speed limit varied between 90 km/h and 130 km/h.

2.4 **Procedure**

Participants were first informed about the goal of the study. They were told to drive like they normally do. There was no information about the issue “lane change manoeuvres” before and during the experiment. Then participants received information about the car. The experimenter calibrated the eye tracker
and started the data logging. At least two experimenters were present during the test drive that could influence the driving behaviour. However studies indicate that the results are comparable to normal driving [11]. One of the experimenters sat on the passenger’s seat and gave directions. The second one sat in the back of the car, watched the driving scene, and indicated silently a slow leading vehicle as a motive for a lane change by pressing a button, not noticeably for the driver. This signal was logged with a time stamp and was used for the post experiment interview. Participants were not urged to perform a lane change manoeuvre at all. They could initiate it when they wanted to. After the test driving, the data were immediately processed in order to find the sequences with a motive to change lanes in the video. With this information participants were questioned in two ways, depending on whether there was a lane change following or not. If there had been no lane change following, the participants were asked whether they had thought about executing a lane change or not. In the case of thinking about executing a lane change they were asked to show the starting point and the point where they had decided not to change lanes in the video. If there had been a lane change following, the participants were asked to show the point where they had started to think about a lane change and the point after the execution of a lane change where they had stopped thinking about the lane change. After the interview, participants filled out a questionnaire on demographic data. Finally they were debriefed and thanked.

2.5 Data Analysis

The following raw data was collected with the instrumented car: accelerator pedal position, brake pedal position, clutch pedal position, indicator lights, positions of gear stick, kilometric point, speed, steering wheel angle, distance to object ahead, time to collision, headway, GPS longitude and latitude, GPS indications about current road segment, and eye tracking data.

This raw data was analyzed through a step-by-step process of abstraction. This process of abstraction was made with a methodology and a software tool called ABSTRACT (Analysis of Behavior and Situation for menTal Representation Assessment and Cognitive acTivity modelling) [12]. The implementation of this tool took place in a collaboration between INRETS and the Chemnitz University of Technology.

With this method, the analyst is able to specify “patterns of interest”, which are relevant to the analysis of lane changes. These patterns of interest are: acceleration, deceleration, stable speed, steering wheel angle threshold crossing, steering wheel angle maximum, eye glance to left mirror, eye glance to center mirror, eye glance to left side of the road, and obstacle detection.

Once specified by the analyst, these patterns are automatically computed. So the overwhelming raw data is filtered in such a way that only the data that we judge to be significant is finally displayed.

This computation produces a representation of the driving activity which is shown in figures 3 and 4. In these figures, the circles at the bottom are events on the basic level of abstraction (e.g. minima and maxima in the sensor data), whereas the triangles and squares above are the symbols of the higher level
which are inferred from the basic level. Detailed descriptions of those symbols are shown in the qualitative description of a lane change manoeuvre.

In a post experimental process, a coding of valuable indicators from the video took place. The additional indicators were: distance to lane edge, distance to the following car in the destination lane, and the size of the gap in the destination lane. All these data were also incorporated into the ABSTRACT software tool.

3 Results

3.1 Quantitative description of a lane change manoeuvre

Altogether, 194 lane changes to the left were analyzed. The duration between the starting point of the lane change schema (‘start thinking about a lane change’) and the actual lane crossing for all lane changes are shown in Figure 2.

![Histogram](image_url)

**Fig.2.** Histogram of the duration of all lane change schemas

The mean value is 10.53 sec (SD = 10.18 sec) with a median of 7.82 sec. The maximum was at 88.64 sec.

All lane change manoeuvres were caused by a slow leading vehicle and were performed in order to pass this vehicle. This study focuses on the following indicators: a) first glance to the left outside mirror, b) turn signal, and c) the actual lane crossing. There was at least one glance to the left outside mirror in 99.0 % of all lane changes and the turn signal was used in 99.0 %. In 87.1 % of all lane changes the glance to the left outside mirror preceded the turn signal, in 11.3 % the order was preserved. Three lane changes were not preceded by a glance to the left outside mirror or a signal or both. The mean duration between the first glance to the left outside mirror and the lane crossing was 6.12 sec (MEDIAN = 4.00 sec, SD = 7.01 sec). The mean duration between the onset of the left turn signal and the lane crossing was 2.28 sec (MEDIAN = 2.00 sec, SD = 2.17 sec).
3.2 Qualitative description of a lane change manoeuvre

As an example, two lane change sequences were modelled with the help of ABSTRACT. The first schema (Figure 3) is characterized by the fact that it begins in a situation, where the driver had to drive below his preferred speed. In this schema, the acceleration associated glance into his left outside mirror appeared as a good predictor of the lane change. One second after this possible predictor the participant switched on the left turn-signal.

In the second schema (Figure 4), the participant is not blocked by the obstacle and he performs the lane change “on the fly”. In this case, there is no predictor before the turn signal itself. Nevertheless, the turn signal appears to be a sufficient predictor, since it is switched on by anticipation several seconds before the manoeuvre.

4 Conclusions

The preliminary results of the analysis suggest that there is a potential for several types of indicators and combinations of indicators to predict the intention to change lanes. It is shown that the left turn signal and the glance to the left outside mirror are two strong indicators. The high use of the turn signal in this study seems due to the presence of the experimenter. Olsen [2] reports a much lower frequency in using the turn signal in naturalistic driving conditions. In addition, it is shown that the glance to the left outside mirror is of high potential to increase the predictive power in two ways. On the one hand, the glance to the left outside mirror allows an earlier prediction than the left turn signal. On the other hand, the glance to the left outside mirror represents a chance to predict the intention to change lanes even if the driver does not use the turn signal. However, this glance to the left outside mirror is also present to
a certain extent if there is no intention to change lanes. In two studies, Henning et al. [5] reported a probability for a lane change given a glance to the left outside mirror of $p = 0.40$ and $p = 0.79$, respectively. It shows that 60 % and 21 %, respectively, of all glances to the left outside mirror are within the baseline. The predictive power of the glance to the left outside mirror could be increased with the help of other predictors like the acceleration which is shown in figure 3. Another option could be the combination with the approaching of a slow leading vehicle or the specific patterns of a driver. A detailed analysis and discussion of this topic can be found in Henning and Krems [13].

This study has the chance to go beyond the previous work by a combination of four features: i) the use of field data, ii) a sufficient number of participants, iii) the chance to combine the indicators in a psychologically useful way, which incorporates the knowledge about human processes in the field of attention, memory, and decision making, and iv) the labelling of the lane change sequence by three sources (experimenter in the car, observation and labelling of the video after the driving by the participant, and a rating of three independent observers on the basis of the video). The practical implication of this study for the design of ADAS is that it shows that the use of eye glance data and the incorporation of several sources of data from the environment could not only increase the prediction accuracy, it also allows the assistant system to have information about the driver's intention earlier. One advantage and at the same time a limitation is the presence of experimenters while driving. This influences the driving behaviour to a certain degree [11] of the participants so that it is not “naturalistic” anymore. To get an idea about the differences between “naturalistic” and “observed” driving, it is planned to compare data from naturalistic driving studies with the data of this study.

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6 References


ANALYSIS AND MODELLING OF DRIVER PREPARATORY BEHAVIOUR BEFORE TURNING AT INTERSECTIONS

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ABSTRACT: This study focuses on an analysis and modelling of the naturalistic driving behaviour before making a right turn at an intersection. We developed instrumented vehicles and conducted long-term experiments on a public road to measure driver behaviour, vehicle state, and headway and rear distances. The relationships between the onset locations of covering the brake pedal and activating the turn signal and the traffic conditions of driving with or without lead and/or following vehicles were analyzed based on the data measured in the real road environment. The results suggest that the existence of the front and rear vehicles and the vehicle velocity influence the onset location of covering the brake pedal. Structural equation modelling was applied to estimate these relationships quantitatively. The results imply that the model with two latent variables, free-driving condition level and location of transition to preparatory behaviour, can represent the hypotheses obtained from the naturalistic behaviour analysis. Finally, we investigated the driver preparations before making turns at other intersections with various road structures and discussed the differences of the influence of the traffic conditions between the road environments.

1 Introduction

The popularization of in-vehicle navigation and telecommunication systems is progressing rapidly all over the world as one of key components for realizing ITS. Drivers use route guidance information via the in-vehicle navigation systems while driving from the origin to the destination. The route guidance instruction helps drivers to choose and maintain the correct routes with lower mental workload. In this study, we focused on the presentation timing of the voice instruction just prior to making the turn. This information can trigger a change in driving behaviour from straight mode to preparation mode while approaching a target intersection. The presentation timing is usually constant in any road traffic conditions. However, the constant timing can lead to a reduction in the driver acceptance of the provided information, because there may be some variations in the driving operations due to the influence by the road traffic environment [1]. It is essential to develop a human-centred design, i.e. to develop a presentation timing adapted to the typical driver’s preparatory behaviour before making a turn at an intersection based on the investigation on the naturalistic driving behaviour under actual road traffic environments.

We conducted long-term experiments using instrumented vehicles on a public road in order to measure the natural driving behaviour before making a right turn at a specific intersection. This experiment was carried out in left-hand
driving, i.e. under Japanese traffic contexts. We focused on leading and following vehicles as the traffic conditions in the vicinity of the target intersection. In this study, the leading vehicle is defined as a forward vehicle that travels straight toward the target intersection. We did not analyze the traffic situations in which the forward vehicle turned to the right, as did the driver’s own vehicle, because the stopping locations for waiting for the right turn when there are leading vehicles stopping at the target intersection are different from those without the leading vehicles. The following vehicle is defined as a vehicle that follows the driver’s vehicle in the same traffic lane, regardless of whether or not the following vehicle turns to the right at the turning point.

1.1 Aims of this study

(a) Analyze naturalistic driving behaviour before making a right turn at a specific intersection and investigate the influence of the traffic conditions in the vicinity of the target intersection on the onset location of the driver’s preparatory behaviour.

(b) Construct a driver model for describing the relationships between the traffic conditions and the driver behaviour.

(c) Investigate the driver’s preparatory behaviour before making turns at other intersections with various road structures in order to clarify the road conditions where the driver’s behaviour is influenced by the existence of the leading and following vehicles.

2 Experiments

2.1 Participants

Four non-professional drivers (three males and one female) participated in the long-term experiments. The average age of the participants was 34.8 years (age range: 22 - 52 years). The average driving experience was 16.3 years (experience range: 3 - 33 years). All participants drove a passenger vehicle almost every day in their daily lives.

2.2 Experimental vehicle

Figure 1 presents an instrumented vehicle to measure driver behaviour used in this experiment. Various sensors and a recorder system detected the vehicle driving state, including vehicle velocity, vehicle acceleration, and geographical position, and measured driver’s behaviour, including steering, accelerating, and braking operations. The relative distance and relative speed of the lead and following vehicles were measured with two laser radar units attached to the front and rear bumpers. The driver’s foot position (covering the accelerator pedal or brake pedal without pressing) was detected by laser sensors fitted above the pedal surfaces. The turn signal activation was detected by adding encoders to the lever. The data was recorded on a laptop computer and mobile hard disks via a driving recorder system. This recorder system was fixed inside the trunk of the instrumented vehicle to encourage naturalistic driving behaviour of the participants.
2.3 Target intersection

We carried out repeated experiments on a public road in Tsukuba. The selected driving route was a 30-minute trip (total mileage: about 15 km) that included several left and right turns. Figure 2 presents a diagram and images of the analyzed intersection on the experiment route. The intersection has a designated lane for making a right turn. There is a long straight road about 2 km as far as the target intersection, which has two traffic lanes.
2.4 Variables

Driver’s preparatory behaviour before making the turn corresponds to activating the turn signal and decelerating. We focused on the foot movement to cover the brake pedal as the decelerating operations.

The behavioural events were quantified by using the remaining distance to the centre of the target intersection (the stop line for turning to the right) at the onset of each preparatory manoeuvre. In an analysis of the driver preparatory behaviour, we investigated the onset location of each operation by classifying the traffic conditions while approaching the target intersection, i.e. driving with both leading and following vehicles, driving with a leading vehicle and without a following vehicle and with a following vehicle, and driving without either a leading or following vehicle, in order to clarify general influence of the traffic conditions on the preparatory behaviour. The driving with a leading or following vehicle was defined as the existence of a vehicle running in front of or to rear of the driver’s own vehicle before the driver entered the designated right-turn lane. In a construction of the driver model, we used the vehicle velocity when the brake pedal was covered by the driver’s right foot, the remaining distances at the onset of each preparatory behaviour, and the relative distances to the leading and following vehicles before the driver entered the designated right-turn lane, in order to evaluate in detail the impacts of the traffic situations on the preparatory manoeuvres.

2.5 Experimental procedure

We developed the four instrumented vehicles, and four participants started driving on the identical route at 10-min intervals to measure each participant’s driving behaviour under similar traffic conditions. The recorded trip was made once a day on weekdays and the total was 40 trips (over a period of about eight weeks). Practice drives were made before the measurement trials so that the participants could drive from the origin to the destination without using a map. The participants rode alone in the instrumented vehicle during the experiment trials. They were instructed to drive in their typical manner.

3 Analysis of driver preparatory behaviour

The average remaining distance to the centre of the target intersection when each behavioural event occurred was calculated in the categorized traffic conditions. Figure 3 presents the results of the relationships between the onset location of the driver preparatory behaviour and the traffic conditions.

The remaining distances to the centre of the target intersection when covering the brake pedal without either a leading or following vehicle were the longest among the four traffic conditions. The closest onset locations of the right foot movement were found when driving with both leading and following vehicles. The existence and number of other vehicles around the driver’s vehicle may influence the onset location of driver’s decelerating manoeuvre.

The remaining distances when activating the turn signal with leading and following vehicles were shorter than those during trials without leading and
following vehicles. However, the decreasing tendencies were not remarkable compared to the results of covering the brake pedal. The onset location of the turn signal activation ranged from 80m to 95m and was independent of the existence of other vehicles in front of or to rear of the driver’s vehicle.

(a) Cover a brake pedal  
(b) Activate a turn signal

Fig.3. Average onset location of each behavioural operation in the four traffic conditions

It is hypothesized that the drivers drive at a lower speed when they follow a forward vehicle. Figure 4 confirms this hypothesis. The driving speeds while driving with leading and following vehicles and with a lead vehicle were lower than those of the driving conditions without a leading vehicle. The participants drove the fastest when the leading and following vehicles did not drive in front of and to rear of the participants’ vehicles.

In the comparison analyses of the driver’s preparatory behaviour in a restricted vehicle velocity from 16m/sec to 17.5m/sec, it was suggested that the locations at the onset of covering the brake pedal were closer to the centre of the intersection when driving with leading and following vehicles, compared to driving without a leading vehicle.

Fig.4. Average driving speed when covering the brake pedal in the four traffic conditions
4 Modelling of driver preparatory behaviour using structural equation model

4.1 Method and result

The behavioural analysis suggests that the existences of leading and/or following vehicle correlate with the vehicle velocity while approaching the target intersection. The experiment results reveal a linear relation between the onset location of driver's preparatory behaviour and the traffic conditions. We evaluate these relationships quantitatively by using the structural equation model with the following five variables: the vehicle velocity, the relative distance to the leading vehicle, the relative distance to the following vehicle, the remaining distance to the centre of the target intersection when covering the brake pedal, and the remaining distance to the centre of the target intersection when activating the turn signal. When there are no leading and following vehicles while approaching the target intersection, the relative distances to the forward and rear vehicles were compensated with the driving speed based on a regression equation between the driving speed and the headway or rear distance under conditions of driving with leading or following vehicles.

Figure 5 presents a path diagram of the proposed structural equation model after several trials of model construction and estimation, and the results of model fit indices. We introduced two latent variables, free-driving condition level describing relative distances to leading and following vehicles and location of transition to preparatory behaviour describing onset locations when covering the brake pedal and activating the turn signal.

![Path diagram of the constructed structural equation model](image)

The chi-square value is non-significant, indicating an acceptable model-to-data fit. In addition, the results of the model fit indices demonstrate that the proposed structural equation model fits the observed data well. The path coefficients between the vehicle velocity and the location of transition to preparatory behaviour and between the free-driving condition level and the location of transition are almost equal, suggesting that the influence on the onset locations of the preparatory behaviour is almost equal between from the vehicle velocity.
and from the relative distances to the leading and following vehicles. The factor loadings from the location of transition to preparatory behaviour to each preparatory manoeuvre present the difference in the impacts of the driving speed and the traffic conditions on each onset location, i.e. the two factors have large effect on the onset location of covering the brake pedal and have less effect on the location at the onset of activating the turn signal, corresponding to the analysis results of the driver preparatory behaviour.

### 4.2 Implication for route guidance presentation

The constructed structural equation model suggests that the driving speed and the relative distances to lead and following vehicles should be taken into account when determining the presentation criteria of the route guidance instruction. This is because the driver’s onset location where they begin to decelerate before making the turn differs according to the vehicle velocity and the traffic conditions while approaching the target intersection. For example, the presentation timing can be closer to the target intersection when drivers drive slowly or they follow a lead vehicle.

In addition, the proposed structural equation model may contribute to predicting the onset locations of the driver’s foot movement to cover the brake pedal and turn signal activation, based on the vehicle velocity and the relative distances to leading and following vehicles when the route guidance information is provided for drivers. We confirm higher prediction accuracy of the proposed structural model, compared to the prediction by a single regression model of vehicle velocity, by evaluating the differences between the predicted values and the observed values at the onset of each behavioural event which were not used for the model construction. The in-vehicle system linked with the speed pulse sensor and laser radar units can predict the driver’s onset location of preparation for a right turn by using the path coefficients of the constructed structural model. If driver does not begin to prepare to make a right turn after reaching the predicted onset location, the system can access the driver’s navigational error, i.e. the driver did not accurately identify the turning point, or did not notice the information provision, and then restate the route guidance or issue a warning.

### 5 Application to other intersections on other manoeuvres and with various road structures

We focus on only one specific intersection with two traffic lanes and a designated right-turn lane. We analyse the driver’s preparatory behaviour while approaching the other intersections with various road structures and on the other manoeuvres involved with a left turn, and investigate the influence of the existence of the leading and following vehicles on the onset location of the driver’s decelerating manoeuvre.

Figure 6 presents an overview of the analyzed intersections on the same experimental route as the target intersection in Fig. 2. Intersection 2 has two traffic lanes, and the other intersections have one traffic lane. The participants
made a left turn at Intersection 2 and Intersection 6. They approached Intersection 4 and Intersection 6 after driving along curves.

Figure 7 presents the results of the onset locations of covering the brake pedal in the four categorized traffic conditions at each intersection. At Intersection 1, Intersection 2, and Intersection 5, the remaining distances to the centre of the intersections while driving with leading and following vehicles were shorter compared to the drives without either a forward or rear vehicle, indicating the similar tendencies to the analysis at the specific intersection with a designated right-turn lane.

At Intersection 4 and Intersection 6, the onset locations of the root movement to cover the brake pedal while driving with the leading and following vehicles were the longest among the four traffic conditions. The drivers tended to begin to prepare to make a turn at an earlier point while they approach the intersection after a curve in a car-following condition compared to in a free-driving condition.

At Intersection 3, the onset location of covering the brake pedal is closer to the centre of the intersection while driving with only a leading vehicle or without leading and following vehicles, compared to driving with a following vehicle. A road construction was conducted around Intersection 3, and the participants tended to begin to decelerate earlier while approaching the intersection with a following vehicle, due to avoidance of the rear-end collision caused by the following driver who is distracted from noticing the intersection.

The results of the additional analyses suggest that the same relationships between the driver’s preparatory behaviour and the traffic conditions as the specific intersection with a designated right-turn lane are found on the left-turn manoeuvre and the intersection with one traffic lane where there is no designated lane for making a turn. However, the relationships are different on the intersection with a road construction and the intersection after a curve. It is important to take into consideration the traffic conditions in a different manner when determining the route guidance presentation criteria at the intersections with a curve or a road construction.
6 Conclusion

We developed instrumented vehicles and conducted experiments on a public road to measure driver’s preparatory behaviour while approaching intersections, vehicle velocity, and traffic conditions around the driver’s vehicle. The relationships between the onset locations of covering the brake pedal and activating the turn signal and the existence of the forward and following vehicles were analyzed based on the data measured at a specific intersection with a designated right-turn lane. The results suggest that the existence of the front and rear vehicles and the vehicle velocity influence the onset location of covering the brake pedal. Structural equation modelling was applied to estimate these relationships quantitatively. The results imply that the model with two latent variables can represent well the hypotheses obtained from the naturalistic behaviour analysis.

Finally, we investigated the driver preparations before making turns at other intersections on the other manoeuvre and with various road structures. The additional investigation results indicate that the traffic conditions around the driver’s vehicle and the driving speed have an influence on the onset location of the driver’s decelerating operation before making a left turn or while driving on one traffic lane, and the influence is the same as the specific intersection with the designated lane. However, the influence differs at the intersections with a road construction and the intersection after a curve. Further studies with various categories of drivers will be conducted to validate the findings obtained from this analysis.
Fig. 7. Average onset locations of covering the brake pedal on the analyzed intersections

7 References

INFLUENCE OF UNEXPECTED EVENTS ON DRIVING BEHAVIOUR AT DIFFERENT HIERARCHICAL LEVELS: A DRIVING SIMULATOR EXPERIMENT

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ABSTRACT: Computer based simulation models of human driving behaviour can be used effectively to model driving behaviour and behavioural adaptation to Intelligent Transport System (ITS). This can be a useful step in human centered design of ITS. To construct a comprehensive model of driving behaviour, the interaction between the three levels of the driving task has to be determined. This gives insight into how different driving tasks influence each other. A driving simulator experiment was conducted to determine the relationship between levels of the driving task. The influence of workload on this relationship was determined by giving subjects an additional cognitive task. Subjects had to drive many similar intersections, with two unexpected events. Their reaction on the tactical level to the compensation on the control level was measured. Participants lowered speed and increased headway after having to brake; level of unexpectedness increased this effect. Workload decreased this effect on driving speed.

1 Introduction

1.1 Modelling behavioural adaptation to Intelligent Transportation Systems (ITS)

Driving is and has always been a complex task. Next to controlling the vehicle, which is a complex task in itself, the driver has to determine why, when and where he wants to drive. He has to determine his route, make sure he takes the correct turns, avoids collisions with vehicles crossing his lane and keeps the appropriate distance to lead vehicles. Furthermore, many secondary tasks such as tuning the radio or talking on the phone are performed while driving. This requires constant attention, goal management and use of memory. Today, in a time with more vehicles on the road than ever [1], both industry and governments have set their focus on making driving safer and more comfortable. One of the ways to achieve this goal is through the development of Intelligent Transport Systems (ITS).

When developing ITS, the driver is not always at the center of the designing process. Therefore, it is not always guaranteed that the application will fulfill a certain user need. Furthermore, in many cases it is uncertain how the human user of ITS will react to the system. This is an important step in the designing process of ITS. Drivers may adapt their behaviour in an unexpected way, which
may turn out to be both positive and negative. Determining the effects of this behavioural adaptation can be done in many ways, depending on the stage of the development process and the possible safety effects of the system [2]. A cost-effective and safe way to determine the effects of ITS is by developing a computer simulation model of driving behaviour, which can interact with such a system. We will develop a simulation model of driving behaviour based on the structure of the driving task, making it possible to develop a comprehensive driving behaviour model.

1.2 Levels of the driving task

Our computer simulation model of driving behaviour will have to meet a number of constraints [2], such as running in real-time, focusing on intersection behavior, and the possibility to build the model structure on Michon’s hierarchical model of the driving task [3]. According to Michon [3], driving consists of three hierarchically ordered levels: strategic, tactical and operational. On the strategic (navigation) level, the goals of the trip are set and the route and departure time are determined. On the tactical (guidance) level, the driver has to follow the road, maintain a steady speed and keep enough distance to other vehicles. On the operational (control) level, the driver controls the vehicle by pressing the gas pedal and the brakes, turning the steering wheel and using the vehicle controls. These levels can be active at the same time and can influence each other. This is most clear at intersections, where route choice, tactical maneuvers and control tasks are equally important. This is also where the top-down influence between the levels becomes most clear. When a certain route has been chosen, the driver has to make the turns according to this route and therefore control the vehicle to do so.

On the other hand, bottom-up influence is also possible. Michon [3] expected that this would have a relation with expectations and unexpected situations. Unexpected situations can lead to a higher priority for lower level tasks when they have to take over to guarantee safety or the original task can not be performed successfully. For instance, when one drives a certain route and a street turns out to be blocked, the tactical level solution of taking a different turn will take precedence over the original route. When a driver suddenly has to brake for a crossing child, the distance to other vehicles or the next turn to take can be altered according to the outcome of the situation. In these cases, lower levels influence the outcome of higher levels.

Alexander and Lunenfeld [4] describe how primacy increases with lower level tasks, whereas complexity increases with higher level tasks. Tasks on a higher level therefore often take more time to complete and are more complex. On the other hand, lower level tasks sometimes have to take over in order to ensure safety. These latter situations are of interest for our research, because this is bottom-up influence between levels of the driving task. These are the situations in which the driver compensates for unexpected events.

Unfortunately, the hierarchical relation between the levels of the driving task, and especially the bottom-up influence resulting from this, has not yet been determined precisely, and can therefore not yet be fully integrated in a computational model of driving behaviour. Only when we know how normal
driving behaviour takes place, we can make a valid and complete comprehensive model of driving behaviour, which can in turn be used to determine the effects of behavioural adaptation to ITS.

### 1.3 Research objective

We conducted a driving simulator experiment to determine in which situations normal top-down interaction between the levels of the driving task is overruled by bottom-up influence. This bottom-up influence can be seen as compensation for an unexpected event. In order to determine the relation between this event and the participants’ reactions, we also looked at the influence of cognitive workload and at the level of unexpectedness of a situation on this bottom-up influence. We focused on the tactical level and the control level, because it is very difficult in an experimental setting to control the expectations of a group of participants on the strategic level (route and trip goals).

### 1.4 Hypotheses

An unexpected event will cause compensation behaviour on a lower level of the driving task, influencing higher level tasks. After a while, the effect of the unexpected event on the task will fade away. The operational level tasks that we studied were sudden braking as a reaction to a braking lead vehicle, and steering away from an approaching vehicle from the left. These operational level tasks will have an impact on following distance and intersection approach speed, as well as anticipation and lateral acceleration, which are tactical level tasks.

We expect that compensation behaviour on the operational level to a braking lead car (by braking), increases the participants’ following distance, increases anticipation to the intersection (measured by minimum speed based on distance and time to intersection) and decreases overall intersection approach speed. After a number of intersections, this effect will fade away. We also expect that the level of unexpectedness has an influence on this.

We furthermore expect that compensation behaviour in reaction to an accelerating vehicle from the left decreases overall intersection approach speed as well as the distance-to-intersection and time-to-intersection of the onset of speed decrease (anticipation), and influences lateral acceleration. After a number of intersections, this effect will fade away. We also expect that the level of unexpectedness has an influence on this.

### 2 Method

#### 2.1 Participants

87 subjects participated in our experiment. They were between 23 and 60 years old, had their driver’s license for five years or more and drove 10,000 kilometers or more annually. Due to simulator sickness, 11 participants did not complete the experiment. 76 participants completed the experiments. An error in the data storage led to an incomplete dataset for 37 participants. 39 complete datasets were used for analysis.
2.2 Data measurement

The experiment was performed in a driving simulator of TNO Human Factors. This simulator was a fixed-based driving simulator with manual transmission (see Figure 1). The participant could control the driving simulator by means of normal vehicle controls. The road environment and other road users were projected on three screens with a total horizontal field of view of 180° and the total vertical field of view of 45°.

In order to determine the participants’ workload during driving, participants had to perform a Peripheral Detection Task (PDT) [5]. Measuring workload objectively is difficult with self-report measures [6], but with the PDT, this is less of a problem. A LED light is shown to the participants randomly every 3 to 5 seconds (see Figure 1). Participants have a small switch attached to their index finger, which they have to press every time they see the LED light. Workload is determined by reaction times and the number of missed signals. As workload increases, visual attention narrows [5], which increases response time and the chance of missing a signal. If a participant did not respond to the LED light for 2 seconds or more, this was registered as a missed signal.

2.3 Experimental design

An urban layout was simulated with one long road, crossed by twenty other roads, creating 20 intersections. Subjects were instructed to drive with a maximum speed of 50 km/h and give priority to traffic coming from the right, according to Dutch traffic regulations. They had to go straight on each intersection and park the simulated car at the end of the road (see Figure 1).

The infrastructure was similar at each intersection, and the other road users always behaved similarly. A lead car drove in front of the subject the whole time. This vehicle slowed down when the subject fell too far behind, and speeded up when the subject came too close. This way, the lead distance was always between 18 and 48 meters from the bumper of the simulated car.

When the participant was approaching an intersection, a car coming from the right always crossed the intersection first, followed by a car from the opposite direction. The participant and a lead car then reached the intersection, and a car from the left yielded and crossed after they had passed the intersection. The intersection layout and the positioning of other road users, including the lead car, are depicted in Figure 1.

The experiment consisted of four experimental drives and an introduction drive. In the first experimental drive, participants only drove on standard intersections, setting their expectations about the situations to come. This was the reference condition for normal driving. After 5 standard intersections in the second drive, an unexpected event happened: the lead vehicle suddenly braked. The third drive was a reference condition again. At the eighth intersection in the fourth drive, the car from the left that had always yielded now suddenly accelerated and stopped before colliding with the participants. Both unexpected events could occur at three levels: strong, medium and mild.
Half of the participants were furthermore given an additional, cognitive task, to determine the effect of cognitive load on the influence between the levels of the driving task. They had to count back from a high number by steps of a certain size (ranging between 4 and 9, depending on the drive). All participants with the additional task were given exactly the same task, and they were told to do it as fast as possible, making sure that they had additional cognitive load during driving. Participants were encouraged to continuously perform the additional task and were reminded of their task after a number of seconds without an answer, but they could give their final answers at their own pace, ensuring that all participants were equally challenged.

The two levels of cognitive workload (no additional task or additional task) and the three levels of unexpectedness of the events (mild, medium, hard) leads to 6 event conditions. The event conditions were counterbalanced among participants to eliminate possible learning effects. Participants always encountered the same version (mild/ medium/ hard) of both the unexpected events, and always drove a drive without an unexpected event as the first and third drive. Participants with an additional cognitive task also had to perform this cognitive task during reference conditions.

After each drive, participants were given a break and a questionnaire, with questions related to simulator sickness, the level of predictability of the driving task and the level of difficulty of the PDT. For the participants with the counting task, additional questions were asked about the level of difficulty of this task, and whether it had influenced the participant’s way of driving.
2.4 Data registration

Twenty-one variables were registered with a frequency of 256 Hz during the experiment:

1. Time (s);
2. Path number;
3. Distance to intersection (m);
4. Distance from next intersection (m);
5. Velocity (m/s);
6. Acceleration (m/s²);
7. Lateral position (m);
8. Lateral velocity (m/s);
9. Steering angle (angle);
10. Gas pedal angle (percentage of maximum pressed);
11. Brake pedal angle (percentage of maximum pressed);
12. Time headway (s);
13. Distance lead vehicle (m);
14. Velocity lead vehicle (m/s);
15. Time to intersection (s);
16. Time to collision (s);
17. Time to collision with left approaching vehicle (s);
18. Time to collision with right approaching vehicle (s);
19. Distance to intersection of lead vehicle (m);
20. Speed of lead vehicle (m/s);
21. PDT reaction time (ms);

2.5 Analysis

All recorded twenty-one variables are related to tactical level or control level driving tasks. These were used to answer the question whether, and in what way, control level compensation for an unexpected event influences tactical level task performance. In this paper, we only focus on the first unexpected event, the braking lead car. A full description of the second part of the analysis and its results will be published in [7].

First, we determined whether the standard intersections were actually seen by the participants as “expected” and the unexpected events as “unexpected”. This was determined by studying the answers given in the questionnaire and by looking at learning effects in driving. Next, we tested our hypotheses that the braking lead car would have an effect on following distance, moment and
location of anticipation to the intersection and the intersection approach speed. This was tested by comparing these variables in the reference case (third drive) to the intersections directly after the event. Finally, the effects of the level of unexpectedness (mild, medium or hard braking) and of the additional cognitive task were examined.

3 Results

3.1 Expectations

The expectations of the participants were tested by studying their driving behaviour and related learning effects, and by examining their answers to selected questions of the questionnaire.

3.1.1 Learning effects in driving behaviour

A learning effect can be determined by examining the average speed on intersections. Average driving speed increases with experience, as a result of the participants' knowledge of what to expect. Indeed, a significant increase of average driving speed can be found during the experiment (p<.0001). The standard deviation of speed also tells us something about the learning effect of standard intersections: when participants get more used to situations, they know better what to expect and therefore can drive more smoothly through these intersections. A decrease in the standard deviation of speed therefore also points to a learning effect. The standard deviation of speed decreased significantly during the experiment (p<.0001). This supports our expectation that participants were getting used to the standard intersections during the first experimental drive.

3.1.2 Answers to selected questions of the questionnaire

Participants were given a questionnaire after each experimental drive. Some questions concerned the participant's comfort during the experiment, some were related to the difficulty of the driving task, the PDT and the additional task. A third topic in the questionnaire was the predictability of other road users' behaviour in the experiment and the intersections. The answers to these questions were used to determine whether participants had expectations about the situations and whether an unexpected event was actually seen as unexpected. The answers to the questionnaire revealed that the reference conditions were seen as significantly more predictable than the drives with the unexpected events (p<.006, see Figure 2). Also, 50% of the unexpected events were explicitly mentioned in the field for additional information about the experiment. It is safe to conclude that the unexpected events were really not expected by the participants.
3.2 Effects of control level compensation on tactical level tasks to a braking lead vehicle

In reaction to the braking lead vehicle, participants drove at significantly lower speeds on the directly intersections following the unexpected event than they did on the same intersections in the standard drive (p<.0018). Figure 3 shows the average speed on the intersection area (100 meters before until end of intersection) measured over 7 intersections in drive 2 (braking lead vehicle) and drive 3 (standard drive), and the interaction effects between drive and intersection (p<.001). It can be seen that overall speed for these intersections is significantly lower in the drive with the braking lead vehicle; the reaction to the braking lead vehicle (intersection 5 in drive 2) is also clear.
Furthermore, participants increased their headway significantly during the second drive (p<.001), compared to the reference drives.

### 3.3 Effects of level of unexpectedness and additional workload

The level of unexpectedness (L.O.U.) has a significant effect on the percentage of time participants drove with the minimum headway (p<.038): when the lead car would brake harder, the participants would drive less time with the minimum headway (see Figure 4).

![Fig.4. Effect of level of unexpectedness (lou) on % of time driven with minimum headway.](image)

There was no significant influence found on driving speed of the level of unexpectedness.

The additional task increased PDT reaction time (p<.001) and number of missed PDT signals (p<.001), and this increased workload influenced the effect that was seen on driving speed: with the additional task, the speed decrease in the second drive was significantly less than without the additional task (p<.027).

A full description of our experimental results will be published in [7].

### 4 Conclusions

It can be seen from our results that tactical level tasks are influenced by operational level compensation tasks in case of an unexpected event, and that this effect fades away after a certain amount of time. A significant effect of the level of unexpectedness on this influence between levels of the driving task was seen, and additional workload seems to change the relation between levels of the driving task as well. A full description of conclusions regarding the structure of the driving task and our conceptual model of intersection driving behaviour will be published in [7].
5 Acknowledgments

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6 References


SUBJECTIVE STRAIN ESTIMATION DEPENDING ON DRIVING MANOEUVRES AND TRAFFIC SITUATION

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ABSTRACT: An inadequate level of workload while driving is leading to increased errors and accidents. Therefore, there is a need for levelling the driver’s workload through some assistance system. In addition to their specific functionalities (e.g. coordinate, prioritise information), these systems aim to optimize the driver’s workload. Therefore, an assessment of the workload is required. As workload depends on external stress factors which can change dynamically, e.g. driving manoeuvres or environmental conditions, the workload estimation needs to be as dynamic and continuous rather than discrete. In this paper, the effects of traffic density and changes in the demands within a complex manoeuvre are estimated using a new developed method for a continuous subjective rating of the driver’s workload. The results demonstrate that the variation of the stress factors moderate driver’s strain. By integrating these findings with former results a qualitative and quantitative model of stress and strain is introduced.

1 Introduction

1.1 Workload measurement within the driver-vehicle-environment context

Workload is a very complex concept of interrelations between e.g. external task demands, internal resources, processing capacities and performance capabilities. These aspects are often indicated with the same term “workload” [1]. The approach presented here is based on a concept of stress and strain. According to DIN EN ISO 10075-1 [2] psychological stress is defined as “the total assessable influence impinging upon a human being from external sources and affecting it mentally”, whereas strain is defined as “the immediate effect of mental stress on the individual (not the long-term effect) depending on his / her individual habitual and actual preconditions, including individual coping styles.” While driving stress factors arise from different sources: First of all, the driving task poses differing demands on the driver. Follow a road requires primarily lateral control whereas following a preceding car additionally requires longitudinal control actions. The second source for increased stress is the environment modifying the requirements of the driving task as well as acting directly on the driver. For example follow a road during fog should likely be more difficult and strenuous than under the condition of high visibility because the availability of relevant information is restricted. On the other hand, e.g. high temperature influences the driver directly by making him / her tired. A third category of stress sources are additional secondary tasks like operating a
navigation system, using a mobile phone [3, 4] or communicating with passengers. The actual level of driver’s strain evoked by the stress depends on driver characteristics such as abilities, skills and his state. Therefore, the same stress level does not necessarily result in the same strain for different drivers. Due to the vehicle motion within the driving environment and the interaction with other road users none of the three stress sources acts statically on the driver. They can be characterised by different distinctive changing dynamics which again demands a comparable high dynamic description of the possible resulting strain.

In general, strain cannot be measured directly but indirectly and is normally assessed multimodal [1, 5] by subjective, physiological and performance indicators. Behavioural indicators, e.g. steering wheel reversals or the standard deviation of the lateral position indicate individual coping strategies in terms of action control. Physiological measures such as the heart rate describe the driver’s state by indicating his activation or arousal [1, 6]. Both indicators dynamically assess changes in strain but have problems in regard to are partly problematic with regard to sensitivity and specificity. This makes interpretation of these indicators sometimes very difficult. Indicators e.g. have to be differently interpreted according the test design (primary versus secondary task) but also with regard to different sources (changing of the driver state versus changing of the task demands) [7]. Besides, both types of indicators require special sensors in the vehicle which are not available in current series-production vehicles but would be mandatory for a wider application of strain adaptive systems not only in the field of research. The third group of subjective self report measurements like NASA-TLX or Instantaneous Self Assessment Method [8] don’t need any specific sensors for assessment and in general have a higher sensitivity than the indicators mentioned above. However, these indicators are usually collected at discrete points in time like at the end of a test drive or at certain spatial- or time-triggered situations during the trip to analyse differences between systematically varied independent variables, system configurations, vehicles or drivers. This event-triggered and discrete assessment of the data is not suitable for measuring the effects of dynamically changing stress factors over time. In recent own real vehicle driving studies [9] it was shown that driver strain varies not only between different consecutive driving manoeuvres but even within one manoeuvre. Therefore strain should be analysed in regard to structural changes in place of level differences between certain time- or event-sections only by means of a likewise dynamic and continuous measurement. The second reason for a continuous measurement of both stress and strain is the final objective of this research: the definition and implementation of an online working model of driver stress and strain to manage the human machine interaction. These systems require continuous access to the workload level and its changes in order to provide an optimal support for the driver.

1.2 Estimation of strain by continuous subjective rating measurement

To benefit from the higher sensitivity of subjective self-report measures and to avoid the disadvantages of the rather discrete time- or spatial-triggered methods, a continuous subjective rating method was developed and tested in
different former experimental studies. Within a real car driving study subjective
strain was measured subsequent to the test drive through a video analysis
where 16 participants rated their experienced strain during the drive using a 15-
point rating scale (see Figure 1). The rating scale consist of five verbal main
categories (very little strenuous, little strenuous, moderate, strenuous, very
strenuous) with 3 subcategories each. Participants were not informed about the
underlying stress factors varied by different driving manoeuvres and
environmental factors, to not influence their ratings. They were instructed to
give a new rating whenever they perceived a change of their subjective strain
and their actual rating was displayed within the video.

<table>
<thead>
<tr>
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Fig.1. 15-point rating scale of the rating method

After mapping the continuous ratings to the different driving manoeuvres and
environmental factors the results of the study demonstrated that these stress
factors were associated with significantly different Perception of strain [9].
Different driving manoeuvres with different requirements were identified as
stress factors leading to different strain levels. As an example, approaching and
following a preceding car was shown to cause more strain than just following a
road as these manoeuvres pose, additional to lateral control, also longitudinal
regulation demands on the driver. However, situational characteristics were
shown to modify the effects. For example strain increases only during
approaching and following a preceding car in situations where the driver had the
possibility to overtake and prepared this manoeuvre. In addition the increase
was larger with oncoming traffic (rural road) and difficult road characteristics,
such as narrow lanes and curves, which posed extra demands on the lateral
regulation and velocity adaptation. In road sections where overtaking was not
allowed, these manoeuvres did not differ in strain. In these situations the
existence of the preceding car seemed to rather support the driver in
longitudinal regulation than posing additional demands on the driver. The
relationship between the described stress factors and subjective strain was
validated within the study by analysing the physiological indicator heart rate
variability as well as the performance indicator steering wheel reversal rate
which both resulted in comparable results.

As continuous subjective strain was measured post-hoc subsequent the test
drives, it was not clear whether memory effects or the restricted availability of
information within the video display influenced the results. With the intention to
estimate these effects and to test if it is possible to rate subjective strain
continuously while driving (online) a second study was conducted [10]. In order
to vary different stress factors within the DLR Virtual Reality Laboratory (VR
Lab), different road sections were constructed and surrounding traffic was
implemented so that test drivers conducted different driving manoeuvres on
different road sections for several times repeatedly. Resulting strain was
measured multimodal and continuously by subjective (by the abovementioned
rating method) as well as performance indicators. To analyse possible
interferences between driving and rating participants were divided into different
groups, two experimental groups that rated first simultaneously while driving
and secondly after the test drive by means of a playback-function. A control
group rated exclusively offline. Influences of the rating time (online vs. offline) on subjective strain were analysed by comparing the ratings of the experimental groups. To control the effect of different rating modes, a manual and a verbal rating input have been compared additionally. It could be shown that a continuous assessment of the subjective strain is not differing between the online and offline approach. The analyses of the driving performance indicators (e.g. average speed, standard deviation of lateral position) showed no statistical significant interferences between rating and driving although the online rating groups tended to decrease their driving speed with the additional rating task. Furthermore no significant main effect of rating time (online versus offline) and the rating mode (manual versus verbal input) on rating behaviour was found. However, there were significant interactions between these factors and very strenuous situations (e.g. the situation overtaking on the rural road). The control group which exclusively rated offline underestimated strain as well as the online rating group that rated by means of the manual input. Difficulties by only post-hoc rating may be due to difficulties in the perception of distances and velocities within the playback function of the VR Lab. The manual online rating seemed to be somewhat difficult in situations where participants had to focus on motor actions during the overtaking for example. On the other side these participants adjusted their underestimated ratings afterwards during offline rating, which led to a significant interaction in the comparison of online and offline rating behaviour of the experimental group. Therefore it can be subsumed that if the driving situation is not characterised by extremely high demands for the driver, online rating is applicable and preferred to exclusively offline rating. Whereas in very high demanding situations participants should have the possibility to adjust their online ratings by an additional offline rating. The influence of the varied stress factors on strain and its intercorrelations found in the first study were validated within the second study.

To summarize the results of both former studies it was demonstrated that the developed method to assess subjective strain continuously is an alternative to time- or event-triggered self report measures. By using this method, dynamic subjective strain information which is related to dynamically changing stress factors can be collected. Concerning the rating method (online or offline), it can be suggested to chose the method dependent on the experimental setup, i.e. whether it is a real driving tests or a simulator study, as both approaches result in comparable results.

1.3 Relation between stress and strain taking into account different levels of dynamics

Within the studies mentioned above the examined stress factors can be described as being of relatively low dynamics as within the real driving study e.g. participants passed within one hour of test drive only through seven different road sections. On the other hand, mapping subjective strain ratings on different driving manoeuvres also taking into account the manoeuvre sequence means estimating strain on a higher, more moderate dynamic level as the participants conducted several manoeuvres within the different road sections. For example within the abovementioned real driving study 16 participants conducted within a one hour test drive a total of 3452 driving manoeuvres, 1130
on the motorway, 32 on the motorway exit, 701 on the city road and 1589 on the rural road. Additionally there were indices that strain does not only differ among the manoeuvres but also even within a manoeuvre where the dynamic of changes is even higher and can be described as short-term changes. Within the following study higher dynamics of stress factors changes will be examined.

The other main issue of the research is validating the method for different dynamically stress factor changes, testing the sensitivity of the method and as a prospective objective establishing a qualitative and quantitative relationship between the measures of external stress factors and driver strain.

2 Method and test design

The main objective of the simulator study was to see whether even short time changes of external stress factors could be represented by means of the continuous rating method. As an environmental stress factor, traffic density was varied. By this the influence of different traffic densities on driver strain while driving on the motorway in general was measured. As former studies indicated that strain even differed within a complex manoeuvre the second aim was to assess the influence of different requirements within the complex manoeuvre “entering the motorway” on the driver’s strain. To systematically distinguish between different demands “entering the motorway” was divided into four subtasks: First the orientation phase (at the beginning of the slip road), second the planning phase were participants begin to search for appropriate gaps, estimate velocities and plan their lane change during driving parallel to the other vehicles on the acceleration lane, third the active lane change phase characterised by the actual execution of the lane change and the last phase of driving on.

13 subjects (8 male and 5 female) between 24 and 35 years old (mean = 28) participated in the simulator study. The DLR simulator SimCar is characterised by a dynamic motion system and a high quality projection system that provides the image of the surrounding virtual environment and traffic. A wide field of view (240° × 40°) combined with a high resolution of approx. 9200 × 1280 pixels provides a detailed visual representation. For an overall realistic impression a complete vehicle has been integrated into the simulator. Driver behaviour (e.g. acceleration, steering) and the resulting vehicle dynamics (e.g. lateral acceleration, velocity) are recorded as well as information from the environmental model (e.g. preceding cars, road characteristics). The test track consists of two different parts: The first part is characterised by a set of two driving situations on the motorway with increasing and decreasing local traffic density in order to analyse the general influence of changing traffic on driver strain. The second part consisted of six consecutive manoeuvres “entering on the motorway” with fixed different local traffic densities. The order of increasing and decreasing traffic within the first part as well as the sequence of density levels within the second part was balanced between and within the subjects in order to control time- and cross-over effects. A total of about 1 hour of driving was realised within the simulator study.

Local traffic density was implemented by the traffic model introducing different numbers of vehicles. Local traffic density was defined by the coverage level of
vehicles in front and besides the own vehicle and was then classified into 10 stages from 0 (no traffic) to 1 (traffic congestion) [11]. In order to allow analyses with repeated measures and to ensure equal traffic conditions for all participants during the second part of the test drive (the six consecutive manoeuvres “entering the motorway”) the coverage level was classified and applied by six conditions of different levels of traffic density. The six traffic densities were defined according the distinction of the different LOS-levels LOS1 (no traffic) to LOS6 (traffic congestion) [12].

Driver strain was measured continuously and multimodal by subjective (assessed by means of the online rating method with manual input), physiological (e.g. heart rate) and performance indicators (e.g. parameters of lateral control). Regarding the continuous rating method the participants were instructed to change their subjective strain ratings by pressing a steering wheel button whenever they experience a change in strain. Their actual rating was displayed in a head-up display on the 15-point rating scale and the verbal description of the main category (e.g. little strenuous, very strenuous). In order to ensure safe driving with simultaneous subjective rating and to counteract possible simulator sickness, the participants have been trained intensely to get used to the simulator and the rating task.

3 Results

In order to analyse the overall influence of dynamically changing traffic densities on subjective and physiological strain, these indicators were mapped to the different coverage levels while driving on the motorway and the 6 LOS levels on the slip road by computing mean values for each level of the factors. Concerning the different demands of the manoeuvre “entering the motorway”, the indicators were mapped likewise and mean values dependant from both factors, the manoeuvre phase and the LOS-level were computed for each participant (e.g. mean subjective strain during the orientation phase with high traffic density LOS6).

Although systematic control of the environment is an advantage of simulator studies, sufficient high coverage levels (> 0.7) of local traffic density on the whole motorway were not realised for all test drivers. This is probably due to the fact that the local traffic density strongly depends on the interaction between vehicles and therefore on the individual driving behaviour of the test drivers and the individual interaction with surrounding traffic respectively. As a consequence the number of analysed coverage levels is only 7 (0 to 0.6) and only 6 out of the 13 subjects can be included in the analyses concerning the influence of traffic in strain during the whole drive on the motorway. Therefore the results have to be interpreted as trends. The heart rate values have been intra-individually z-standardised across the whole data to control different inter-individual physiological initial levels. Subjective ratings have not been standardised as the inter-individual variability was marginal by reason of the extensive training phase.

In order to describe the overall influence of dynamically changing traffic density on strain two separate two-way 2×7 Design ANOVAS with repeated measures (sequence of increasing / decreasing traffic density, 7 levels of traffic density
coverage, $\alpha = 5\%$) were performed for the subjective ratings and the heart rate. Concerning the subjective rating the effect of “traffic density” was significant ($F_{6,30} = 8.720, p < .001$) whereas the second main effect “sequence” ($F_{1,6} = .335, p = .588$) and the interaction between “traffic*sequence” ($F_{6,30} = .891, p = .514$) were both not significant. The pairwise comparisons demonstrated that subjective strain increased with raising traffic density up to a medium coverage level of 0.3 but then remained on this level without increasing any higher. The equivalent analysis was computed for the intra-individual z-standardised heart rate. The results tend to demonstrate comparable effects (traffic density: $F_{6,30} = 2.304, p = .060$, sequence: $F_{1,5} = .424, p = .544$, traffic*sequence: $F_{6,30} = 1.048, p = .415$). Mean heart rate also increased significantly with raising traffic density up to a medium level but in contrast to the subjective rating decreased again with even higher traffic, whereas the decrease was not statistical significant. In Figure 2 both strain indicators are displayed.\(^1\)

![subjective and physiological strain](image)

**Fig.2.** Strain dependent from traffic density ($n = 6$)

Besides this overall effect, the influence of different traffic densities on strain during the complex manoeuvre “entering the motorway” is described within the following analyses. The 6 different traffic densities on the slip road and the different demands of the manoeuvre can be characterised as of higher dynamics as the increasing and decreasing traffic density during the drive on the motorway. The analysed factors are therefore traffic density by means of the LOS levels and the 4 different phases of the manoeuvre “entering the motorway”. For both strain indicators two separate two-way 6×4 Design ANOVAS with repeated measures (6 LOS levels, 4 phases, $\alpha = 5\%$) were performed. Due to technical problems not all traffic densities have been realised completely in the simulation and therefore only 11 out of the 13 subjects can be included in the analyses. Regarding the influence of the different LOS levels the main effects are significant in both analyses (mean subjective rating: $F_{5,50} = 3.484, p = .009$, mean heart rate: $F_{5,50} = 4.947, p = .001$). Subjective strain increases with increasing traffic, whereas only the lower stages differ significantly from the higher ones with subjective strain reaching a plateau. Physiological strain as well increases up to a medium traffic density but then

\(^1\) By reason of a better demonstration z-values of both indicators are displayed within the figure. The analyses of subjective z-values result in comparable findings as the absolute ratings.
decreases again. The difference between the lowest level and the others is the only significant result. The factor “phase” has a significant influence on strain for the subjective indicator ($F_{3,30} = 13.406$, $p < .001$) whereas only a tendency is found for the z-standardised heart rate ($F_{3,30} = 2.786$, $p = .058$). Both indicators increase up to phase 3 followed by a decrease so that the highest strain is related to the active lane change in both indicators (see Figure 3).

Furthermore, a significant interaction between LOS level and manoeuvre phase for both indicators (mean subjective rating: $F_{15,150} = 4.338$, $p = .000$, mean heart rate: $F_{15,150} = 2.665$, $p = .001$) can be found.

Figure 4 demonstrates the interaction between the both factors. Regarding the subjective indicator strain increases during low traffic densities (LOS2 and LOS3) in phase 2 (planning phase) and decreases during the actual lane change and the continuation of the manoeuvre. From LOS3 strain remains on a high level and increases even more with increasing traffic respectively. In phase 4 strain is comparable to during the actual lane change except during the highest density level. Within the highest level (LOS6) strain decreases within phase 4 which is probably due to the very low velocities within the congestion. The interaction concerning the physiological indicator demonstrates a somewhat different relation. At high density levels a comparable increase in strain up to the lane change manoeuvre can be described, whereas at low levels strain first decreases in phase 2 and then gets its maximum in phase 3.
Fig. 4. Interaction between LOS level and manoeuvre phase (n = 11)

4 Discussion and perspective

The results of previous studies demonstrated that the developed approach of continuous subjective strain measurement is applicable to assess the effect of different stress factors (manoeuvre and situation) on driver strain in different experimental setups such as real driving and simulation as well online as offline. Furthermore it was demonstrated that the relation between the measurement of varying external factors and the resulting driver strain, taking into consideration different levels of dynamics can also be represented by the method. The influence of short-term change of local traffic density is describable as well as the influence of various demands within the complex manoeuvre “entering the motorway”. Concerning the general influence of traffic density on driver strain the analyses of the subjective and the physiological indicators show only partly comparable results: During high traffic densities subjective strain remains on a plateau whereas physiological strain decreases. This may be due to different sensitivities of the mean heart rate regarding physical and mental load. Mean heart rate is seen as sensitive to physical load but less sensitive to mental load.
It can be argued that mental load is higher than physical load in high traffic density situations due to a restricted scope of action or behaviour within the congestion. As a result the indicator of mean heart rate might be less sensitive in high traffic density situations than in low traffic density situations. In order to validate this interpretation other physiological indicators being more sensitive to mental load as e.g. the heart rate variability, should be analysed in further studies. Besides it can be stated that during high traffic densities strain increases until the actual lane change, whereas strain reached its maximum already during the planning phase in low densities, where the driver has to estimate velocities and distances to other vehicles and decide the lane change. The significant interaction demonstrates the importance to describe relations among different dynamically changing stress factors and resulting subjective driver strain more precisely. By means of the continuous subjective rating method more detailed information about the influence of factors on strain can be gathered than by a subjective questionnaire after the whole test drive which in turn results in a better understanding of the analysed aspect. However the dynamics should be analysed in more detail in further studies by examining the changing sequences. To reach the general aim of the research to model stress and strain within the driver-vehicle-environment context the relative influence of different stress factors with different changing dynamics on strain can be described and modelled by integrating the results of the studies. The final and prospective aim of the research is then the indirect estimation of the related strain via the underlying model of stress and strain by directly measuring the involved stress factors via CAN-Bus (e.g. manoeuvre recognition) or laser scanner (e.g. traffic density) in order to provide this information to possible adaptive assistance or information systems.

5 References


IDENTIFYING USER STRATEGIES FOR INTERACTION WITH IN–VEHICLE INFORMATION SYSTEMS WHILE DRIVING IN A SIMULATOR

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ABSTRACT: The study analyzes the efficiency of different strategies for interaction with in-vehicle information systems. N=24 drivers completed a test course in a motion-base driving simulator containing different critical situations. At predetermined points of the route an additional menu navigation task was offered to the driver. The driver could decide whether the actual situation was suitable to execute a task and when to interrupt it. The results show that drivers are able to adapt their secondary task behaviour to the situational demands. The anticipation of potential conflicts could be shown both in secondary task behaviour (complete task rejection or task delay in critical situations) as well as in driving behaviour (e.g. lower approaching speed in front of demanding situations). These strategies were successful to maintain driving safety. Adequate situational assessment prior to the start of the task and adequate monitoring of situational development during secondary task execution are identified as relevant processes for Situation Awareness in this context.

1 Introduction

Extended research has been done on the effects of dealing with in-vehicle information systems (IVIS) while driving. The overall result is that performance of an additional secondary task clearly reduces driving performance and safety. Typical effects are a decrease in lateral control (e.g. [1]) or delayed reaction times to sudden events (e.g. [2]). On the other hand also compensation strategies can be monitored, e.g. reduction of speed ([3] and [4]), an increase of safety margins [5] or fewer lane changes [6]. An often neglected fact is that drivers are also able to compensate additional workload by specific interaction strategies dealing with the secondary task. Like McCartt et al. [7] argue: “phone and driving tasks are paced by experimenters, but in the real world drivers decide when and where to use their phones and may adapt their phone use to varying traffic conditions” (p.92). This freedom of decision is often not given in typical experimental studies analyzing the potential risk of dealing with secondary tasks while driving. Some results from telephone interviews [8] and video observations [9] hint to specific compensation strategies, for example while using a cell phone. Some drivers do not use the phone in a moving vehicle at all, some use it only while they are waiting at a red traffic light, some even stop the car. While calling, drivers tend to drive more slowly, avoid lane changes, choose sections with lower traffic density for calling someone or ask a passenger to do the call. In demanding traffic situations drivers interrupt the conversation, or the remote caller is informed about the environmental
conditions to adapt the conversation. While performing a secondary task, drivers try to divide the tasks into smaller chunks and look back to the road in adequate intervals [10].

2 Objectives

Compensation strategies in the interaction with IVIS while driving can be executed on the level of driving task as well as on the level of secondary task. The premise for those compensation strategies is to have Situation Awareness of the driving task. This concept was originally developed in aviation but has become more and more important also in the domain of driving. The most famous definition is the one by Endsley who defines Situation Awareness as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future” [11; p. 792]. It is argued that a cognitive representation of the current and the future situation is formed on the base of knowledge in long-term memory which guides attention to the relevant cues in the environment. Due to the dynamics of the driving situation, this mental representation has to be continuously updated. According to a model of Adams, Tenney and Pew [12] this update is understood as a cyclical process, including an active search in the environment for information which may prove or disprove the activated schema and lead to modifications.

In the context of interactions with IVIS we postulate two different processes of Situation Awareness necessary for a situationally adaptive use of secondary tasks while driving:

1. An adequate assessment of the situation prior to the start of a secondary task for proper decisions if a secondary task can be performed in the current situation at all. In highly demanding traffic situations the driver should ignore an additional task or should delay the beginning of the task.

2. An adequate monitoring of situational development during secondary task execution in order to permanently compare the expected situational development with the actual one. In case of observed differences, the secondary task has to be interrupted.

We argue that the control process during secondary task execution is restricted to a subjectively relevant part of the environment. Therefore, the anticipative process of situational assessment prior to task execution is crucial for the proper control of situational development. It influences which of the cues in the environment will be monitored during secondary task execution.

In this paper we try to identify the two postulated processes of Situation Awareness in the driving task as well as in the interaction with secondary tasks while driving. Therefore, we examine anticipative compensation strategies in the decision process just before the beginning of a task as well as more reactive compensation strategies during secondary task execution and analyze their effects on driving safety.
3 Method

3.1 Driving task

To examine different compensation strategies in interactions with IVIS, a study in a driving simulator with motion system of the WIVW (Wuerzburg Institute for Traffic Sciences GmbH, for more information see www.wivw.de) was conducted. The 1.25 h test course consisted of sections with rural roads and urban areas. Within this course, eight specific situations, including a potential conflict, were realized (e.g. a vehicle parking out from a parking zone in front of the subject’s vehicle, a pedestrian crossing the road just in front of the subject’s vehicle, a broken-down car on a rural road, curvy sections etc.). Each of these situations was realized three times varying in the salience of environmental cues pointing to the specific conflict (good, medium, hard to predict; not further discussed in this paper). For all these situations, it was characteristic that the conflict could possibly be anticipated by the driver. Figure 1 shows the driving simulator of the WIVW (left) and a screenshot of a simulator scene of a typical urban situation (right).

N=24 subjects participated in the study: one control-group with a baseline driving condition (n=8 subjects) and one dual task group which performed an additional menu navigation task while driving (n=16 subjects). The mean age of subjects was 36 years (sd=10.1 years) with n=12 female and n=12 male drivers. The two groups did not differ in relevant trait factors like driving experience, age or gender. They were all well trained in simulator driving.

Fig.1. The driving simulator with motion system of the WIVW (left) and a screenshot of a typical driving scene (right).

3.2 Menu navigation task

In the dual task condition, the driver had to perform a secondary task while driving. The presentation of this task was the following: At predetermined points of the route, the driver was offered the choice to perform an additional task. This offer was given either just before a critical situation (e.g. just after a parked car started to indicate but was still standing) or in a non-critical situation (on road segments between the critical situations). The offer was signalled by a question mark shown in the Head-Up Display on the front scene (see figure 2 left).
Human Centred Design for Intelligent Transport Systems

Fig. 2. Screenshot of the HUD for offering a secondary task (left) and the menu selection task (right).

The offer given, the driver had to decide within 3 seconds whether the situation was suitable for the secondary task or not, according to the situational demands (‘decision phase’). To start the secondary task, the driver had to pull a joystick on the middle console of the vehicle to the right (see figure 2 right). Then a “start display” was presented on a visual display located at a lower position on the middle console of the vehicle (‘start phase’). To reject the offer, nothing must be done. After 3 seconds the question mark disappeared and the driver had to wait for the next opportunity to perform a task.

The task itself was a hierarchical menu navigation task simulating the interaction with a typical in-vehicle information system. The task could be interrupted at any point within the menu navigation. The driver was instructed to navigate to a specific menu function (e.g. “control average fuel resumption”; ‘instruction phase’). To navigate within the menu, the joystick was used. After reaching the correct function the driver confirmed the selection and the task was finished (‘performance phase’). For limiting the time for task performance until the next task was offered, menu navigation was stopped automatically after 15 seconds. The driver was instructed to interrupt the secondary task and return to the driving task whenever the driving task required full attention. To motivate the subjects to execute tasks at all, they received rewards for every completed task but also penalties for severe driving errors.

4 Results

In a first step, compensation strategies in the secondary task (ST) were analyzed by the following parameters of the menu task:

- Mean number of rejected tasks [%]
- Mean preparation time before starting menu navigation (start phase + instruction phase), only for executed tasks [sec]
- Mean execution time for menu navigation (limited to max. 15 sec), [sec]
- Number of tasks with minimum one interruption (delay times between two steps within the menu system > 3 sec), [%]
Fig. 3. Mean % of rejected tasks (left), mean preparation time (right), for urban and rural, critical vs. non-critical situations.

The percentage of rejected tasks was generally higher in critical situations (43% vs. 17%; see figure 3 left), especially on rural roads (in front of curves and the broken-down vehicle; significant main effects “criticality” \(F[1;14]=74.737, p<.000\) and “road type” \(F[1;14]=6.217, p=.026\) and significant interaction; \(F[1;14]=33.023; p<.000\)). Drivers seemed to anticipate these demanding situations and therefore avoided any additional load of dual task performance. If drivers decided to execute a task in critical situations (after all over 50% of tasks) they try to await how the situation will develop (see figure 3 right). This resulted in longer mean preparation times until the menu system was started in front of critical situations (significant main effects “criticality” \(F[1;14]=54.613, p<.000\) and “road type” \(F[1;14]=8.399; p=.012\) and significant interaction \(F[1;14]=5.109; p=.042\)).

Fig. 4. Mean performance time (left) and % tasks with interruptions (right), for urban and rural, critical vs. non-critical situations.

The execution time for menu navigation was also longer in critical situations, especially on rural roads (significant main effects “criticality” \(F[1;13]=9.756; p=.008\) and “road type” \(F[1;13]=27.214; p<.000\) and significant interaction \(F[1;13]=28.016; p<.000\); see figure 4 left). This can be referred to a greater
number of necessary interruptions during ST execution in these situations. The results for task interruption didn’t reach significance (“criticality” $F[1;14]=2.671$, $p<.124$, „road type“ $F[1;14]=3.877$; $p=.069$ and interaction $F[1;14]=2.011$; $p=.178$).

Figure 5 shows the relevant driving parameters in the different phases of ST execution, separated for straight and curvy roads. In both conditions, speed is continuously reduced, beginning with the decision phase until the end of ST execution. This implies that driving behaviour is first of all directed by the driving task, but then adapted to the requirements of ST execution.

The parameters SDLP/second and steering wheel_sd/second (due to variable phase durations standardized to sd/second) show an increase in steering activity at the beginning of the secondary task which may be interpreted as an attempt to get an optimum lane position, anticipating that during ST execution lateral control will be worse. During the execution of the secondary task, steering activity was then reduced which can be interpreted as a distraction effect of the secondary task that lead to a disregard of lateral control in the driving task. After the ST execution, often larger steering corrections could be observed in order to adjust the accumulated lane position error during the ST execution.

Fig.5. Mean velocity, mean standard deviation of lateral position (SDLP) per second and mean standard deviation of steering wheel activity per second in different phases of the secondary task execution on straight and curvy rural sections. Decision=decision phase, start=start phase, instr=instruction phase, perform=task performance phase, after=phase 2.5 s after ST performance.
For analyzing the effects on driving safety, we defined performance strategies in the interaction with IVIS in critical situations based on the following groups:

- Rejection of a task (not performing the task at all)
- Delayed beginning of the task (beginning of the task after a critical point; defined separately for each of the situations; e.g. the moment when the other vehicle is just parking out)
- Execution of the task without any interruptions
- Interruption of the secondary task, implicating a return to the driving task after the secondary task was started

![Graph showing the percentage of different performance strategies for secondary task offers in critical situations.](image)

Figure 6 left gives the percentages of how often the different performance strategies were selected related to all offered secondary tasks in the defined critical situations. In most cases the task was rejected completely (43%). In 30% the beginning of the task was delayed until the critical event had happened. Further 14% of the tasks were performed without any interruptions straight through the critical situation. In 13% of the tasks the task was interrupted after the beginning of the task.

To prove the efficiency of the different strategies, driving errors were defined as decelerations > 8 m/s², critical safety margins < 1 m or critical TTC < 1 sec. Figure 6 right gives the results for the different strategies compared to the errors in the baseline condition without secondary tasks. If the task was rejected or delayed, there was no important increase in driving errors compared to the baseline condition (baseline-rejected Chi²=0.019; p=.890; baseline-delayed Chi²=1.765; p=.184). If the secondary task was performed straight through the critical situation there was a visible increase in driving errors (baseline-without interruptions: Chi²=3.596; p=.058). The highest percentage of driving errors occurred if the task had to be interrupted after it was started (baseline-interrupted: Chi²=20.748; p<.000). Evidently, the interruption of the secondary task was not successful to avoid driving errors.
5 Conclusions

Results show that drivers are able to adapt their secondary task behaviour to the situational demands. The anticipation of potential conflicts can be shown both in secondary task behaviour (task rejection or task delay) as well as in driving behaviour (lower approaching speed or preparation of proper lane positions in front of demanding situations like curves). These strategies seem to be very successful in maintaining an adequate driving safety. We observed less driving errors in critical situations when no secondary task was offered (baseline), when the secondary task was rejected or when the beginning of the task was delayed.

During the execution of a secondary task, drivers try to further adapt their behaviour to the situational development. They further reduce speed, e.g. on curvy sections and interrupt a task if the situation gets critical. In contrast to anticipative strategies, the control of situational development after the beginning of the task seems to be much more difficult. The results show that drivers who didn’t use anticipative strategies and performed the menu task straight through the critical situation, had a higher risk of driving errors, e.g. colliding with a suddenly braking preceding vehicle.

Also an interruption of ST performance was not a successful strategy in this study. In fact, the interruption of the task is an indicator of an adequate monitoring of the situational development during ST execution. But we believe that the success of this strategy is largely based on the time criticality of situations. Most situations in this study were so time-critical that an interruption of the menu navigation after starting the task could only be performed reaction-based but not anticipation-based. In less time critical situations a timely interruption of the secondary task execution should be successful to avoid negative effects on driving safety.

The still high number of executed tasks in critical situations indicates the potential problems of the interaction with in-vehicle information systems while driving. Drivers tend to perform secondary tasks also in situations where the load of the driving task is already very high and then may have problems to maintain driving safety. First of all, we explain this finding with an inadequate assessment of the situation’s potential risk. In further analyses on the influence of situation’s predictability in the study, varied by the availability of environmental cues pointing to the specific conflict, it could be shown that the less easy it was to predict the situation’s criticality the higher the number of executed tasks was in this situation. This result indicates special problems for a situationally adaptive use of in-vehicle tasks in real traffic situations with low predictability. Another explanation would be that motivation for secondary task may have been very high (drivers got rewards in the form of bonus points for every completed task; the subject with the highest number of points at the end received a gratification) despite the instruction that primary task should be prioritized (they received a deduction of points for severe driving errors, e.g. crossing the lane). For real traffic this indicates a special risk for tasks with high relevance for the driver (e.g. important job-related phone calls). Furthermore, drivers may have underestimated the associated risk of secondary tasks in general. Results from a special questionnaire on the general attitudes of the
drivers towards the use of secondary tasks while driving indicate that drivers who rated secondary tasks less distracting, rejected fewer tasks in the study.

In summary, the results show the importance of the two postulated processes of Situation Awareness for situationally adaptive interactions with IVIS while driving. The adequate situational assessment prior to ST execution is crucial to avoid overload due to the additional load of a secondary task in already demanding driving situations. Monitoring of situational development during ST execution is also necessary but much more difficult for maintaining Situation Awareness in interactions with IVIS.

The specific experimental setting, in which the driver decides whether and how to interact with a secondary task, allows a realistic assessment of driver interaction strategies with in-vehicle information systems. It permits analysis of specific compensation strategies and of their effects on driving performance and safety. Not only can possible distraction effects of an additional task be explored, but also the conscious decisions for the neglect of the driving task and their correlation to Situation Awareness.

6 Acknowledgements

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7 References


PARAMETERS RELATED TO MODELLING INTELLIGENT SPEED ADAPTATION SYSTEMS WITH THE EMPLOYMENT OF A MICROSCOPIC TRAFFIC MODEL

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ABSTRACT: This paper addresses the incorporation of intelligent speed adaptation (ISA) systems into microscopic traffic models. The suggested model is Gipps’ car-following model and the study involves the identification of the appropriate model parameters that need to be modified as well as the necessary steps towards the design of the modified model. Driver behaviour under the use of three different functionalities of ISA, namely – informative, warning and intervening – was investigated with the conduction of a driver simulator experiment. Specific parameters that would describe the implementation of the system were identified including parameters related to system operation and impact on driver behaviour. Driver behaviour as described through these parameters was also quantified to confirm the necessity of their modification or introduction into the model.

1 Introduction

Intelligent transport systems (ITS) comprise a fast developing field and are anticipated to contribute to a more sustainable road traffic network by improving road safety, traffic conditions, environmental conditions and mobility [1]. A prerequisite of their successful implementation is determining their anticipated impact which can be achieved with a variety of tools including on-road and simulator studies, laboratory experiments and simulations based on traffic/driver models. In relation to the latter tool, traffic models need to be updated to include the operation of intelligent transport systems.

In the recent years effort has been made into incorporating intelligent transport systems into traffic models. This offers the possibility of enhancing the utility of the models and the opportunities of intelligent transport system evaluation and consequently of the assessment of traffic management and road safety strategies. However, current applications mainly involve advanced traveller information systems, rather than advanced driver assistance systems, and more specifically the impact of information provision on driver route choice and consequently on road network conditions. Such examples include the traffic simulation programs AIMSUN [2], CONTRAM [3], PARAMICS [4] and VISUM [5]. In a rather different application [6] simulated the differences in lane changing and gap acceptance behaviour at congested road sections when drivers are informed of traffic incidents downstream, using the traffic simulation model SITRAS [7]. Intelligent speed adaptation has also been incorporated in
the microscopic traffic simulation model DRACULA [8]. [9]. This application however concentrates on the operation of the system itself and its representation employing model parameters rather than the representation of the impact of this operation on driver behaviour.

This study discusses the specific aspects of the impact of intelligent speed adaptation systems on driver behaviour related to driving speed (speed, acceleration and deceleration), and the possible ways of incorporating them in a traffic model. The impact of the systems on driver behaviour is elicited from the analysis of simulator data and the model used to illustrate the proposed approach is Gipps’ car-following model [10].

2 Intelligent speed adaptation simulator study

2.1 System operation

A study at the Transport Research Laboratory driver simulator to investigate driver behaviour under the use of intelligent speed adaptation (ISA) systems was conducted, and three different ISA functionalities – related to the human machine interface (HMI) were investigated: informative, warning and intervening.

A pictogram indicating the prevailing speed limit as well as its justification was transmitted through an in-vehicle screen during the informative ISA application. The operation of the warning ISA involved a tone repeated 3 times (0.5 sec on, 0.5sec off) the first time that the speed limit was exceeded and a single tone (0.5 sec) every 8 seconds that the driver was continuously exceeding the limit were transmitted. In addition, the auditory warnings were also supported by visual information of the prevailing speed limit through the in-vehicle screen. Last, the Intervening ISA did not allow the driver to adopt speeds higher than the prevailing speed limit. If the system determined that the accelerator pressure would cause the vehicle to exceed the limit, the pedal value was reduced automatically. A smooth deceleration was also applied when the vehicle was about to enter a speed limit zone with speed higher than the speed limit. The image of the prevailing speed limit was presented via the in-vehicle screen and a 0.5sec tone was transmitted, whenever the intervening functionality was triggered.

2.2 Simulation drives

Each driver made four drives, one without a system which will be referred to as “base condition” and one with each of the three ISA functionalities operating. The simulated road environment involved a 2-lane single carriageway road and consisted of rural road sections with 60mph speed limit, road sections through villages with 30mph speed limit and residential areas with 20mph speed limit. The vehicle was driving unimpeded by other vehicles (i.e. no vehicles were placed in front of it), with the exception of three different types of incidents which were simulated within the 60mph speed limit areas. The first involved an accident blocking the lane indicated by two stopped vehicles one of which was an ambulance. The driver had to overtake the stopped vehicles using the lane
of the opposite direction. The second incident involved inserting a slow-moving vehicle in-front of the simulator vehicle, and the third involved the appearance of a green dot on the vehicle windscreen at which the driver was told – prior to the drive – to react by reducing vehicle speed to 10mph. The characteristics of the drives in terms of order of incidents and systems varied both within and between drivers, so as to eliminate possible order effects.

2.3 Participant characteristics

24 participants holding a driving license were recruited from the Transport Research Laboratory database and the quota applied for their selection involved driver age, as the objective was to have a balanced sample between young/novice drivers and experienced but not elderly drivers. Following the experiment 23 drive-sets fulfilled the requirements for data processing; and the characteristics of these drivers appear in Table 1.

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<th></th>
<th>Age (years)</th>
<th>Driving experience (years)</th>
<th>Annual mileage (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>31.22</td>
<td>13.06</td>
<td>12909</td>
</tr>
<tr>
<td>Minimum</td>
<td>17.00</td>
<td>0.67</td>
<td>2000</td>
</tr>
<tr>
<td>Maximum</td>
<td>46.00</td>
<td>28.00</td>
<td>36000</td>
</tr>
<tr>
<td>St. Dev.</td>
<td>8.57</td>
<td>8.53</td>
<td>9506</td>
</tr>
</tbody>
</table>

3 Translation of implementation of Isa into traffic model parameters

3.1 Gipps’ car-following model

Gipps’ car-following model is discrete-time, continuous-space microscopic model. The model was initially intended for simulation of free-flow traffic, and hence used for simulating motorway roads, but is now being employed in various traffic simulation programs including MULTSIM [11], SIGSIM [12], AIMSUN, DRACULA and SITRAS. It is quite detailed, and there is a trade-off with the computational time, which is long by comparison with other simpler models. The variables that are calculated in each time-step are the vehicle’s speed and through this its new position. The formula that is used to calculate the “updated” speed (speed at time $t + \tau$) is:

$$u_n(t + \tau) = \min\{ u_n(t) + 2.5a_n\tau(1 - u_n(t)/V_n)(0.025 + u_n(t)/V_n)^{1/2},$$

$$b_n \tau + \sqrt{b_n^2 \tau^2 - b_n \left[2n(t) - s_{n-1} - x_n(t) - u_n(t)\tau - u_{n-1}(t)^2/b_n\right]} \} \quad (1a)$$
where

\[ u_n(t) \] speed of vehicle \( n \) at time \( t \),

\[ a_n \] maximum acceleration which the driver of vehicle \( n \) wishes to undertake,

\[ \tau \] apparent reaction time, the same constant for all vehicles,

\[ V_n \] speed at which the driver of vehicle \( n \) wishes to travel.

\[ b_n \] most severe braking that the driver of vehicle \( n \) wishes to undertake \((b_n < 0)\),

\[ x_n(t) \] location of the front of vehicle \( n \) at time \( t \),

\[ s_n \] effective size of vehicle \( n \), that is, the physical length plus a margin into which the following vehicle is not willing to intrude, even when at rest,

\[ \hat{b} \] value of \( b_{n-1} \) estimated by the driver of vehicle \( n \) who cannot know this value from direct observation.

The position of vehicle \( n \) at time \( t+\tau \) is thus calculated to be:

\[ x_n(t + \tau) = x_n(t) + 0.5[u_n(t) + u_n(t + \tau)]\tau \] (2)

The model has been calibrated with the following values: \( V_n \) sampled from a normal population \( N(20.0, 3.2^2) \) m/sec, \( s_n \) sampled from a normal population \( N(6.5, 0.3^2) \) m, \( a_n \) sampled from a normal distribution \( N(1.7, 0.3^2) \) m/sec\(^2\), \( b_n \) equated to \(-2.0 a_n\), \( \hat{b} \) minimum of \(-3.0\) and \((b_n - 3.0)/2 \) m/sec\(^2\), \( \tau \) 2/3 seconds.

3.2 Incorporation of driver behaviour under ISA into Gipps’ model

The analysis of driver behaviour within this study involves the driver behaviour parameters related to speed (i.e. speed, acceleration and deceleration) that could be introduced into Gipps’ model. Simulator data for the drives within the 60mph speed limit roads (where vehicle movement is unimpeded) is analysed, for which the threshold limit for ISA operation was set to be at 62mph.

3.2.1 Speed

First, the impact of the systems on driver speed was analysed. Mean and maximum speeds were calculated within appropriately defined periods within which drivers would have already accelerated/decelerated to their desirable speeds when entering from (or exiting to) different speed limit areas and within which vehicle movement was unimpeded, as the road sections in which drivers had to overtake due to lane closure (accident) or slow moving vehicles ahead
were not included in the analysis. Driver speed behaviour is illustrated in Table 2.

Table 2. Driver speed under the different ISA systems (mph (m/sec))

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>Informative</th>
<th>Warning</th>
<th>Intervening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>62.66 (28.01)</td>
<td>62.71 (28.04)</td>
<td>59.73 (26.70)</td>
<td>59.17 (26.45)</td>
</tr>
<tr>
<td>Variance</td>
<td>5.24^2 (2.34^2)</td>
<td>4.69^2 (2.10^2)</td>
<td>6.09^2 (2.72^2)</td>
<td>1.65^2 (0.74^2)</td>
</tr>
<tr>
<td>Maximum</td>
<td>67.13 (30.01)</td>
<td>68.73 (30.73)</td>
<td>63.97 (28.60)</td>
<td>60.38 (26.99)</td>
</tr>
<tr>
<td>Variance</td>
<td>5.01^2 (2.24^2)</td>
<td>6.87^2 (3.07^2)</td>
<td>6.45^2 (2.89^2)</td>
<td>1.00^2 (0.45^2)</td>
</tr>
</tbody>
</table>

Intelligent speed adaptation systems do affect driver speed both in terms of mean and maximum values but also in terms of deviation. Driver maximum speeds are higher than the posted speed limit, and average speeds exceed the posted speed limit at base condition and under the use of the informative system. Driving with the use of the informative system results in somewhat higher maximum speeds (in relation to the base drive); however the differences are not statistically significant (90% conf. level). Warning ISA results in considerably lower maximum speeds (statistically significant in relation to the informative system) and the intervening ISA produces the lowest maximum values (statistically significant in relation to all systems). In terms of mean speeds, the informative system produces similar ones to the base condition, whereas the warning and intervening systems produce quite lower speeds, with both being below the posted speed limit. Statistical analysis indicated that mean speeds follow a normal distribution for the base, informative and warning drives, but not for the intervening ones, which mainly involved similar speeds for the majority of the drivers with some outliers; this was expected as the speed under this system is more controlled.

The speed parameter $V_n$ in Gipps’ model involves maximum vehicle speed, which represents the speed that the driver would adopt when driving under free-flow conditions, which we shall refer to as driver desirable speed. Model dynamics are such that if there is enough empty space downstream, vehicles will eventually reach the desirable speed (assuming that the vehicle starts from being stationary) and will continue cruising at that speed if unimpeded. This concept of the desirable speed in Gipps’ model does not correspond to the driver maximum speed in the simulator experiment, as drivers only reach that speed instantly, but to driver mean speed which describes speed when vehicle movement is unimpeded. Hence, for the implementation of ISA with Gipps’ car-following model the $V_n$ parameter would take the values of mean speed and their corresponding variance, as presented in Table 2, for each of the simulated ISA systems.

### 3.2.2 Acceleration

Vehicle acceleration was also analysed in order to be used as an input in Gipps’ model. Driver maximum accelerations were recorded and averaged over the number of drivers; the results of this analysis are presented in Table 3.
Table 3. Acceleration under the different ISA systems (mph/sec (m/sec2))

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>Informative</th>
<th>Warning</th>
<th>Intervening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>7.08 (3.16)</td>
<td>6.63 (2.96)</td>
<td>7.01 (3.13)</td>
<td>6.49 (2.90)</td>
</tr>
<tr>
<td>Variance</td>
<td>4.68² (2.09²)</td>
<td>4.11² (1.84²)</td>
<td>3.44² (1.54²)</td>
<td>3.25² (1.45²)</td>
</tr>
</tbody>
</table>

Drivers employ rather similar acceleration rates with different systems as the differences are rather small (not statistically significant at 90% conf. level). Still, the trends indicate that drivers using the intervening ISA demonstrate lower acceleration rates, and considerably lower deviations, while use of the informative ISA produces the highest acceleration values. The acceleration rates between the systems, follow the same pattern as the maximum speeds (i.e. reduction with system intrusion), indicating that drivers who employ high speeds also employ high accelerations, thus driving somewhat more aggressively. Furthermore, statistical analysis indicated that accelerations follow a normal distribution only for the base condition and informative ISA drive. This can be attributed to two reasons (a) small sample size and (b) more controlled behaviour with the increase of system intrusion.

The acceleration parameter used in Gipps’ model is $a_n$ and denotes the maximum acceleration that the driver wishes to undertake. Model dynamics can be described as follows [13]: a stationary vehicle that starts to move has an acceleration of $0.3953 a_n$ and continues moving towards $V_n$ with increasing acceleration up to the point where speed is $\frac{0.95}{3} V_n$. It then continues increasing its speed towards $V_n$ with lower acceleration. The evolution of vehicle speed as recorded from the simulator experiment data was somewhat different. Vehicles demonstrated higher acceleration rates, when their speed was lower than $\frac{0.95}{3} V_n$. Hence, the maximum recorded acceleration does not correspond to the model parameter. For this reason, a modified acceleration was calculated which is the maximum acceleration that was recorded from the time-step after which vehicle speed exceeded $\frac{0.95}{3} V_n$ (where $V_n$ the driver desirable speed as calculated in Section 4.2.1). The resulting accelerations are presented in Table 4.

Table 4. Modified acceleration under the different ISA systems (mph/sec (m/sec2))

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>Informative</th>
<th>Warning</th>
<th>Intervening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>4.62 (2.06)</td>
<td>4.98 (2.23)</td>
<td>5.00 (2.24)</td>
<td>4.41 (1.97)</td>
</tr>
<tr>
<td>Variance</td>
<td>2.38² (1.06²)</td>
<td>2.39² (1.07²)</td>
<td>2.14² (0.96²)</td>
<td>1.21² (0.54²)</td>
</tr>
</tbody>
</table>
Modified maximum accelerations are substantially lower than the maximum ones (Table 3), as drivers employ high accelerations at lower speeds. These differences were found to be statistically significant for all systems except for the informative one. In addition, accelerations at base condition and under the informative system follow a normal distribution.

The incorporation of the ISA acceleration in Gipps’ model involves testing which one of the two estimated maximum acceleration values (a) the maximum acceleration (Table 3) or (b) the modified maximum acceleration (Table 4) at base condition produces better model results and then using the corresponding values for the simulation of the different ISA systems.

### 3.2.3 Deceleration

To estimate maximum driver decelerations driver behaviour was investigated in all 60mph road sections, including those containing slow moving vehicles ahead, road closure and stimulus appearance at the windscreen to which the drivers were asked to react by reducing their speed to 10mph.

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>Informative</th>
<th>Warning</th>
<th>Intervening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>-16.18 (-7.24)</td>
<td>-15.44 (-6.90)</td>
<td>-16.40 (-7.33)</td>
<td>-15.65 (-6.99)</td>
</tr>
<tr>
<td>Variance</td>
<td>2.93² (1.31²)</td>
<td>2.71² (1.21²)</td>
<td>2.83² (1.26²)</td>
<td>2.63² (1.17²)</td>
</tr>
</tbody>
</table>

Driver decelerations appear to be rather similar between the different ISA systems, and do not follow similar patterns as driver speed or acceleration. Driving under the informative system involves somewhat lower and driving under the warning system somewhat higher deceleration values. The calculated deviations are also similar.

In Gipps’ model there are two parameters involving deceleration: one is the maximum deceleration that the driver wishes to undertake \( b_n = -2.0 \alpha_n \) and the second is the maximum deceleration of the vehicle in-front as perceived by each driver \( \hat{b} \) minimum of -3.0 and \( (b_n -3.0)/2 \). The observed decelerations (Table 5) are greater than those calculated by the formulae proposed by Gipps. Deceleration in Gipps’ model is applied when the movement of the simulated vehicle is impeded by that of a vehicle in front. It has been found that in the case of sudden braking by the preceding vehicle the required deceleration to avoid a crash can be higher than the vehicle’s desired braking or the perceived deceleration for the preceding vehicle [13]. Hence, the values presented in Table 5, indicate more extreme deceleration than the ones represented by parameters \( b_n \) and \( \hat{b} \), and subsequently the deceleration parameters used in the model shall follow model rules and should be provided by the calibration formulae that Gipps has defined.

As in this study driver behaviour within a 60mph road section is investigated, the operation of the intervening ISA involving the application of smooth deceleration values when entering a road section of a lower speed limit with higher speed, does not apply. It should be noted however, that in the case of
different speed limit areas driver deceleration should take a fixed value (that applied by the system) rather than being calculated from the model formulae.

4 Discussion

Intelligent speed adaptation systems affect several aspects of driver behaviour and their impact varies in relation to the different system HMI functionalities. The impact depends on the degree of intrusion of the system on the driving task. In particular, driving speeds, both in terms of maximum and average values, decrease with ISA systems, and this reduction increases with the degree of system intrusion. The same pattern is observed with the values of driver maximum acceleration; however the differences between systems are considerable lower. Driver maximum deceleration is also slightly affected by the use of the systems, but no clear pattern emerges from the observations.

The elicited differences between the systems should be introduced in traffic models, through appropriate parameters. Initially this seems to be a simple task, but in reality attention should be paid into the (a) the actual meaning of the model parameters; for example maximum speed in the model corresponds to average speed as calculated from the observations, (b) other parameter assumptions; such as parameter distributions, and (c) the calibration of the model with the new proposed values, as model dynamics may be valid with somewhat different values than the observed ones.

Future work on this topic involves the investigation of the use of ISA on other parameters including driver reaction time and vehicle effective size, and ways to incorporate their impact into Gipps’ model, as well as ISA impact in 30mph and 20mph roads. Following that, the use of ISA will be incorporated in a traffic model to investigate ISA impact on network conditions.

5 Acknowledgement

The authors are grateful to the European Commission who provided support for this research and the Transport Research Laboratory for the collaboration during the driver simulator experiment.

6 References


SESSION 4: TOOLS AND METHODOLOGIES FOR ITS DESIGN AND DRIVERS AWARENESS
A SERVICE-ORIENTED SYSTEM ARCHITECTURE FOR THE HUMAN CENTERED DESIGN OF INTELLIGENT TRANSPORTATION SYSTEMS

Jan Gačnik, Oliver Häger, Marco Hannibal (DLR, Germany)

ABSTRACT: The requirements of modern advanced driver assistance systems (ADAS) imply not only technical challenges but also create the need of a human centered development approach, which is necessary to create a unique and useful assistance. A human centered approach itself has high requirements for the technical systems in use, flexible functional development is necessary, features and concepts change quickly. On the other hand, the prototype systems need to be reliable to maintain safe experiments, especially when these experiments are being deducted in a car in a real-world traffic situation. The approach of the Institute of Transportation Systems, German Aerospace Center (DLR-FS), provides a way to maintain a safe but flexible development process using service-orientated architecture (SOA) techniques.

1 Introduction and motivation

The introduction and development of modern intelligent transportation systems (ITS) require a human-centered development approach. This is due to the high degree of automation which enters modern cars, making it necessary to find correct ways to assist the driver in his driving-related and non-driving-related tasks. To achieve this, technical prototypes not only need to be designed with the human-centered approach, but also need to be evaluated at all stages in the development process, as early as possible. These continuous evaluations are necessary to be able to integrate the new knowledge into the next prototyping iteration. This involves simulation and real-world traffic studies.

The institute operates the research vehicle ViewCar® to analyse drivers’ behaviour in real traffic situations, determine causes for driver errors, and conclude in concepts for new assistance systems. Virtual reality laboratories can be used to evaluate driver assistance functions at an early concept stage and to observe driver behaviour in controlled scenarios, so that also rare or dangerous situations may be analysed. Prototype systems can later be evaluated in a motion based driving simulator, creating a higher degree of realism. Finally these prototype systems can be evaluated in real traffic using a specially equipped research car (FASCar). This is equipped with state-of-research sensors and actuators making it possible to perform autonomous and semi-autonomous driving (assisted driving).

To be able to handle the different requirements that these different types of infrastructure and the corresponding development focus impose, a special system architecture needs to be defined to support the human-centered development process in the best way possible.
2 Concept

2.1 Requirements for a system architecture

The special requirements that the human-centered development process imposes are founded in the heterogeneity of the requirements during the development process itself. Figure 1 visualizes these requirements, in the case of the DLR facilities.

The advantage of a simulation is the ability to reproduce certain, specific traffic situations and to deduce experiments without risking accidents. This is especially important for the assessment of new safety-critical systems. Designing a system for the simulator needs to be flexible in the first place; changes in the HMI design or the functionality itself need to be easily possible. To rapidly evaluate visual HMI displays, tools like RaScal and CoEDiT have been developed in the DLR-FS [1].

In an advanced stage of the development the same system will be transferred from the simulation into a real car. For those experiments in real traffic, other aspects become very important for the design of a system architecture. The major requirement in real world traffic experiments is safety, which normally can be neglected in a simulated environment. Up to today only few special requirements for safety of automotive systems exist, compared to the aerospace and railway sector. But the upcoming ISO 26262 (Road vehicles – Functional safety) [2, 3] will define automotive safety-integrity-levels (ASIL), similar to those in the railway sector. These definitions will have restrictions for the development process and system architecture and therefore also delivering a frame for the functions, sensor and actuator configurations.
A way needs to be found to support the developer in the best way possible to support developing cross-platform (and cross-requirement) applications, aiming to achieve a developer centered process, supporting him in creating driver-centered applications.

### 2.2 System architecture concept

The technical system architecture itself consists of two aspects, software and hardware architecture. In this paper we will focus on the software aspects, because this part is present in both the simulation and the real car. Hardware architecture is also addressed by this approach but the resulting hardware architecture is merely a result of an optimization process. It is a combination of fulfilling a certain functional quality (functional requirements) at a given acceptable failure level (safety requirements), minimizing economical costs.

Software modules in a vehicle, as well as in a corresponding simulation, are modeled as part of a distributed system, offering services to other modules (and to the driver in the end). The system uses a hierarchic model (figure 2) aggregating services in domains and providing tree-like structure for domain data.

![Fig.2. Domain model containing services](image)

In a domain, services fulfill certain tasks. These tasks can be a recognise-act cycle or a control loop, depending on the domain. Meta-information describes a service itself and also the data being exchanged between the modules. All services, their requirements and orchestration, as well as the domain data models are described formally using an XML scheme. This description can be edited using a GUI based application. The formal description allows not only creating different views on the system or parts of it, but also establishes a very high degree of portability as most of the platform dependent code can be easily generated from it.

From a computer science viewpoint, the software architecture concept has many similarities with service-oriented architecture (SOA) concepts [4, 5], today often used in modern web applications. One basic idea is the separation of functional code and formal interface description, including functional and non-
functional requirements. Similar as proposed in the rich component model (RCM) concept [6], a service offers certain functionality and information with a certain quality and failure rate (promises). On the other hand, another service might need this functionality and information for its own operation (demands). The meta-information regarding the service’s reliability can be used online or offline for analysis, optimization and verification.

To be able to handle safety-critical services as well as more flexible applications, different runtime environments (RTE) are used. Furthermore, dependent on the target platform and the requirements static or dynamic data models are provided. The system is capable to manage different types of RTE and data models simultaneously, introducing scalable dynamics of the RTE as a design option.

Due to requirements from safety standards, safety-critical services are implemented in a very static environment. The code generation process encapsulates the access to static data on electronic control units (ECUs). Administrative services, including inter-service operation and control, are very lightweight on such systems.

Unlike safety-critical services, higher-level services need a more dynamic environment. This applies for infotainment services, car-to-mobile communications, or even assistance systems that support a traffic participant beyond single transportation systems - mobility assistance. Like in conventional SOA approaches, services can be physically distributed among the system. The concept of loose coupling [7] is realized by an encapsulated IO interface that provides the system communication. Once a service is created, other services can reuse this service and its output data for further purposes.

Furthermore, to provide the specified system behaviour within the scope of a defined system status, a runtime administration concept is part of the architecture. Therefore services are being registered during system initialisation (or if possible during runtime) at the domain master controller (DMC). This controller guarantees the correct execution of participating services. The DMC is able to revive services which are in an undefined state. The observation of given system resources allows system reorganisation by redistribution of services, for example, in the case of resource breakdown. Of course, due to hardware restrictions (e.g., actuator control) in some domains this functionality can only be provided for the dynamic parts of the system.

The whole development process for driver assistance services is an iterative workflow consisting of the following steps:

- Specifications and requirements for new ADAS functions are gathered from the conclusions of ViewCar® studies, but also from literature and ideas or experiences from earlier developments.
- Even without programming skills, a service can be described and specified. The required data can be modeled by a scientist using a GUI application, which handles XML schemes.
- The service’s functionality is implemented by an engineer following the given specification in a programming language suiting the specific domain (C/C++, SCADE, MATLAB/SIMULINK etc.).

- An automated process provides the availability of the service in all facilities. This is done via code-generation from the formal XML scheme, creating the needed view on data, depending on the target RTE.

- Furthermore, the new service is tested and parametrised in its environment.

- The system is being evaluated, possibly resulting in a further refinement or new ideas for ADAS.

The process is visualized in Figure 3.

Because of the very versatile description of services and modeling of data, not only driver assistance systems can be developed with this approach, but also simulation modules. These services include modules like vehicle dynamics simulation and traffic simulation as well as 3D graphics and sound.

## 3 Evaluation

### 3.1 Concept implementation

A first prototype of the architecture concept was implemented. This includes most parts of the different RTEs. As services, all modules of the simulation were integrated using this concept, as well as some driver assistance functions, like an adaptive cruise control (ACC).

### 3.2 Sample ADAS prototype: ACC

The functional behaviour of an ACC system and its requirements is well-known and standardised [8, 9]. A custom ACC version was developed within the scope of this project, serving as the base functionality for new adaptive ACC prototypes which will be developed at DLR-FS. The new versions include, among others, an ACC that is adapting to the current traffic density [10]. These prototypes will change the behaviour of distance and speed controllers. The base ACC is available in the simulators and the real car.
3.3 ACC realisation

Following the idea of service definitions, the classic ACC itself consists of multiple reusable services which offer longitudinal control over the vehicle. These services were realised according to the architecture concept and development process (figure 3). In the case of ACC the functional requirements are mostly standardised. From these requirements several services could be identified (speed control, distance control and the corresponding HMI) and formally described using the XML scheme. Afterwards the service implementation was done. Figure 4 depicts the identified services and their domains.

The first ACC prototype was developed for the simulator, evaluating the basic functionality. The next step was the functionality test in a real car on a test track, thus making migration and parameter fitting very easy. The final step was the use of the same function in a more robust, safe and static RTE within the car, for test drives deducted in real traffic. The development of the basic longitudinal control was a good case study for the evaluation of the interoperability between different research facilities. During the development the architecture concept served its purpose very well and confirmed its suitability. Because most of DLR’s infrastructure itself is part of research projects, changes in the facilities occur very often. This includes the change of hardware parts (ECUs, sensors, actuators) as well as software parts. Due to the formal specification of services, all of these changes could be made with minimal impact on the ACC development. Once an application programming interface (API) in the simulator changed or a new ECU was available in the FASCar, a change within a single template file of the code generator resolved all dependencies.

In further ADAS development the already developed services will be reused to support new services. For example, as mentioned earlier, a traffic density awareness service will directly influence the behaviour of the distance and speed control of the vehicle.
4 Conclusions and Outlook

In this paper we presented a concept for a system architecture with SOA aspects. It provides an integrated approach for the human-centered development process of ADAS. By redefining the ACC in the form of services, the suitability could be demonstrated in a proof of concept implementation with the major focus on the interoperability of different laboratories of the DLR.

The next steps will include further refinement of the architecture, when more ADAS will be implemented. Safety-critical functions, like a collision-avoidance system, might require hardware redundancy concepts, meeting safety standards. Other scenarios like the integration of car-to-mobile and car-to-car communications will be used to extend and demonstrate the more dynamic parts of the architecture, including management of reconfigurable services, aiming at supporting individualised assistance systems and vehicle-independent mobility assistance. Furthermore the integration of specialised industry tools will be evaluated, especially for certifiable development of safety-critical applications.

5 References

1 Introduction

The driving task has become more difficult because the driver has to manage increasing traffic complexity on the road and various onboard systems integrated in modern vehicles. The designer of new systems has to take into account the variability and the multiplicity of parameters concerned in order to design systems where the cooperation with the driver and the distribution between these various tasks will respect the context of use. It is important to consider the interaction between the human and the machine in a dynamic environment such as the automotive domain in order to reduce human and system errors during the design process. Cacciabue and Hollnagel [1] make a review of main existing driver models. For these authors the most useful models for the analysis and the design are the models correlated with the paradigms of the vehicle and the environment (Driver-Vehicle-Environment: DVE). However, the authors specify that to use and select the adequate model, a preliminary analysis needs to be carried out to define the various objectives in terms of system design and evaluation. Consequently, designers need an analytical framework that enables understanding interaction problems with respect to domain specific parameters. Generally, models are too precise or are too targeted on the description of specific interactions or particular driving behaviours. These models do not provide a general analysis framework and an overall picture of the problem but give a specific answer to a clearly defined objective.

During the Global Energy management and driver Interface for a Citizen Optimal driving behaviour (GERICO) project a preliminary analysis was done using a specific framework to understand correctly the domain activity in order to specify the design and the evaluation of a new eco-driving system. The goal of this project was to contribute to the reduction of fuel consumption and CO2 production by optimising on-board energy and designing an appropriate interface that enables the driver to adopt the best driving behaviour, smooth speed and appropriate gear management. A framework adapted from the AUTOS pyramid [2] was used to perform the preliminary analysis. This
framework called “DRIVENTS” includes some existing models to explain some behaviours or specific interactions in the automotive domain. Using this framework, the designer can see the interactions between the agents of the domain studied and especially the links between these agents in order to understand and define the relevance of each one in the design and the evaluation of the human-machine interaction.

In this paper we present the DRIVENTS framework adopted to analyse the automotive domain. According to this analysis, we defined the objectives in terms of human-machine cooperation in order to select the adequate requirements for system design and evaluation. Analysing the domain activity (e.g. automotive domain) allows to take into account dynamic and contextual parameters and associated concepts. This approach considers that the analysis of the domain activity was used as a base to define the design model of the system in order to improve driving performance, comfort and safety of the driver.

2 Automotive domain analysis : DRIVENT framework

The DRIVENT framework (Fig.1) enables four main agents to connect in the automotive domain: the DRIver, the Vehicle and onboard systems, the ENvironment and the driving Task/activity. Each agent was defined by some characteristics. Drivers, and more generally humans, are characterized by the variability of their behaviour (inter-individual and intra-individual variance). In this sense, several factors can influence driver behaviour and are variable for each driver. Personal factors play a fundamental role in the driving activity: age, sex, driving experience, social attitudes, cognitive capacities or handicap. Situational factors depend on the driver’s psychological state at a given time. These factors are fatigue, motivation, stress, vigilance and emotions for example. The road environment is variable and complex and can be characterised by three principal components to define the road context: traffic conditions, climatic conditions and road infrastructure. The tasks and the activity represent the primary driving task and the secondary tasks associated (e.g. radio, phone…). Lastly, the vehicle can be characterised according to its type (4x4, compact…), its onboard systems and more generally by all its characteristics (weight, engine…). The analysis of the various relations between these four agents during the design process is multidirectional in the sense that each entity influences the other or involves specific relations that the designer has to consider in the automotive domain before the system specification.

![Fig.1. DRIVENT Framework](attachment:fig1.png)
Driver ↔ Tasks: There are three interconnected levels proposed by Michon to define the driving task [3]: operational, tactical and strategical. The operational level is related to vehicle control and concerns very short-term actions (this level can be defined as skill-based according to the Rasmussen terminology). The tactical level is related to vehicle guidance and concerns short-term actions (rule-based). The strategical level is related to itinerary-following and concerns long-term actions (knowledge-based). Moreover, two other tasks were carried out by the driver during the driving activity. The tasks of driving indicators management (speedometer, engine, oil…) and the secondary tasks that correspond to manage different instruments like the radio, the onboard computer, the navigation system, but also instruments added in the vehicle cockpit such as the mobile phone for example. These systems are not essential for the driving task and provide information which should not disturb it. These different tasks involve the mobilisation of drivers’ cognitive resources. Humans have limited capacities or limited attention resources. Driver attention corresponds to cognitive processes: as perception, access in memory, reasoning, control, decision-making, and actions [4]. The driver must share his/her attention and mobilize resources between these various tasks. The process of time-sharing represents the driver’s capacity to maintain this attention between the various processes necessary to make the decisions and provide the adequate actions. Applied to the previous driving task analysis the driver must share these cognitive processes between five tasks, resulting in the limitation of available resources. These concepts are important for the designer because the addition of new onboard systems can increase the mobilisation of the drivers’ cognitive resources.

Tasks ↔ Vehicle: The driver interacts with the vehicle via the controls and with the various onboard systems that form an integral part of the vehicle. The driver is responsible for the management of these various systems. In some situations, this can result in a possible overload according to the contexts of use. The workload generated by the accumulation of tasks can have an impact on driver performance. Thus, it is important that the designer of new systems makes sure that operator workload is maintained on an acceptable level. Independent systems integrated in the vehicle can generate interferences with the driving tasks and can be an important source of distraction. Indeed, in double task situations, interference or competition for the resources between concurrent tasks need to be taken into account by the designer. According to Wickens [5], two tasks that share the same requirements of resources will be carried out in time-sharing with less effectiveness than two tasks that do not overlap. Thus, the designer has to select appropriate inputs/outputs and manage the role and priority of the different tasks to avoid possible coverings.

Driver ↔ Environment: Situation awareness is defined by Endsley [6] as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future”. Endsley defines three dependent hierarchical levels preceding decision-making and the action in dynamic situations: perception, comprehension and projection. Endsley’s model is influenced by the external factors of the task such as systems which can influence situation awareness from their interface, interaction level, complexity, and by individual factors specific to each person, such as experience or training. The designer has to
develop the system to reduce or to improve the impact on driver situation awareness. The driver is responsible for his/her mobility and his/her environmental impact on pollution, traffic or on the other road users. According to this point of view, the social interaction in the automotive domain is also a factor where the good citizenship of the driver plays an important role. For this reason, the interactions between the drivers are an integral part of the driving activity and can explain some driving behaviour. Onboard systems can have an impact on the improvement or the deterioration of the relation between the various agents of the environment. For example, the use of mobile phones or navigation systems can modify the driver performance (deceleration, approximate trajectory) and consequently impact on the other road users.

   ➢ **Driver ↔ Vehicle:** The link between the driver and the vehicle can be seen in two ways: the first is the direct interaction with vehicle controls and onboard systems and the second is the relation between the driver and his/her vehicle, for example paying more attention in town to avoid small collisions or on regular maintenance to reduce the risk of breakdowns. These types of behaviour can be considered safer while the opposite can contribute to increasing unsafe driving behaviour. The vehicle gives sensory feedback indications to the driver on acceleration, deceleration or the aspect of the road for example. This information is necessary to provide the driver with driving sensation. The concept of driving sensation can also be considered according to the vehicle type. The driving behaviour will be different if the driver has a sports or a city vehicle. Thus, it is necessary to take into account the driver/vehicle couple and the relation that exists between them to study and to understand some driving behaviour.

   ➢ **Environment ↔ Tasks:** The driver analyses environmental situations and takes adequate actions according to a given context. The environment can generate specific interactions and modify the task and the activity of the driver. The driver will react consequently while adapting to the external conditions such as climatic or traffic condition for example. This type of interaction is more a direct perception-action cycle and can correspond to the driver’s automated responses. We can take the example of an emergency action in a very short time like emergency braking or obstacle avoidance.

   ➢ **Environment ↔ Vehicle:** The relation between the vehicle and the environment can be seen by physical interactions (tires for example) but also by some onboard systems which communicate with the environment (electronic pricing or GPS). In the near future, it will be important for the designer to consider the possibilities of communication between the environment and the vehicle, generally called “Car to Infrastructure Communication” and communication between vehicles called “Car to Car communication”.

3 **System design analysis : DRIVENTS framework**

At the first stage of the analysis, four agents and their main relations were defined by the DRIVENT framework for the automotive domain. In the second stage, the DRIVENTS framework purposed to show the relations and the concepts linked to the integration of a new system in the vehicle in order to
define the requirements for the system design and evaluation (Fig.2). The designer has to take into account the different agents to have a clear understanding of different parameters and variables involved in these relations.

Fig.2. DRIVENTS Framework

The DRIVENTS framework (Table.1) resumes the different concepts coming from the DRIVENT analysis and the concepts used to design a new system to cooperate with the driver, the driving activity, the vehicle and the environment.

Table 1. DRIVENTS matrix (Top-down lecture)

<table>
<thead>
<tr>
<th>Driver</th>
<th>Vehicle</th>
<th>Environment</th>
<th>Task/activity</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver</td>
<td>Dri</td>
<td>Driving</td>
<td>Situation</td>
<td>Cognitive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>sensation</td>
<td>awareness</td>
<td>resources</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mobilisation</td>
</tr>
<tr>
<td>Vehicle</td>
<td>Relational aspects</td>
<td>V</td>
<td>Communication Infrastructure</td>
<td>Vehicle &amp; on board systems management</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Integration</td>
</tr>
<tr>
<td>Environment</td>
<td>Social aspects</td>
<td>Mechanical interactions</td>
<td>En</td>
<td>Situated actions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Interaction &amp; communication</td>
</tr>
<tr>
<td>Task/activity</td>
<td>Task &amp; activity analysis</td>
<td>Role &amp; priority</td>
<td>Reaction</td>
<td>T</td>
</tr>
<tr>
<td>System</td>
<td>Interaction</td>
<td>Coordination</td>
<td>Contextualisation</td>
<td>Training</td>
</tr>
</tbody>
</table>

The DRIVENTS matrix shows the different parameters involved to design a new system such as integration, coordination, contextualisation, training, prescribed tasks, interface and interaction that the designer has to consider to improve the human-machine integration according to the concepts defined in the DRIVENT preliminary analysis, e.g. with respect to the agents of the automotive domain. In this chapter, we give an overview of different parameters that we took in consideration for the design of an eco-driving system in relation with the different concepts defined in the DRIVENTS framework.

- **Eco driving system principle**: The goal of the eco-driving system was to change the driving task to reduce fuel consumption. The GERICO system
interacts with the other agents defined in the DRIVENT framework. The relation existing between them was modelled to describe agent interactions (Fig.3). The system developed was based on a partial analysis of the environment and did not determine and anticipate all road situations. Indeed, the automation of some system functions was not an optimal solution to aid the driver in his/her driving task. The system only provides information and warning to assist the driver that keeps the control of the vehicle. The principal problem in the interaction was the choice between intrusiveness/severity of the system to keep an optimal driving performance and a good acceptability for the comfort and safety of the driver.

![Fig.3. Agents interactions](image)

The system provides prescribed tasks via an HMI to reduce fuel consumption with respect to contextual and dynamic constraints of the automotive domain. A global optimisation algorithm takes into account the environmental data via the navigation system (road type, topography, traffic), and internal data from on-board computers (fuel injection, engine speed). This algorithm processes these data to provide the driver with an economic driving pattern (prescribed tasks) for a given trip (Fig.4).

![Fig.4. GERICO principle](image)
System ↔ Tasks: In the analysis of the eco-driving principles, the speed and gear management were two main factors to be considered for the reduction of fuel consumption. Consequently, the Eco-driving system provides prescribed tasks, e.g. optimal speed and gear advices, to the driver. Some information concerning eco-driving activity will not be provided by the system (for example optimal acceleration or deceleration). The system will aid the driver for some driving tasks but other tasks will be entirely performed by the driver to adapt his/her driving activity in some situations. In this sense, it is human-machine cooperation with an allocation of the cognitive functions between the system and the driver. However, the driver remains the person in charge of the human-machine couple to adopt the best eco-driving activity with respect to the road context. We can consider that the first impact of the system was on the operational level because the system provides information influencing directly the control of the vehicle (speed and gear advice) and consequently influences the other levels. These changes were considered during the design process and observed during evaluations. The social impact of this system was also important to consider. This system acts on the “driving style” and tries to change driver habits. From this perspective, the driver’s motivation to use the system is crucial. Consequently, system usefulness needs to be demonstrated in terms of fuel consumption reduction, as well as usability and acceptability.

System ↔ Driver: The driver interacts with the system via a specific interface. The ergonomic questions concerning the interface are important to facilitate the human-machine interaction. For Norman [7, p61] “User-centred design emphasizes that the purpose of the system is to serve the user ... The needs of the users should dominate the design of the interface, and the needs of the interface should dominate the design of the rest of the system”. Thus, the interface of the system was developed using many guidelines such as ISO (International Standards Organisation), AAM (Alliance of Automobile Manufacturers) guidelines and so on, a user-centred and participatory design approach during the design process to improve perceived complexity and affordance of the system with respect to driver needs in order to avoid human errors and dysfunction of the “Human-Machine coupling”.

Fig.5. GERICO instrument cluster view
A multimodal interface [8] was developed based on the analysis of the possible interferences with the driving task. Four types of information were provided by
the system with two modalities: Navigation (visual and auditory), Assistance (auditory), Advice (visual and auditory) and Warning (visual and auditory). All visual information was proposed via an instrument cluster design (Fig.5). The auditory information was implemented in addition to the visual modality to provide information to the driver. This modality enables better information management to avoid excessive workload in visual perception that can generate disturbances at the level of the main driving task.

➢ **System ↔ Environment:** Dey [9, p4] gives the following definition of the context: “context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application including the user and applications themselves”. This author defines that “a system is context-aware if it uses the context to provide relevant information and/or services to the user, where relevancy depends on the user’s task” [9, p5]. Thus the designer has to take into account as well as possible the situational parameters of the road context during the driving activity such as climatic conditions, traffic conditions, infrastructure and specific events that can occur on the road. Consequently, optimal advices, warning and assistances information are contextualised with respect to the road context. The system developed diagnoses some driving activities and determines the mode of interaction and the most adequate type of information in the situational context. Even if we send the right information, the way it is delivered is as important as the information itself. Information sent to the driver has to be useful and well synchronised with the car’s position and driving context (essentially road topography and infrastructure). For example, the system provides limited information in town due to driver workload and cognitive resources mobilisation. Moreover, anticipation of situations can improve driving performance to reduce pollution as well as safety. Thus, the system provides assistance information to anticipate some elements of the road infrastructure such as right of way, dangerous curves and zones limited to 30 km/h for example.

The Interaction Control System (ICS) was developed to provide the driver with visual information (optimal speed and gear advices) and vocal messages with respect to road context in order to reduce cognitive interferences, risk and human errors. A multi-agent model was used [10], based on cognitive function analysis, to define the structure of the ICS (Fig. 6). The ICS includes several specific agents that take into account internal and external parameters involved in the driving task. Agents are involved in Driving Activity Assessment (DAAs), in Driving Activity Analysis (DAAAn), in Environment Assessment (EA) and in Multimodal Management (MM). DAAs agents control the driving activity (speed, gear and pedals), DAAAn agents compare the global driving activity with the optimal driving pattern, EA agents analyse the road context and MM agents manage visual and auditory information provided to the driver.
Tools and methodologies for ITS design and drivers awareness

![Diagram of Interaction Control System architecture](image)

**System ↔ Vehicle:** The system integration was controlled in function of the technological limits of the vehicle and onboard systems integrated. The system developed needs resources from other systems (vehicle and GPS data). It was necessary to set up communication and reliable coordination in order to manage the roles and the priorities with the other systems. Information was provided to the driver via the LCD (liquid crystal display) instrument cluster (fig.5) and vocal messages via the vehicle radio.

### 4 Conclusion

This paper presented the “DRIVENTS” framework used to analyse the driving activity context during the design process of a new eco-driving system. This framework enables the specification of the design of the system with respect to the agents involved in the automotive domain. This framework can associate a systemic approach to the problem and an anthropocentric approach. It can be used for a simple system or a complex system in order to improve comfort, performance and safety. Moreover this framework was used to identify and define variables for the system evaluation [11]. The framework showed that different driver’s factors can be influenced by the addition of new systems in the vehicle such as workload, situation awareness, time-sharing, cognitive interference and mobilisation. The questions concerning ergonomic, communication, interaction or interface aspects need to be resolved with respect to the driver’s needs in order to reduce the influence of the new system on the agents in the automotive domain defined in the DRIVENT framework. Finally, during the design process, the designer has to verify as well as possible that all points were considered and evaluated to improve the system design in order to obtain the best human-machine cooperation with respect to the context of use.
5 References


AN ANALYSIS OF THE REQUIREMENTS OF DRIVER ASSISTANCE SYSTEMS – WHEN AND WHY DOES THE DRIVER LIKE TO HAVE ASSISTANCE AND HOW CAN THIS ASSISTANCE BE DESIGNED?

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ABSTRACT: The development of Advanced Driver Assistance Systems (ADAS) strongly depends on engineering prospects [1]. In addition to that, users’ needs are a basic prerequisite in the development process of ADAS to increase users’ acceptance [2, 3]. The two main goals when developing ADAS are increasing driving safety and comfort [4]. But what are additional motives for the usage of ADAS? Within a focus group 12 experienced drivers (four women, eight men) discussed why and in which critical driving situations the driver would like to be assisted. Seven motives were identified: driving safety, comfort, speediness, flexibility, driving pleasure, health, and saving of costs. Driving safety, comfort, and driving pleasure are the core motives for “good” driving. The study gives indications that besides driving safety and comfort there are other motives which have to be considered or can be potential starting points for the development of novel ADAS.

1 Background

Traditionally, the development of Advanced Driver Assistance Systems (ADAS) strongly depends on technical possibilities [1]. The driver often does not have an active role in the development of such systems. Consequently, there are many ADAS technologies available on the market which are not readily adapted to the needs of the driver. According to Kollmann [5], not every system that is technically possible ensures success in the users’ acceptance and in sale. Therefore, not every driving task which can be supported technically by ADAS has to be implemented on a system. In addition to the technical limits, the needs of the user are also a basic prerequisite in the development process. A product like an ADAS is accepted and demanded from the driver, when both the user’s need exists and the product is adapted to that need [2]. According to INVENT, involving potential users in earlier stages of development ensures close connection to the requirement and acceptance of systems [6]. Thus, when developing ADAS the driver should be involved early in the development process, e.g. in assessing driver needs for ADAS.

Increasing driving safety and comfort are the main goals when developing ADAS [4]. The task of ADAS is to support or relieve the driver in “normal” driving, e.g. with navigation and speed control, but also to support or counteract mistakes of the driver when they lead to an accident, e.g. ESP and ACC [4].
The question is, whether there are other criteria in addition to driving safety and comfort which should be followed when developing ADAS. To answer this question, the general aim of this study is to determine additional factors that influence the driver in the driving situation and are therefore important for the driver during driving. According to Fuller's “Task-Capability Interface model of the driving process (TCI)”, driving is defined as “the management of task difficulty” [7, p. 48]. Certain factors influence whether the driver has a driving situation under control: Driving is the interaction between (1) the demand of the driving task to achieve a safe outcome and (2) the capability applied during the task (0).

The “task demands” (D) are the objective parts of driving and contain features of the environment, the driving behavior of other road users, and the characteristics of the vehicle, like its speed and road position. The task demands represent the dynamic element in the model. The “capability” (C), which is the subjective part, contains the driver’s limit of competence his or her skills. These competences are, e.g. control skills, hazard detection, recognition, anticipatory, and defensive driving skills. The capability refers to “what the driver [...] is able to do at any given moment” [7, p. 49]. It indicates the momentary ability of the driver to deliver his or her level of competences. Consequently, the competence sets the limit on capability. But the capability is also determined by a range of factors, e.g. fatigue, emotion, alcohol and other kinds of drugs, stress, and distraction.

The model (0) shows that the control of the driving situation develops based on the task demands and the momentary driver’s capability. When the capability exceeds the task demands (C>D), the driver has control about the driving situation and s/he will manage the driving task. The driver will consider the driving task as easy and probably boring. When the task demands exceed the capability (D>C), the driver will consider the driving task as difficult.

Fig.1. The Task-Capability Interface model [7]
capability is beyond the scope of the driver’s competence to manage the task demands of the driving situation. The result is losing control which may result in a crash. But also when the capability equals the task demands (C=D), the driver can perceive the driving task as stressful or annoying [7].

Thus, one driving situation, in which ADAS can provide assistance, are situations where the task demands exceed or are clearly below the driver’s ability. Developing assistance systems to support drivers in these situations might lead to a decrease of drivers’ strain and an increase in comfort resulting in an increase in drivers’ safety.

The aim of this study was to find out what is important for the driver during driving and why s/he would like to be assisted. The study was also designed to determine driving situations – with regard to the purpose of the journey, and physical and environmental conditions – that the driver evaluates as difficult and where s/he would like to be assisted. This study focuses on driving situations in which the driver is unable to manage the situation with his or her momentary driving skills (C<D). The need for driver assistance should be indicated by difficult driving situations (1\textsuperscript{st} step). The study should also indicate how assistance systems could be designed in those driving situations to support the driver (2\textsuperscript{nd} step).

To get this information, a focus group was chosen. This method gives a first and wide review about the opinions, values, attitudes, and conflicts of the participants, in a relatively fast and economic way [8]. A focus group is one of the methods that can be used to investigate users’ needs, especially for assistance systems [3]. It provides an insight into up to now unknown or less structured areas under investigation [8], like the development of novel ADAS. A focus group enables people “to ponder, reflect, and listen to experiences and opinions of others. This interaction helps participants compare their own personal reality to that of others” [9, p. 17]. Thus, the requirements of the participants according to ADAS can be pointed out.

2 Method

Twelve experienced drivers, four women and eight men, aged between 25 and 47 years (mean= 36.3, sd= 7.5) discussed the requirements of ADAS within a focus group. They focused on driving situations in which they would like to be assisted and why they would like to have this driving assistance. Furthermore, the discussion sought to identify how the assistance could be designed. Novice drivers and drivers over 50 years were excluded to increase the homogeneity of the subject group.

The discussion was conducted at the German Aerospace Center (DLR) in Braunschweig. It was recorded by a camera and in writing. The timeframe was three hours. The discussion was conducted on the basis of a discussion guide that outlines the concept of the discussion in addition to a “warming-up” and a “final” phase. The concept and the central issues of the focus group are shown in 0. The concept was visualized through the metaplan board.
The approach of the focus group is based on three phases. These phases address the three central issues of the study (0). The first phase – “means of transportation” – addresses the central issue how the driver would like to be assisted. Existing means of transportation ought to provide information about, how the assistance can be designed. It contains, e.g. someone driving for you (e.g. taxi), others driving with you (e.g. bus, train), or others helping during the driving (e.g. co-driver, driving instructor). Compared to driving alone, driving with companions includes persons who assist or make the driving pleasant. It represents a potential approach which can be compared with driver assistance. In the second phase – “motives” – the goal is to determine the advantages and benefits of these collected means of transportation that the driver would like to have in his or her own car. The second phase represents the core module of the focus group. It ought to answer the central question why the driver would like to have assistance. Consequently, the motives provide information about, what is important for the driver. The motives show which needs for driver assistance potentially exist and where the development of ADAS should start. The third phase – “purpose of the journey, physical and environmental conditions” – ought to address the central issue when the driver would like to be assisted. In this phase difficult driving situations are mentioned and the needs for driver assistance will be specified. The third phase is subdivided into three categories: (a) purpose of the journey, (b) physical conditions, and (c) environmental conditions. The purpose of the journey represents the definite reason for driving. According to Benda [10], the purpose of the journey distinguishes between driving to work, running errands, driving in leisure time, and going on vacation. The physical and environmental conditions are according to Fuller [7] the factors of capability and task demands that influence the driving situation, e.g. tiredness and stress of the driver or weather conditions, other road users, vehicles, or road signs.

3 Results

The focus group was transliterated by camera and protocol. The spoken words with participant number were transliterated. This transcript provided the basis of
the interpretation of the data according to the three central issues (0). The interpretation occurred reductively, which means that the quantity of the data was reduced with the goal to gain some compact statements [8]. The interpretation occurred according to the concept of the focus group (0). For the analysis, the statements are considered in terms of the group and not in terms of a single participant [8].

The phase “motives” is the basis for the interpretation of the statements. The number of statements regarding the motives is put into parentheses. The mentioned “means of transportation” point out whereby the assistance can be compared. They will also be named in parentheses. The discussion showed that regarding the “purpose of the journey”, the participants referred to the motives. This general aspect reflects approaches why the driver would like to be assisted at different purposes of driving. According to the specific aspects of driving – “physical and environmental conditions” –, the connection to the motives could not be shown in the discussion. In fact, the participants described system properties of assistance systems in special driving situations. In this paper only the difficult driving situations due to environmental conditions are described.

According to the participants, seven motives out of 112 statements are important for “good” driving (0a). The most important motives are driving safety (36 statements) and comfort (31 statements). In addition to them, the participants mentioned speediness (13 statements), flexibility (6 statements), driving pleasure (6 statements), health (5 statements), and saving of costs (4 statements). The terms of the motives were deduced from the statements of the participants. In this paper we focus on the five motives mentioned most frequently.

(a)  
(b)  

Fig.3. (a) Number of statements in regard to the motives of the requirements of ADAS. (b) Frequency of ADAS addressing the motives driving safety and comfort, divided into environment, other road users, and road.

The motive “driving safety” is considered most important. It is divided into safety with regard to the vehicle and to the driver. The vehicle itself constitutes safety due to the crush zone (e.g. bus, plane). Safety also means to have safe road contact, e.g. on black ice. Driving safety with regard to the driver consists of his or her skills and competences. The participants award the pilot, the bus driver, and the driving instructor the highest competences. Especially, the taxi driver
gets the highest skills in driving situations where the driver is unable to drive due to alcohol or has to drive in an unknown town. Getting feedback about the knowledge of the traffic rules, such as from the driving instructor, is also accepted by the larger part of the participants. Thus, driving safety does not exist when the driver is unable to cope with the driving task. On the one hand this can be a consequence of environmental conditions (e.g. rain, fog), on the other hand due to physical and mental impairment of the driver’s skills (e.g. lack of knowledge about the route). For the development of driver assistance systems, it means that the task of ADAS should be to increase driving safety, but not just by reacting to environmental conditions. Increasing driving safety by ADAS also means the support of the driver and the improvement of the vehicle (e.g. crush zone).

“Driving comfort” focuses on the convenience during driving (e.g. in bus, train, plane, metro, taxi). It would be most desirable that the driver is relieved of the driving task, so the journey time can be used for other things, e.g. the passenger can relax or prepare work. Driving comfort also means to reach the destination with the lowest amount of stress as possible (e.g. in train, rickshaw). When developing ADAS, the systems should contribute to the well-being of the driver, so that driving becomes stress-free, relaxing, and exonerative. These two motives are so important in driving that they are postulated for every purpose of journey – driving to work, running errands, driving in leisure time, or going on vacation.

“Speediness” entails the needs to reach the destination fast, on time, and reliably (e.g. bicycle, metro and over ground in town; car in country side). Especially, this motive is desired on the navigation level when driving with a deadline, e.g. driving to work, to the doctor, or to the theatre. If speediness cannot be provided, driver assistance at the navigation level is useful to make the driving fast and reliably.

“Flexibility” is very relevant in routing. Dropping the search of parking places represents flexibility for the driver (e.g. bicycle, motor cycle). This motive is especially desired in driving to work and going on vacation. On the one hand the driver enjoys mobility, on the other hand s/he wants to increase his or her individuality. Assistance systems should not restrict the driver in his or her manner of driving and in routing.

Additionally, according to the participants, driving is evaluated as “good” when driving is fun (e.g. bicycle, motor cycle, rickshaw, riding a horse). “Driving pleasure” is a basic motive, like driving safety and comfort, which is mentioned independently of the purpose of the journey. Thus, ADAS should not restrict the driving pleasure or reduce the driver’s activity. Driving should be active and suspenseful for the driver, so that a “positive” driving feeling is maintained.

With regard to the physical and mental conditions of the driver, assistance systems are desired when the driver is mainly stressed, tired, overstrained or unchallenged through the driving task, distracted, surprised, aggressive, frustrated, appalled, and alcoholised. These conditions strain the driver. ADAS should avoid these physical conditions and should open up possibilities to counteract them.
According to the environmental conditions, the participants did not refer to the motives. They described system properties of driver assistance systems in special driving situations. There was no association to the motives mentioned, but the mentioned driver assistance systems reflect the motives driving safety and comfort (0b).

0b shows the number of desired approaches of assistance systems in driving situations the driver evaluates as difficult. The situations are divided into three conditions: environment, other road users, and road. In the focus group for almost every mentioned driving situation, the participants gave an approach of assistance systems that are desired in that situation.

Out of 24 mentioned driving situations, 22 desired approaches of assistance systems described the aim to improve the driving safety and comfort. 0b shows that more assistance systems (AS) are mentioned that increase driving safety (18 approaches of AS), compared to comfort (4 approaches of AS). Especially, driving safety (13 approaches of AS) is desired in situations characterized through the environment, e.g. weather conditions, time of day, or temperature. The same is shown in the category “road user”, e.g. traffic flow and traffic density (3 approaches of AS of driving safety and 1 approach of AS of comfort). In the category “road” (e.g. road network, road surface) in each motive two assistance systems are described that aim at providing driving safety or comfort.

According to the results of the category "environment", the driver would like to be assisted in weather conditions like rain, snow, fog, and sun (7 of 13 approaches of AS for increasing driving safety) and darkness (6 of 13 approaches of AS). Especially, the reduced detection of the road and of the traffic in front, due to fog or darkness, are evaluated as difficult. The bad visibility and thus the reduced orientation on the road overstrain the driver. The direct glares due to the sun or its reflection in other vehicles are also mentioned as difficult. It constrains the driver in his or her manner of driving. Another critical driving situation is seen in the slip hazard on black ice or on snow-covered and watery roads. In all these situations, the driver desires a driving assistance system which clarifies the driver’s view and provides a safe road contact of the vehicle (“an assistance system that shows on the basis of arrowhead the course of the road” VP 311; an assistance system that informs the driver about the current weather conditions” VP 040). In the focus group the sudden appearance of wild game at night is also evaluated as critical and in need of assistance. In those driving situations, the driver desires an assistance system with anticipatory perception of wild game and warning of the driver. In regard to the driving at night, one participant mentioned the desire of an assistance system that drives autonomous, so the driver will be relieved (1 approach of AS for increasing comfort).

According to the results of the category “road user”, the participants evaluate driving with low traffic flow or traffic density as comfortable (“you feel free, … you do not feel so hemmed in” VP 231). But in low traffic density in combination with bad visibility conditions (e.g. due to rain, fog, darkness), the driver would like to be assisted by a system that supports the driver’s view and relieves him/her (1 of 3 approaches of AS for increasing driving safety). Driving safety is also desired in driving situations with traffic jam or a sudden braking vehicle in
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front (2 of 3 approaches of AS). The driver desires assistance systems that warn him/her about those unexpected situations. But in traffic jam, the driver would also like to be assisted by stop and go to make the driving more comfortable (1 approach of AS for increasing driving comfort). Drivers desire an assistance system that controls the driving task completely ("so you do not have to put the foot the whole time on the clutch" VP 231).

According to the results of the category "road", a bad road quality (e.g. cobble streets, loose chippings streets) is seen as a risky driving situation (2 approaches of AS for increasing driving safety). Automated driving assistance systems, which interfere appropriately regarding the conditions of the road surface, are desired so the car is not running off the road. Besides the automated lateral control, automated assistance is also desired in regard to braking so that a safe braking is provided by the assistance system. Driving in an environment with a high number of traffic signs is seen as risky, too. In the view of the participants, it leads to excessive demands of the driver (2 approaches of AS for increasing comfort). Especially, when the routes are unknown, this type of driver overload is mentioned. A driving assistance is needed that reduces this excessive demand. The assistance system should perceive the traffic signs and inform the driver about the current driving situations.

Table.1 gives an overview about the mentioned approaches of ADAS in driving situations due to environment, other road users, and road.
Table 1. Overview about the desired approaches of ADAS in critical driving situations due to environmental conditions

<table>
<thead>
<tr>
<th>Environmental Conditions</th>
<th>Driving Situation</th>
<th>Task of ADAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>rain, snow, fog, and</td>
<td>reduced detection of the road and of the traffic in</td>
<td>- Clarifying the driver’s view (S)</td>
</tr>
<tr>
<td>darkness, sun</td>
<td>front</td>
<td>- Informing the driver about the current weather conditions and the course</td>
</tr>
<tr>
<td>snow, rain</td>
<td>direct glares, reflection in other vehicles</td>
<td>of the road (S)</td>
</tr>
<tr>
<td>darkness</td>
<td>slip hazard on black ice or snow-covered and watery</td>
<td>- Providing a safe road contact of the vehicle (S)</td>
</tr>
<tr>
<td></td>
<td>roads</td>
<td>- Autonomous driving (darkness) (C)</td>
</tr>
<tr>
<td></td>
<td>wild game</td>
<td>- Anticipatory perception of wild game and warning the driver (S)</td>
</tr>
<tr>
<td>Road User</td>
<td></td>
<td></td>
</tr>
<tr>
<td>traffic density</td>
<td>low traffic density in combination with bad weather</td>
<td>- Clarifying the driver’s view (S)</td>
</tr>
<tr>
<td></td>
<td>conditions (e.g. rain)</td>
<td></td>
</tr>
<tr>
<td>traffic flow</td>
<td>(unexpected) traffic jam</td>
<td>- Warning the driver about the traffic jam (S)</td>
</tr>
<tr>
<td>and density</td>
<td></td>
<td>- Automated stop and go driving (C)</td>
</tr>
<tr>
<td>other road users</td>
<td>sudden braking vehicle in front</td>
<td>- Warning the driver about the braking (S)</td>
</tr>
<tr>
<td>Road</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road surface</td>
<td>bad road quality (e.g. cobble streets, loose chippings</td>
<td>- Automated interfering appropriately regarding the conditions of the road</td>
</tr>
<tr>
<td></td>
<td>streets)</td>
<td>surface (S)</td>
</tr>
<tr>
<td>Road network</td>
<td>high number of traffic signs</td>
<td>- Perceiving the traffic signs and informing the driver about the current</td>
</tr>
<tr>
<td></td>
<td></td>
<td>driving situations (C)</td>
</tr>
</tbody>
</table>

S= approaches of ADAS for increasing driving safety; C= approaches of ADAS for increasing driving comfort

4 Discussion and Conclusion

The focus group shows that “good” driving involves different criteria. In addition to the traditional criteria of driving safety and comfort, there are other criteria like speediness, flexibility, and driving pleasure that are also important for “good” driving. When these criteria are fulfilled, the driver will perceive driving as optimal. However, when some criteria are not fulfilled in different driving situations, these criteria can be starting points for the development of ADAS.

The focus group confirmed the results of Timpe [4] that the two most important criteria for the driver and thus for the requirements of ADAS are driving safety and comfort. Both are desired in every kind of journey. The discussion shows that especially driving safety contains not only aspects of environmental conditions; also the driver and the vehicle influence the safety of driving. Although in the discussion a connection to the motives was not made according to the “physical and environmental conditions”, the mentioned approaches of assistance systems reflect the two motives. The approaches show that especially the desire for driving safety is shown in driving situations characterized through the environment (e.g. weather conditions or darkness;
and through other road users, e.g. traffic jam or a sudden braking vehicle in front). Besides safe driving, comfortable driving is also important for the driver. The discussion shows that assistance systems should not restrict the driving pleasure. It is a core motive of “good” driving and is desired in every kind of journey. The criteria speediness and flexibility are special motives that are desired in driving to work and going on vacation. For that purpose, driving should be as fast and as on-time as possible, with a routing that is adapted individually to the driver.

The focus group is an established method for the investigation of users’ requirements, especially for assistance systems [3]. But a general problem of a focus group is the incomplete amount of data [8]. Because of the discussion situation, the individual opinions and attitudes of every participant cannot be investigated. In this regard, the subjective data motives of the participants can just be assumed from the investigator. Other problems of the method are opinion leaders and socially desired answers [8]. Because of the group situation, participants may not dare to say their opinions. In following studies the method should be extended, e.g. with interviews or standardized questionnaires. The weakness of the sample is the small number of participants (N= 12). Thus, the results cannot be generalized and should be handled with care. But a focus group is a perfect method for the generation of ideas and for quickly gauging user opinions about a topic, like the requirements of ADAS [3, 8]. The review about the drivers’ attitudes is useful for further research. Thus, in following studies a higher number of focus groups should be conducted, so that more representative data is available.

The study showed how experienced drivers can contribute to the development of ADAS. The focus group showed the focus of requirements of driver assistance systems and the different approaches when ADAS are desired. ADAS should not only be designed according to external influencing factors of the driving task like environment. The systems should also take into account both the physical conditions of the driver and the vehicle. It is important that assistance systems contribute to driving safety and comfort. But driving pleasure is another important criterion which is desired from the driver in every driving situation. Speediness and flexibility are very situational motives for driver assistance. However, these could also be possible starting points when developing novel driver assistance systems. The focus group focused on the long-term aspects for the requirements of ADAS in driving. An additional aspect, which could be put into focus, is the short-term aspect – the driving maneuvers. By this, it could be examined which driving maneuvers are seen as difficult. Such a group discussion could reveal in which driving situations driving assistance is desired from the driver and why it is desired.

5 References


A HUMAN FACTOR-BASED APPROACH FOR THE EFFECTIVE USE OF DRIVING SIMULATORS AND E-LEARNING TOOLS IN DRIVER TRAINING AND EDUCATION

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ABSTRACT: The present state of driving simulator technology makes it possible to implement driver training applications with a growing level of complexity and fidelity to real driving conditions. However, driving simulators only become an effective tool in driver training if they are effectively included as an integral part of the training curriculum. Such integration requires a methodical approach as well as a detailed analysis of the training curriculum, the learning goals and training needs. This paper presents the results of Humanist Task Force G regarding a definition of a human factor-based approach for the effective use of technology in training taking into account cognitive aspects, as well the special needs and requirements of the training process for different target groups: novice drivers, professional drivers, elderly drivers, and disabled drivers. Methodological conditions for enhancing the acquisition of different levels of driving abilities and for using new technologies as a tool of performance measurement are discussed.

1 General framework for driver training

It is generally accepted that driver training must include a theoretical and a practical component, which ideally should enable the student to acquire the required abilities to master the driving task by means of an abstract approach and through practical training by driving in a real vehicle in real traffic.

Driver training curricula are based on theoretical assumptions about driver behaviour and the driving task. A common premise is that driver behaviour is organised in three hierarchical levels – strategic, tactical and operational – as described by Keskinen [2], building on previous work by Michon [2,3]. Based on this work, the European project GADGET described the issues relevant for driver training and in particular training of novice drivers in order to provide a theoretical framework to define and cover the areas of competences that driver training and education need to address [4]. This project provided the basis for developing the Goals for Driver Education (GDE) framework.

The GDE-framework comprises two dimensions. The first dimension includes the three hierarchical levels mentioned above. A fourth level concerning “goals for life and skills for living” was added. It refers to personal motives and tendencies in a broader perspective than simply conducting the driving task. This level is based on the assumption that lifestyle, social background, gender, age, income, etc. have an influence on attitudes, driving behaviour and accident involvement.
In addition to the four levels of driver behaviour, the GDE-framework operates with another dimension constituted by three goals for training: knowledge and skill, risk-increasing factors, and skills for self-assessment. These dimensions all relate to behaviour at the different levels thus influencing both driving preconditions as well as the accomplishment and execution of the driving task.

The knowledge and skill level refers to the skills a driver needs for driving under different circumstances.

Risk-increasing factors deal with aspects of driving or traffic that may increase the risk, such as perception of the traffic situation, speed adjustment, and risk acceptance.

The skills for self-assessment refer to the driver's capability to assess his performance on the four behavioural levels. It really points to critical self-adjustments of everything from skills in vehicle handling to a reflection of individual risk attitudes.

Ideally, driver training curriculum should cover all the areas of the framework and address the appropriate driving behaviour associated with them [5]. However, traditional driver training typically only covers the last two levels of behaviour (vehicle manoeuvring and mastery of traffic situations). Similarly, at the goal dimension level only the first level of knowledge and skills is included and risk increasing factors are covered to a lesser extent in existing training programs. The third level is rarely encountered during driver training.

2 Target groups

2.1 Novice drivers

Novice drivers need to acquire both theoretical and practical skills as well as knowledge at all levels of the GDE-framework.

Novice drivers are the group with the highest accident risk. Fatality rates for 18 to 24-year old drivers (number of driver fatalities per million age group) in industrialised countries are about the double of those of experienced drivers (aged 25 to 54). During the first years after having passed the driving test, the accident risk declines sharply. Several studies have found that the accident risk decreases rapidly during the first years of driving experience. However, it takes about 7 years of driving experience before the accident risk reaches an acceptable, low level [6].

In-depth accident analysis of crashes involving young novice drivers has revealed that it is not so much a lack of basic driving skills that has caused the accident, but a lack of so-called higher order skills. These skills deal with risk perception, risk acceptance, self-assessment, the motivation to drive safely, etc. Young drivers tend to misinterpret traffic situations and show an inefficient visual search. Furthermore, they have difficulties in adapting their speed and driving distance to the driving conditions [7]. They also tend to underestimate the risk of a hazard resulting in an accident and overestimate their ability to deal with hazards [8].
There are indications that simulator training helps to speed up the learning process, although at present the knowledge on transfer and retention of the skills acquired during simulator training is insufficient to assess its effects on the performance of the drivers after the training period [9].

2.2 Professional drivers

Professional drivers typically undergo training in handling difficult driving manoeuvres and driving special vehicles or goods. Simulators have been developed for both research and training of professional drivers. Already in 1958 the Iowa State driving simulator linked a vehicle cabin mock-up to a scaled physical terrain model allowing the driver to control actions in a rudimentary road layout. Since then there have been many different technical innovations including videos of real scenes and, more recently, computer generated environments. At present, several European countries employ truck driving simulators as part of in-service training.

Brock et al. studied the effects of training with three types of simulators that are often used in the US to retrain experienced drivers: an open-loop video simulator, a low-end simulator, and a mid-range simulator [10]. The use of simulation decreased trainee drop-out rates by 35% for an agency using the midlevel simulator, decreased student failure rates by 50% in an agency using the open-loop and the low-end simulators, and decreased the collision rate by 10% in an agency using a combination of open-loop and low-end simulators. In addition, the use of simulation reduced training time in one agency from 19 days to 17 days by replacing classroom bus training with simulator training. In another agency using only the open-loop system, training time was reduced by 5 days when simulation was employed.

Strayer and Drews conducted an experiment with professional drivers who spent 2 hours in a simulator learning shifting strategies in order to maximise fuel efficiency [11]. The participants’ fuel consumption performance when driving their normal route in their own vehicles was monitored for 6 months. Training increased fuel efficiency by an average of 2.8% over the six-month interval. Drivers who drove not specifically simulated vehicles in the training sessions were also found to improve their performance after training.

In the UK, Parkes and Reed conducted a longitudinal cohort study that sought to provide an analysis of the benefits of synthetic training in the area of fuel efficiency improvement [12]. 36 drivers received training designed to improve their driving style in a range of traffic situations in a truck simulator. During each simulator visit, apparent fuel consumption figures were recorded and compared to real-world fuel consumption records for the same drivers. In addition and over the same period, fuel consumption data were obtained for a matched cohort of drivers who did not attend the training. The mean change in fuel efficiency observed of the drivers in the simulator group showed an improvement of 15.7 % in their on-road performance.

These results suggest that simulators can be effectively used to improve specific driving skills in experienced drivers.
2.3 Elderly and disabled drivers

Similarly, training groups of elderly or disabled drivers would have to implement different approaches such as focusing on the functional awareness of their abilities and limitations and adapting their driving behaviour accordingly without exposing them to the risks of real traffic.

Roenker et al. (2003) designed a study to examine if a speed-of-processing training can improve at-risk older adults’ driving performance. Training transfer and retention were assessed in an on-road driving evaluation immediately after training and 18 months after training. Simulator training resulted in an improvement in the specific driving manoeuvre skills that were expressively practiced during training. However, those effects were mostly temporary, and dissipated at the 18-month follow-up [13].

Disabled drivers are typically trained in order to identify functional weaknesses, i.e., not for the purposes of training per se but rather to be able to identify the driving conditions in which they would encounter difficulties. In this context simulators can be of great use in helping the subjects to gain functional awareness of their abilities and to adapt their driving behaviour to them without being exposed to the risks of real traffic [14].

Akinwuntan et al. designed a study to test the effectiveness of simulator training in heart stroke patients [15]. Eighty-three first-ever subacute stroke patients entered a 5-week 15-hour training program in which they were randomly allocated to either an experimental (simulator-based training) group or a control (driving-related cognitive tasks) group. Simulator-based driving training improved driving ability, especially for well educated and less disabled stroke patients. However, the findings of the study may have been modified as a result of the large number of dropouts and the possibility of some neurological recovery unrelated to training.

Simulation can also be a useful tool for assessing drivers with disabilities. Driving aids could be simulated so that drivers could test them together with the assessor in a safe artificial environment.

3 Including simulators in the training curriculum

Driving simulator technology makes it possible to implement driver training applications with a growing level of complexity and fidelity to real driving conditions. Driving simulators only become an effective tool in drivers’ training if they are effectively incorporated as an integral part of the training curriculum. Such integration requires a methodical approach and a detailed analysis of the training curriculum, the learning goals and training needs [16].

A simulator is an abstraction of reality, and many aspects cannot be reproduced with sufficient detail or realism. The term fidelity refers to how closely the simulation imitates reality. From an educational point of view the learning goals determine the required level of fidelity. Limited fidelity restricts the range of tasks or task aspects that can be trained in the simulator.

Slick et al. found that transfer of training from simulated environments to the real world was maximized when training is characterized by a high degree of
both physical and psychological fidelity [17]. Nevertheless, some research results indicate that higher fidelity does not always improve the training results [18]. Beginning trainees could be overwhelmed by the complexity of the real system and environment and may, therefore, sometimes be better served by a simplified, lower fidelity simulation [19]. More experienced trainees, however, would learn more from a high-fidelity simulation [20].

### 3.1 Basic vehicle handling skills

Simulators can be used for training in the first steps of vehicle handling. The advantages are related to safety - trainees would be able to learn these skills without endangering themselves or other road users - and to environmental preservation since the use of simulators instead of practice on a motor vehicle eliminates the pollutant emissions created by the latter.

Trainees should learn to recognise or experience closely the risk-increasing aspects of the tasks, especially underestimation of speed. By enabling trainees to evaluate their skills in a realistic way, they will learn to compare their estimates with the real outcome.

### 3.2 Cognitive aspects and decision process

Novice drivers lack perceptual skills and anticipation in traffic. On the one hand they do not use peripheral vision, and on the other hand they underestimate the time needed for many manoeuvring tasks such as overtaking, merging, lane changing, reaching an intersection, stopping, and turning. They have problems estimating the behaviour of other road users as well, i.e. how much time these drivers need to perform the tasks mentioned above. When an unexpected and unusual situation does occur, they do not know how to react adequately.

Recent developments in software make it possible that drivers in a simulator can learn to behave in very realistic way. Automatic Traffic Generation and Autonomous Driver models reproduce the circumstances in real traffic and enable users to repeat and therefore train certain tasks in changing environments, with varying risk, and different road users, with variable behaviour. These devices facilitates training of anticipatory skills, like risk or hazard perception, which are highlighted by recent research as very important for safe driving [21].

The main advantages of simulators compared with real driving are that trainees can experience scenarios which are too dangerous to create on the road, and that they can train cognitive skills without fully automated manoeuvring skills.

In order to increase driving skills without increasing excessively the self-confidence of the trainees, the manoeuvring component should not be overemphasised. It is preferable that the training process includes demonstrations and exercises in which novice drivers may fail in order to develop a realistic self-evaluation of their capabilities. Additionally, trainees should be given comprehensive feedback on their attitudes, risk perception and personal tendencies during training. Self-assessment tools like questionnaires and scales, discussions with other trainees about personal experiences and
evaluations made by instructors or examiners seem to be appropriate educational methods.

In a simulator trainees will better experience the harmful influence of factors such as stress and mood on driving behaviour, and how drivers can cope with these risk-increasing aspects.

### 3.3 Training of higher order skills

Training of higher order skills included in the GDE-matrix would mean that the present driver training should extend the theoretical and practical training curriculum to areas including confrontation with difficult or risky situations or with situations where the drivers’ attitudes (motivations, representations and emotions) are challenged.

However, the sequencing for the acquisition of higher order skills is important. Higher order skills are primarily integrated through experience and not solely obtained through education or training. They should be introduced in training after the trainee completes the skill-and-knowledge based levels.

Groeger casts some doubts on the usefulness of driver simulators for the acquisition of higher order skills [22]. Simulators make it possible to structure driver training and to introduce mass repetition of skill drills. Laboratory experiments have shown that mass repetition of partial tasks helps speeding up the learning process; but retention is lower. This is in particular the case when subjects have to conclude from the context what skills have to be applied. Therefore, in Groeger’s opinion, associative learning during many hours behind the wheel under varying conditions with an experienced driver next to the learner driver is a better way of acquiring higher order skills than structured simulator training in a reduced environment.

Falkmer and Gregersen [23] conducted an experiment to assess the effectiveness of hazard perception training with simulators in Sweden. Driving school learners received multimedia training on PC’s and subsequently simulator training focused on hazard perception and risk acceptance in addition to their driving lessons. A limited positive effect was observed when using a simulator with a 120° screen view angle and simple movement feedback. When a very simple simulator (40° view angle and no feedback) was used, the simulator training had absolutely no effect on the hazard perception and risk acceptance by these driving school learners.

These results indicate that the potential of driver simulators for the acquisition of higher order skills is limited.

### 4 Conditions for an effective use of simulators in driver education

Training effectiveness depends on the degree to which trainees are able to apply the knowledge, skills, and attitudes gained in a training context to the real context. This means that training is effective when transfer of training is achieved, and the value of a training device is determined by the degree of
learning and transfer that occurs. Barnard et al. [24] defined the following forms of transfer:

- **Positive transfer**: Extent to which trainees have acquired knowledge, skills and attitudes, which can be applied effectively in work practice.
- **Negative transfer**: Extent to which an undesired effect occurs after following a course.
- **Far transfer**: Transfer when the initial learning task and the subsequent tasks to be learned differ substantially.
- **Near transfer**: Transfer when the initial learning task and the subsequent tasks to be learned differ only slightly or not at all.
- **General transfer**: The trainee acquired certain working methods, knowledge and skills, which can be used in tasks other than the original learning task.
- **Specific transfer**: The learning task is so specific that no transfer can be expected to other tasks, but only to the same task.

The main goal of driver training is to achieve positive transfer: the things learned in the simulator should be transferred to the real-life driving task. At the same time it is important to avoid negative transfer. With simulators this is a possible risk, as the technical driving task is certainly not the same as in a real car, especially with relatively simple simulators. Perceptive tasks are also different. For example, the perception of speed and distance is different compared with real driving.

Although specific transfer is not a problem in itself - the trainee only needs to transfer the learned driving task to a driving task in the real environment - general transfer is desired when it concerns traffic insight. The traffic situations encountered in the simulator should be generalised to other traffic situations [25].

Despite their prevalent use, there still exists a lack of evaluation studies to provide evidence on the effectiveness of driving simulators in driver training. Humanist Task Force G has synthesised the existing experience on the effectiveness of simulators as an educational tool [26]. It was found that at present there is not enough knowledge on transfer and retention of the skills that are acquired during simulator training to assess its effects on the performance of the drivers after the training period. Nevertheless, existing research provides indications of the potential efficiency of simulators and e-learning with respect to improving some aspects of driver training [27].

The following recommendations for effective use of simulators in driver training and education were formulated as a conclusion of Humanist TFG work.

### 4.1 Novice drivers

Simulator-based training scenarios and instruction program should provide:

- A valid environment for practicing the necessary skills.
- Clear goals and contents for training.
• Enough feedback to improve behaviour and to learn.
• A possibility to gain enough experience.
• A learning period long enough to commit the skills and knowledge learned to memory, and a learning climate favourable to safety.

It is recommended to extend the curricula in order to cover all the levels of the GDE-framework. Trainees should learn to know or better experience the risk-increasing aspects of the tasks, especially underestimation of speed. In order to enable trainees to evaluate their skills in a realistic way, it should be possible for them to compare their estimates with the real outcome.

In order to increase driving skills without excessively increasing the trainees’ self-confidence, the manoeuvring component should not be overemphasised. It is preferable that the training process should include demonstrations and exercises in which novice drivers may fail so that they may develop a realistic self-evaluation of their capabilities.

Training of novice drivers should include instruction on the proper and safe use of ITS devices. Discussion and work groups combined with simulator and multimedia training might be appropriate methods to make novice drivers aware of specific problems in connection with the use of ITS.

4.2 Professional drivers

Training safe driving strategies can only be successful if driver training covers motivational and self-evaluative aspects. Trainees should be given comprehensive feedback on their attitudes, risk perception and personal tendencies during training.

Physical fidelity is not a sufficient precondition for optimal training effects. For the training of certain skills (e.g. hazard perception) simulations with lower fidelity (e.g. video scenes) can be efficient training tools.

4.3 Elderly and disabled drivers

Retraining of disabled older drivers requires the development of specific scenarios based on their particular needs.

Simulation can also be a useful tool for the assessment of drivers with disabilities. Driving aids could be simulated so that drivers could test them together with the assessor in a safe artificial environment.

5 Further research

As a conclusion of the analytical review of driver training and education process conducted by Humanist Task Force G, research needs were identified in the following areas [28]:

a) Pedagogical and didactical components
   • Development of effective training curricula (activities, sequence of activities, scenarios etc) including simulator-based training particularly
design for the needs of specific target groups including novice, experienced, professional, elderly and impaired drivers.

- Guidelines for the role of the trainer and his task in the simulator training process.
- Criteria for the selection of training media (classroom, slide show, mechanical devices, computer, e-learning, simulation, real driving, etc.) for different training activities.
- Assessment of the effectiveness of using simulators for the acquisition of higher order skills such as risk perception, and the retention of skills acquired through simulator training.

b) Technological aspects

- Technical specifications defining the minimum conditions required for a simulator in order to be suitable for use at the different levels of driver training applications.
- Development of a framework for converting vehicle performance data into usable training feedback for the driver.
- Development of a driver performance monitoring tool to assess the driver's decisions and actions in specific driving situations in real time.
- Development of an advanced traffic model to produce a realistic traffic environment around the learner.
- Techniques to avoid simulator induced sickness.

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COMPARATIVE EVALUATION OF TRAINING METHODS IN IMPROVING DRIVERS’ UNDERSTANDING ABOUT THE FUNCTIONALITIES AND POTENTIAL LIMITATIONS OF ADAS

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ABSTRACT: A common study was undertaken to evaluate the effectiveness as regards knowledge acquisition of three different methodologies for drivers’ training on new in-vehicle technologies, a standard paper manual, a multimedia software tool and a driving simulator. 93 persons from three countries were assigned to three groups, the first being trained on four systems by a paper manual, the second group being trained by a software tool and the third being trained by a software tool and acquiring practical experience of the system on a driving simulator. The analysis focused on the correctness of answers given by the participants on multiple-choice questions. The software group answered better than the other groups in one of the four systems (Lane Departure Warning), but no clear effect of the additional training via the simulator was found. However, people trained with the software and the simulator feel better trained than the rest. Based on the analysis performed, we can conclude that the use of software tools and driving simulators for training drivers in the use of new assistance systems should be further explored.

1 Introduction

1.1 Background

Within Task Force F of the HUMANIST project a new methodology for training all drivers on the use of new in-vehicle assistance systems has been developed [1,2]. The work has focused on the use of information technology for this training, thus a multimedia training tool (MMT) and specific scenarios for a driving simulator have been realised, the latter aiming to acquaint the driver with operational specificities of in-vehicle assistance systems.

The assumption is that the use of MMT for training in in-vehicle assistance systems and the users’ familiarisation with such systems in a driving simulator will improve the users’ knowledge on in-vehicle assistance systems potential benefits and limitations [2,3]. It is supposed that drivers usually do not read detailed manuals and hence, if such a structured curriculum does not exist, they may misinterpret the in-vehicle assistance systems functionality which may even result in adverse safety effects, i.e. due to overconfidence in the system or due to risk homeostasis effects. These potential effects have been analysed in detail in ADVISORS project Deliverable 3/8.1 [4].
1.2 Objectives of the study

A common study was performed by three partners of the HUMANIST Consortium, CERTH, IBSR/BIVV and VTI. The objective of the study was to evaluate the effectiveness of three training/learning methods in improving drivers’ understanding about the functionalities and potential limitations of Advanced Driver Assistance Systems (ADAS), In-vehicle Information Systems (IVICS) and Driving Support Systems (DSS).

The three training methods that were tested are training/learning by:

- Group A: reading a paper manual,
- Group B: using a specific developed multimedia training tool (MMT),
- Group C: using the MMT in addition to hand-on experience of each system.

By comparing the first two groups, one can identify differences between a simple manual and the MMT. By comparing the second and third group, one can identify the effect of a simulator compared to the use of an MMT only. The simulator can not be used as stand-alone training method, as its aim is only to emphasise the limitations of each system and not to demonstrate all of its functionalities.

Four systems have been chosen for consideration [5].

<table>
<thead>
<tr>
<th>System</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptive Cruise Control (ACC)</td>
<td>ADAS</td>
</tr>
<tr>
<td>Lane Departure Warning (LDW)</td>
<td>ADAS</td>
</tr>
<tr>
<td>Navigation system &amp; Route Guidance</td>
<td>IVICS</td>
</tr>
<tr>
<td>Anti-lock braking system (ABS)</td>
<td>DSS</td>
</tr>
</tbody>
</table>

2 Method

2.1 Experimental design

The independent variable was, the training method used, with three levels (A: training by reading manual, B: training by using the multimedia training tool, C: training by using the multimedia training tool and providing in addition hand-on experience). For each training method, all the above mentioned systems were learned. Providing that, training by reading a manual constitutes the existing standard training method, this condition was considered as reference (control condition) for the evaluation of the second condition. Comparison between second and third condition allowed reviewing any effects caused by the use of the driving simulator.
2.2 Participants

93 drivers from three countries, 33 from Greece, 30 from Sweden and 30 from Belgium, were randomly assigned in the three experimental conditions, balancing between gender. Subjects were found through advertisements and calls. The selection strategy was random selection of novice drivers (having had a driving license for less than three years), who had at least a sufficient level of English understanding, trying to have equal men and women drivers in each group. The sample can be considered as representative of the novice drivers population as far as gender is concerned. The sample size is rather small, and this was due to time and resources limitations, thus the results presented in the following sections should be considered as indicative.

The characteristics per group are given below.

Table 2. Participants’ sample

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean Age (years)</th>
<th>Male</th>
<th>Female</th>
<th>Mean driving experience (years)</th>
<th>Mean Annual Mileage (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group C</td>
<td>27.26</td>
<td>15</td>
<td>16</td>
<td>7.77</td>
<td>9984</td>
</tr>
<tr>
<td>Group B</td>
<td>27.10</td>
<td>15</td>
<td>15</td>
<td>7.56</td>
<td>8297</td>
</tr>
<tr>
<td>Group A</td>
<td>27.63</td>
<td>15</td>
<td>17</td>
<td>6.51</td>
<td>7536</td>
</tr>
</tbody>
</table>

Table 3. Participants’ experience with the systems surveyed

<table>
<thead>
<tr>
<th></th>
<th>ABS</th>
<th>ACC</th>
<th>LDW</th>
<th>Navigation system</th>
<th>Driving Simulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group C</td>
<td>22</td>
<td>2</td>
<td>1</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Group B</td>
<td>25</td>
<td>2</td>
<td>0</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Group A</td>
<td>19</td>
<td>2</td>
<td>0</td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>

The group participants were matched as regards PC skills, level of English understanding and educational background. No pre-test for these background variables was used, due to time and resources constraints. English understanding was assessed, based on the subjects’ statement. Subjects with not sufficient English understanding were not able to participate anyway, as they were not able to read and understand the manual. The majority of the participants were of university level background, and only few were of basic education. The participants were assigned to each group, so as to match their educational background per group, however this fact should be kept in mind in the following sections.
Table 4. Group matching

<table>
<thead>
<tr>
<th>PC use</th>
<th>Level of English understanding</th>
<th>Educational background</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Expert</td>
<td>Average</td>
</tr>
<tr>
<td>Group C</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Group B</td>
<td>5</td>
<td>24</td>
</tr>
<tr>
<td>Group A</td>
<td>6</td>
<td>21</td>
</tr>
</tbody>
</table>

2.3 Apparatus

All the educative information that was provided to the participants was the same, irrespectively of the training used. However, depending on the learning/training method, different kind of apparatus/equipment was necessary.

In condition A (control condition), participants were given a printed manual providing all relative information in regard to the selected ADAS/IVICS. The manual was in the form of text, containing a detailed description of systems’ functionality, benefits and limitations in the systems’ use depending on road/weather/traffic conditions, as well as, some indicative interfaces providing information about the type of warnings/messages that drivers might receive from the system and the type of actions that drivers are supposed to undertake.

In condition B, namely, learning by using the multimedia training tool, participants were trained on the selected system, not only through text information but also through videos and simulated examples (e.g. sounds) projected on a PC screen [2]. In essence, the same information provided into the manual was also provided to the text of the MMT. In addition to these, there were videos and simulated examples.

In condition C, namely, learning by using the multimedia training tool and providing hand-on experience, participants were given the additional opportunity to have a realistic experience on how systems would work in practice, by driving a driving simulator. Moreover, in this condition they were experiencing situations where system limitations appear. The simulators used in the three sites were of the same manufacturer, so exactly the same scenarios have been used in each site.

The manual and the multimedia training tool were developed in the English language, as this was the official language of the project, within the framework of which the present survey was conducted. There were not enough resources available to have the material translated into the native language of each of the three countries.

For the evaluation of training methods’ effectiveness, a set of four questionnaires with multiple choice questions (one set for each system with 5-7 questions per system) was administrated to participants.
Questionnaire for LDW

Please answer the following questions. Only one answer is correct.

1. When the LDW system is active, steering is:
   ? Controlled by the system to follow a trace
   ? Controlled by the system to keep the position in the lane
   ? Controlled by the system according to the traffic flow
   ? Controlled by the driver according to the received LDW information

2. In which of the following situations will the LDW warn you properly?
   ? If the vehicle in the adjacent lane is coming towards you
   ? If you are drifting to another lane without using your direction indicator
   ? If you are drifting to another lane, even if you are using your direction indicator
   ? If you are drifting to another lane where another vehicle is already occupying it.

3. Which one of the following road types would be the most appropriate for LDW?
   ? Rural roads
   ? Urban roads
   ? Highway
   ? Peri-urban roads (i.e. ring-road)

4. Which preconditions in the road infrastructure should be met in order to get the LDW to work properly?
   ? Good road surface
   ? Good lane markers with a specific range of lane widths
   ? Open road with good lane markers
   ? None

5. What should you do if you get an LDW warning?
   ? Return immediately to your original lane
   ? Return to your original lane if you did not want to change lane, but keep on to the next lane if you purposely did it
   ? Operate your change lane indicator and continue the manoeuvre
   ? Return to your original lane if you did not want to change lane, but keep on to the next lane if you purposely did it checking that there is no other car at the adjacent lane that did not foresee your lane change manoeuvre.

6. Which of the following is not an effect of the LDW?
   ? Enhance driver comfort
   ? Enhance traffic safety
   ? Reduce driver responsibility
   ? Improve steering performance

Fig.1. Questionnaire used for the Lane Departure Warning system

2.4 Procedure

Participants were seated in a quiet room and were administrated by the experimenter an entry questionnaire asking general questions about their characteristics (e.g. age, gender, driving experience, previous experience with ADAS/IVICS/DSS).
After a brief description of the scope of the experiment, all participants were given sufficient time to become familiar with the information provided about the systems, either by reading the manual or by using the multimedia training tool for each one of the systems. The participants were asked to read carefully the manual or to browse themselves all the pages of the MMT reading all the information included and activating all multimedia content. The experiment leader asked the participants whether they felt confident that they had understood well the manual or the MMT. According to their answer, they were either given more time for the study or they proceeded further. No assistance was provided by the experimenter in regard to better understanding the context of the information provided. But since all material was written in English, the experimenter was however allowed to translate expressions into the native language of the participant.

In the multimedia training + practice condition, apart from training by using the multimedia training tool, participants were also provided with a realistic experience on how systems would work in practice by driving in the driving simulator. Initially, there was a warm-up scenario, so that the participants were familiarised with the driving simulator. As two environments were used in the scenarios, highway and rural road, the participants were driving for 5 minutes in each environment. Then, there were four categories of scenarios, those related to ACC, LDW, ABS and the navigation system. The experiment leader was giving the following instructions to the participants:

Navigation scenarios: Drive following the traffic rules. Try to follow the navigation system instructions so as to reach destination. Do not overtake.

ABS scenarios: Drive normally without overtaking.

ACC scenarios: Drive in the right lane, without changing lane.

LDW scenarios: Driver in the right lane, imitate that you are drifting towards the road marker (lane exit) without using indicators.

For each category there were the following scenarios, one showing the normal functionality of the system and a second showing a limitation of the system:

Navigation scenarios
- Normal functionality
- With roadworks

ABS scenarios
- Vehicle braking in good weather with ABS
- Vehicle braking in bad weather with ABS

ACC scenarios
- Slow vehicle ahead
- Sudden cut in

LDW scenarios
- Good weather
- Bad weather
2.5 Analysis of results

The analysed measures are the correct answers of the participants to the questionnaires after the end of each training. We have compared the number of correct and wrong answers in all questions among group A (learning due to the use of a manual) and group B (learning due to the use of the MMT). Then, we have compared the number of correct and wrong answers among group B (learning due to the use of the MMT) and group C (use of MMT and experience in a driving simulator), summing up for each system only the questions that are of relevance for the simulator, namely Q1 and Q6 for ACC, Q2 and Q4 for LDW, Q3 and Q5 for navigation system, Q1 and Q2 for ABS. The chi2 test was used for both comparisons.

The graphs below depict the participants’ performance in each question separately. The reason is that we wanted also to analyse also the understandability and usefulness of each question. If the majority of people had failed or respond worse in one question than in the rest questions, this could be due to the phrasing of the question itself, moreover since the training material and the questionnaires were not in the participants’ native language.

Country effects were not analysed, as the sample size was very limited, to acquire meaningful results.

3 Results

The percentages of correct answers per system and per group are given below. Significant differences were found for the Navigation system (p<0.05, effect size=0.86), where participants in the Manual group answered more correctly than participants in the MMT group and for the LDW system (p<0.05, effect size=0.71), where we note the opposite, participants in the MMT group answered more correctly than participants in the Manual group.

Fig.2. Correctness of answers per system among Groups A and B
No effect of the driving simulator was found for any system, according to the analysis of correct answers in the questions which were relevant to the simulator scenario applied.

The participants’ answers to the question if they think that they have learnt to use the system after the training are given below. The chi2 test was used to evaluate the distribution of answers in each group. Answers were given in a 5 rate scale, surely no: -2, rather no: -1, neutral: 0, rather yes: +1, surely yes: +2. There were effects found for the LDW (p<0.01) and for the ABS (p<0.05), where in both cases participants in the simulator group are more convinced that they have learnt to use the system than participants in the other two groups. The figure below have derived after we have transformed the qualitative answers into numbers and calculated the mean for each group and system.

The participants answers to the question if they think that they need additional training before using the system are given below. There were significant effects found for the LDW system (p<0.01), where participants in the simulator group
are more confident that they do not need additional training participants in the other two groups. Effects were also found for the Navigation system (p<0.05), where participants in the MMT group are more confident that they do not need additional training participants in the other two groups.

![Fig.5. Participants' feelings about need for additional training per system among Groups](image)

**4 Conclusions**

Compared to training with only a paper manual, the MMT showed advantages in the case of only one of the four systems studied, the Lane Departure Warning system. However, no clear effect of the additional training via the driving simulator on the correctness of answers was found for any of the systems.

However, people trained with both the MMT and the simulator feel better trained in the case of LDW and ABS. Moreover, in the case of LDW, people trained with the MMT and the simulator feel that they need less additional training than the people trained with the MMT only or with the manual.

These results are rather inconclusive as regards the potential of the MMT and of the driving simulator to improve acquisition of knowledge by the participants, as regards the functionalities and limitations of new systems, although positive effects were found for the MMT in one of the four systems. Further development of the MMT and of the scenarios employed in the driving simulator, or selection of different scenarios, showing more clearly the limitations of the system, could lead to higher impacts on knowledge acquisition. The language issue could have also played a role in this.

It must be noted that the evaluation of the training effectiveness was based on number of correct answers in a paper quiz, that is the acquisition of knowledge by the participants was analysed. Results could be different if evaluation was based on actual driving assessment in real road or on simulator, namely if we had analysed the skills acquisition, and if long-term effects could be studied.

Moreover, the sample mainly consisted of people having a university degree, of whom it can be expected that they can easily learn well by only reading a paper
As a conclusion, we may say that further research is needed, with bigger sample size coming from various educational backgrounds and with analysis of actual driving behaviour, in order to clarify if there is a positive impact from the use of a MMT and of a driving simulator in the training of drivers. Emphasis should be put on analysing possible negative side impacts of these tools, like creation of overconfidence, as possibly implied by the participants’ subjective perceptions in the present study.

5 References


SESSION 5: DIVERSITY AND SPECIFICITY OF ROAD USER GROUPS
APPLYING THE RESPONSE CODE OF PRACTICE FOR EVALUATION OF DRIVER ASSISTANCE SYSTEMS: HOW THE AGE OF THE DRIVER INFLUENCES PERCEPTION OF STEERING TORQUE SIGNALS

Gerrit Schmidt (Volkswagen AG, Germany)  
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ABSTRACT: This paper describes the effects of additional steering torque as a haptic signal on the driver-vehicle interaction. Its use for lane departure warning and lane keeping systems is conceivable, for example. For proper signal design with regard to the controllability of driver assistance systems required by the RESPONSE Code of Practice, these signals should be tested on potentially weaker driver groups. This requirement is taken into account here and therefore both learner drivers and older drivers were tested in this real vehicle study on test track. The analyses compare the effect of the signals among these subpopulations with the effect on middle-aged drivers. A total of 30 drivers were investigated and metrics of the driver and vehicle reaction were examined. The results do not indicate that age influences reaction and perception. Neither the reaction times nor the strength of the reactions differ significantly between the age groups.

1 Haptic signals and their use for driver assistance systems

The stark increase in information and assistance features in vehicles has brought with it a constant increase in the number of acoustic and visual signals. The driver's haptic channel is used comparatively little for the transfer of information even though very fast information preparation was proven in many studies. For example, it has been shown that, in comparison with acoustic feedback, haptic information (vibration of the handwheel) to support lane keeping leads to faster correction by the driver when the car is about to leave the lane [1]. Due to the faster correction, a lower maximum deviation of the vehicle from the centre of the lane can be observed (figure 1, left).

Figure 1 on the right shows, however, that signals of different modality lead to the same deviations on average. A closer analysis of the reactions to the applied steering torque clearly shows the weak points of haptic signals: Some test persons interpreted the signals incorrectly and responded by steering in the opposite direction (figure 1, right: Incorrect Strategy). In this case, the consequence is large lateral deviations [2]. This problem underlines how important a good ergonomic design of the haptic signal is.

Unfortunately in almost all of the known studies exclusively developed signal characteristics and scenarios were investigated. This makes it virtually impossible to make a general statement on design recommendations of haptic...
signals. A systematic investigation of signal characteristics like amplitude or gradient and of situation features like the current steering torque or the steering activity in the initial situation has been missing so far. Before using additional torque for driver assistance systems (e.g. lane departure warning), haptic signals in the vehicle need to be investigated systematically. In addition to signal design parameters, situational and usage contexts need to be taken into consideration in particular.

This paper therefore looks at the effects of directed additional steering torques in the form of haptic signals in the steering. Unlike vibrations, this type of haptic feedback contains direction information and, at the same time, shows effects on the vehicle movements. In the study presented here, the signals were investigated driving straight ahead. Results on the effect of different driving manoeuvres on the driver-vehicle interaction are presented in [3].

Fig.1. On the left, the comparison of acoustic (sound) and haptic warning (torque) modality according to [1]. At the top right, the comparison of acoustic warning (sound) with two haptic signals (vibration/torque) mod. according to [2]. At the bottom right, distribution of the reaction to pulse-like torque of correct and incorrect steering strategy of test persons.

2 RESPONSE Code of Practice: Controllability of ADAS

In addition to generally understanding the relationships of vehicle and driver reactions when additional steering torque is applied, the maximum allowable interventions should be defined before such signals are used. Therefore it should be ensured that the driver is not distracted from driving by the application of such an additional steering torque and is always able to control the vehicle safely. This central aspect of controllability is covered by the RESPONSE Code of Practice [4]. This agreement of different OEMs defines a process for the design and the assessment of driver assistance systems. Controllability is defined in the Code of Practice as the “likelihood that the driver can cope with driving situations including ADAS-assisted driving, system limits and system failures” [4, p5].
Fig. 2. Driving performance-related risk of causing an accident, car accidents for 1000 persons every 1 million kilometres driven, [8; p43].

The Code of Practice proposes alternative approaches to test this aspect. One suggested possibility is testing at least 20 “naïve” test persons. This suggestion is taken into account in this investigation and the effects of the torque signals on normal drivers are looked at. Furthermore potential subpopulations at less or more risk should be taken into consideration according to the Code of Practice. Accident analyses [5; 6] show that the risk of causing an accident is above average, on the one hand, among people over 65 years of age and, on the other, among young drivers under 25 years of age. Figure 2 shows the risk of causing an accident related to age. Among older drivers, the reasons include deterioration in vision, motor functions and the ability to process information although considerable individual differences can be observed [7; 8; 9]. As a rule, older drivers are able to compensate for many of these performance reductions by adjusting their driving style [7, 10]. The reasons for increased accident responsibility among drivers include a lack of driving experience and a high level of risk taking [11; 12]. Younger and older drivers have therefore been considered as driver groups with potential risk in this study.

3 Questions

The study aims to describe the driver’s perception of and reactions to additional steering torque signals. This should provide design recommendations for haptic signals that are transmitted via the handwheel. These results are relevant for the configuration of further steering assistance functions, for example, lane keeping systems or yaw moment compensation [13].

With regard to guaranteeing the controllability of interventions via additional steering torque signals, test situations need to be found that allow useful determination of reasonable interventions and their validation with normal drivers. One central aspect in this study is the investigation of potentially weaker driver groups. If it is shown that the applied torque signals lead to other results among potentially weaker driver groups like new drivers with little driving experience and elderly drivers than with middle-aged drivers, these groups should be given special attention in further investigations. To this end, subpopulations of different ages are confronted with additional steering torque signals of different amplitudes. The effects on the driver and vehicle are then
recorded. This study thus makes a contribution to the test design in the investigation of steering system faults as part of the guidelines from the RESPONSE Code of Practice [4].

4 Test design

4.1 Driving scenario

In previous internal investigations into the reaction of drivers to steering torque signals, corners in particular were looked at in addition to the application while driving straight [13]. These driving scenarios have been further developed for this investigation. A bottleneck was selected here as a worst case scenario for driving straight ahead and was simulated using a 2.5m wide track marked with traffic cones. This bottleneck represents, for example, lanes becoming narrower at motorway road works and its size is based on the minimum requirements from road-building guidelines [14]. Since the width of the vehicle used is 1.82m, the bottleneck only allows very small deviations from the lane guidance. The driver therefore needs to be able to correct errors very quickly and precisely.

In addition, torque signals on curves of different radii and during the dynamic manoeuvre “single lane change” were carried out in compliance with the guidelines from the ISO standard [15]. These measurements are not covered here. See [3] for the comparison of the driving manoeuvres. The driving situations were performed in an oval in a fixed order (figure 3). The driving speed was set at a constant 80km/h using a cruise control system. The task for the driver was to drive through the four scenarios without hitting the cones or leaving the lane in the curves. While driving through the scenarios an additional steering torque was applied. This force resulted in a movement of the handwheel the driver had to cope with.

4.2 Variation of additional steering torques

Additional moments with four different amplitudes are set within the different driving situations. As regards the amplitude levels, 0<A<B<C applies. The additional signals with amplitude 0 were integrated in the procedure to provide a baseline measurement. No additional torque was applied, a measurement was

![Fig.3. Realised driving situations on the test course.](image-url)
simply triggered in the respective situation. All depicted torque signals were repeated three times and randomly distributed to the right and left. The order was completely random among the test persons.

The torque signals were held up to approx. 2s after triggering. The reduction is very slow so that the driver is not confronted again with a fast change in torque. The test persons are asked for an assessment immediately after completion of the steering torque signal. The effects of the additional moment were assessed with the aid of the disturbance assessment scale [16] (figure 4). Five categories are distinguished on the scale. The test persons made the assessment in a two-stage procedure using a scale with a total of 11 stages.

4.3 System setup and investigated sample population

A VW Passat B6 equipped with measuring instruments was used for the test. In the test vehicle, it was possible to apply additional steering torques using modified control unit software for the electromechanical power steering. The investigator accompanied the tests in the front passenger seat and triggered the additional torque signals invisibly for the test persons during the test drive.

As the evaluation of the torque signals was to be made by normal drivers, participants were sought who had no experience in the development of driver assistance systems. 30 test persons, including 22 men and 8 women, took part. In addition to 16 drivers between 25 and 55 years (m=38.12; sd=5.24), seven participants between 18 and 25 (m=20; sd=1.92) and seven persons over 55 years (m=66.83; sd=6.43) were investigated. The oldest participant was 78 years old at the time of the test. The average distance driven was for participants from 25 to 55 years 16063km/year (sd=6875), for under 25 years 17143km/year (sd=4298) and over 55 years 15250km/year (sd=6364).

4.4 Measuring variables and data processing

The recorded physical driving data is filtered (5Hz low pass) and corrected for offsets. The triggering and the respective vehicle statuses are checked during data processing. 613 measurements with applied additional steering torques were used in the analyses. Minimums and maximums of the steering and vehicle reactions are calculated according to the application of the additional torque. The maximum handwheel rate after the first maximum of the handwheel angle is used as a characteristic value for the strength of the driver reaction (figure 4). As it is not the level, but more the change that is relevant for the driver, for the yaw rate the span was calculated as the difference between minimum and maximum within two seconds after the torque signal was triggered. The calculated characteristic values are combined with the evaluations. The average values are used in the analyses for the repeated faults. For all steering inputs and vehicle reactions a smaller value indicates a better coping of the situation. Due to the experimental design, Split-Plot ANOVAs with repeated measurements are used for the statistical analysis. The amplitude of the additional torque is used in the analysis as within subject factor, the age group as between subject factor. The post-hoc testing of different factor levels is performed using LSD tests.
Fig. 4. Time pattern of target additional torque, handwheel angle and speed (left). Disturbance rating scale according to [16] (right).

5 Results

The following results show the effects of different amplitudes of the additional steering torques. The direct effects of the torque on the steering as well as the time and strength of the driver reaction are taken into consideration. In terms of the dynamic reaction of the vehicle to the additional torques and the subsequent driver entries, the yaw reaction is analysed and set in relation with the subjective assessments. The analyses compare the different age groups.

Fig. 5. First maximum of the handwheel angle (left) and its time (right) per age level depending on the amplitude of the torque signal.

Figure 5 shows the effects of the additional steering torque on the first maximum of the handwheel angle. For all amplitudes greater than 0, an average movement of the handwheel of 3.77deg results due to the torque application. In the following Split-Plot ANOVAs, only the amplitudes A, B and C are taken into consideration. Incorporating the baseline amplitude 0 is not useful since the effect strengths should be illuminated in the different levels. With regard to the influence of the amplitude of the steering torque, there is a greater handwheel movement at the amplitude B and C compared with A ($p=0.011; \eta^2=0.149$; LSD post hoc Tests: $p_{A,B}=0.002; p_{A,C}=0.018; p_{B,C}=0.657$). This shows that up to a certain amplitude, the effects on the handwheel angle rise. At
amplitudes B and C, the signal is compensated by the driver after the same handwheel movement for the signals used here. It cannot be presumed that there are differences between the age groups (p=0.984). Figure 5 (right) shows the reaction time by the time of the first maximum of the handwheel angle after application of an additional moment. This maximum marks the time when the driver is actively intervening to the applied torque. As regards the speed of the reaction, no difference between the age groups can be found here (p=0.714). Younger and older drivers react to the additional torque signals applied here on average equally fast after 431ms. The reaction time of amplitude level A to the two other levels B and C rises significantly here (p=0.002; η²=0.201; LSD post hoc Tests: p_{A-B}=0.003; p_{A-C}=0.001; p_{B-C}=0.334). As for the higher amplitudes with a limited slope it takes more time until the signal has inclined until the desired amplitude is reached, it can be presumed that the reason for this longer reaction time is due to this longer inclination and not to slower driver response in these cases.

The severity of the driver reaction is described using the maximum handwheel angle rate after the first maximum of the handwheel angle. Figure 6 shows this maximum of the handwheel angle rate on the left-hand side. The observed driver reactions are well below 100°/s on average. These values speak for a quite slow and controlled reaction and support the assumption that the additional steering torque signals presented here were easy to control by the driver. The severity of the reactions is not distinguished between the age groups (p=0.410). At amplitude A, lower values occur compared with B and C (p=0.001; η²=0.214; LSD post hoc tests: p_{A-B}=0.005; p_{A-C}=0.002; p_{B-C}=0.100). The strength of the yaw reaction shown on the right in figure 6 behaves in a similar way: Here too, there is no difference between the age groups (p=0.496). A greater amplitude leads, however, to greater yaw reactions (p<0.001; η²=0.625; LSD post hoc tests: p_{A-B}=0.004; p_{A-C}<0.001; p_{B-C}<0.001).

Fig.6 First maximum of the handwheel angle rate after driver intervention (left) and its maximum yaw rate span (right) per age level and amplitude of the torque signal.

The subjective ratings of the disturbance effects in figure 7 on the left shows a significant increase in the ratings with increasing amplitude of the applied additional torque (p<0.001; η²=0.765; LSD post hoc tests: p_{A-B}<0.001; p_{A-C}<0.001; p_{B-C}<0.001). The assessment of the lane deviation is shown on the right in figure 7. At the greatest amplitude C, the deviation from the centre lane position is rated as greater compared with the lower amplitudes (p<0.001; η²=0.384; LSD post hoc tests: p_{A-B}=0.060; p_{A-C}<0.001; p_{B-C}<0.001). There are no significant age effects (disturbance rating: p=0.239; lane deviation: p=0.240).
Fig. 7. Rating of the effects of the additional torque (left) and the deviation from the lane centre (right) per age level depending on the amplitude of the torque signal.

6 Summary

To summarise, it can be stated that no difference between older and younger drivers can be observed on the level investigated here. However, it should be mentioned that the volunteers who took part in this study tended to be people with an affinity for and who enjoy driving. Drivers with performance limitations, who increasingly face problems on the road, hardly ever volunteer for this kind of driving study. The recruitment of older weaker drivers poses a dilemma that seems impossible to solve for the time being. In the selection for this study, it was important that older participants were taken into consideration.

By investigating younger drivers, we aimed to look into driver experience as a factor. However, the results here do not confirm that little driving experience negatively influences the reaction and perception of additional torque signals. This takes the requirements from RESPONSE into account and includes potentially weaker driver groups in the investigation. It should be expressly stated that the aim was not the identification of a sensitive manoeuvre to differentiate age differences. Moreover the manoeuvre was selected on the basis of ecological validity: It represents a maximum requirement in road traffic with regard to the precision of the lateral guidance. Nevertheless, it can be criticised that these test track scenarios might not cover the full complexity of situations in real traffic.

In the presented study, both older and younger drivers showed the same performance as the middle-aged participants in the set driving task and therefore the results do not indicate that the age is influencing the perception and reaction to steering torque signals. Not least due to the small sample sizes of the subgroups in this experiment, further studies with the same setup are needed for replication.

7 References


EFFECT OF ADDITIONAL TASKS IN DRIVING PERFORMANCE: COMPARISON AMONG THREE GROUPS OF DRIVERS

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ABSTRACT: The growing introduction of new technologies inside vehicles represents a set of extra information sources that drivers have to manage at the same time. Their use can interfere with the driving activity and induce performance decrements. An on-road experiment was conducted to investigate how drivers reacted to the inclusion of an additional task and how this situation interfered with guidance and driving activities. Forty eight subjects (elderly, experienced, novice) participated in the tests. During the course they interacted with a navigation system and a mobile phone and were their performance levels evaluated on four parameters: navigation errors, turning indicator activation, visual behaviour and critical situations management. As a result, phone conversation did not significantly affect the guidance task. Concerning the driving, the visual behaviour was less efficient and the activation of the turning indicator was delayed. Young drivers were least affected by the conversation while elderly drivers were the most affected in all the parameters.

1 Background

The development of new technologies and their recent incorporation into road vehicles represents a set of extra sources of information for drivers. This implies drastic modifications of the main activity of driving especially when the driver has to manage simultaneous information from different sources. This information can be linked to the driving activity to assist the driver (such as information from a navigation system or Adaptive Cruise Control) and on the other hand, it can also not be directly related with the driving activity and may enter in the car without any safety device (e.g. mobile phones).

One example of such technology, designed to help the driving task, is the navigation system. Such systems inform the driver about the itinerary, directing him or her to reach a specific place. As soon as the driver enters the destination into the device, the system can select the fastest or shortest route, guiding him/her in the most efficient manner without becoming lost, frustrated or feeling bad about not finding the way. Many studies showed the advantage of using electronic route guidance instead of the old paper map. To Wochinger et al. [1] the interaction with a route system (turn-by-turn) leads to better driving performances than the use of a paper map. The system allows for faster mean speeds on all road types, lower workload ratings and less navigation errors. Moreover, the large amount of cognitive attention required by paper map use leads to a higher rate of abrupt braking manoeuvres [1]. Conversely, a turn by
turn indication presents the relevant information in a simple way. This suggests that a system providing this kind of instructions, rather than complex route information, is less distracting to the driver and presents the most usable means of navigation. Thus the use of a route guidance system is more adequate than paper map use and can efficiently guide the driver in an unfamiliar area [2].

The growing presence of mobile phones inside the vehicle is also a result of the emergence and popularity of communication technologies. Their use is risky and raises the problem of driver distraction. According to Redelmeier and Tibshirani [3], a mobile phone conversation quadruples the risk of being involved in a car crash. Laberge et al. [4] also tried to evaluate this risk by comparing two groups of drivers: users of mobile phone while driving and non users. Their study shows that the risk is 38% higher during a phone call. The main question is to determine in which way a mobile phone conversation diverts the driver’s attention and how it interferes with the driving activity. Several studies stressed driving performance impairments in terms of reaction times, decision making, lane keeping [5], and lower driving speed [6]. The quality of perception and information processing is also affected. Indeed, Recarte and Nunes [7] [8] and also Harbluk and Noy [9] showed that the added workload due to a phone conversation increases the driver’s effort of attention. At the perception level, this is conveyed by a reduction of the visual attention with a decrease of peripheral stimuli detection like checking the mirror and speedometer [8]. This decrease was explained as the result of a multitasking situation induced by the mobile phone conversation. A secondary task, like a mobile phone conversation, increases the workload, competes with the attention and, as a consequence, diverts the attention away from the primary driving task.

Regarding the use of in-vehicle technology, it can be considered that individual driver’s characteristics are very important and can also induce different types of interactions, which may have diverse consequences on behaviour. One of the groups of drivers that studies have been focused on is the “Elderly” due to the fact that they are an increasingly important cluster. Studies have shown that the aging process can induce some decrements in driving ability [10]. Among other examples, some declines are related with the visual, cognitive and motor abilities; difficulty in discriminating relevant information and longer time required to process it; a decline in selective attention and attention switching. The elderly are also characterized by being highly distractible and can also be easily confused by competing sources of information [11]. However in order to compensate their perceptual-motor degradation they tend to adapt their driving behaviour and use residual resources. While driving the elderly try to reduce the stressful mental load they are experiencing and, as a consequence, they are more conscious, drive slowly, and attempt to over control their actions [12]. When interacting with in-vehicle information systems older drivers can express especial difficulties because this interaction may represent a factor of distraction once it imposes the allocation of cognitive resources to an additional task. During this period, they could be temporarily unable to react appropriately to an event or even manage the driving task in complex situations due to the risk of overloading [10].
Liu [13] conducted a study to evaluate the interaction with such systems and tried to check if performances, in terms of reaction time, depended on the modalities of the displays and on the complexity of the messages. Results showed longer reaction times and an increase of the navigation errors for the elderly drivers. They also registered higher performance degradation than novice drivers during complex or critical situations. Dingus et al. [14] also found an age effect and they stated that drivers felt an important workload effect during these situations. The authors explain this tendency by the fact that elderly drivers suffer from an impairment of their cognitive and perceptive abilities and also due to the fact that these systems need a considerable amount of attention to process the information. Due to this gap, elderly drivers felt unable to process the extra information. Indeed, the performance of an in-vehicle task needs interpretation and decision making. All of this could lead to an impairment of the driving activity [15]. Therefore, older drivers require a more stable and user-friendly road environment and in-vehicle information devices should be designed in order to avoid an increase of their mental workload. Unless the systems interfaces and the forecasted interactions are ergonomically designed, they will overload and confuse the driver, especially the elderly [10].

Another group, with extreme importance in the driving context, is the novice due to their higher crash rates [16] [17] [18] [19]. This group is characterized by being more exposed to risk because they drive more often at night [17] [20], travel at higher speeds and at closer following distances [21] [20] [22]. Furthermore, they are more easily distracted by non-driving events [23], they tend to overestimate their driving ability in being over confident of their correction of error [24] [20] [23]. In their literature review, Whelan et al. [25] showed that the lack of skills of novice drivers (information-processing, self-calibration, hazard and risk perception and situation awareness) is related to their crash involvement. Their lower driving experience is frequently associated with less effective approaches to search visual information and with a poorer ability to process the perceived information [26]. Due to this lack of experience, novice drivers have not developed the automatisms in the driving task that allow for fast switching between tasks [23] [27]. They detect hazards slowly and perceive them as less risky [19], therefore being unable to anticipate and control efficiently the vehicle in emergency situations [23]. Furthermore, they may use some devices in a non-optimal way due to their lack of knowledge and risk awareness [23].

The impact of additional tasks on young drivers was also analysed by some authors. Lansdown [28] found driver group differences in the accomplishment of a secondary task where young drivers took longer to react to a stimulus and had higher glance frequency towards the additional task interface. In fact, in multitask situations, novices are not as efficient as experienced drivers for processing useful information due to their lack of ability to automate cognitive processes [29] [28]. Indeed, with increasing levels of experience, the driving activity becomes less demanding and the driver can easily share his/her attention between the driving activity and the secondary task [28]. It seems that experienced drivers are less affected by the secondary task given the fact that they have more ability than novices to share their attention [30]. Moreover, when a situation is cognitively demanding and when it needs a high level of information processing like turning left, Gugerty et al. [31] stressed an impact of
mobile phone use on decision making. This kind of process needs an integration of all the information presented to the driver in order to anticipate the future events and other users’ actions.

2 Objectives

Several studies have been conducted in order to investigate the interaction between the driver and one in-vehicle system. However, the increased number of new in-vehicle technologies raises the problem of having several not connected sources of information. Therefore a study was developed in order to investigate how drivers reacted to the inclusion of an additional task and how this situation interfered with driving and influenced the guidance task performance. With more detail, the objective was to analyse the consequence of a mobile phone conversation in the subject’s behaviour while driving with a route guidance system. It was important to know how drivers managed both sources of information originated from the guidance system and the mobile phone, which information they prioritised, and also what kind of errors occurred during the driving task.

For this study, it is hypothesised that the mobile phone task will have an influence in both the guidance and driving tasks. In a more specific way, it is expected that the mobile phone conversation poses a negative impact, inducing to a strong decrease in the guidance performance and also to a significant decrement in the driving activity. Concerning drivers’ specificities, it is believed that elderly and young drivers will be the groups that perform worse due to the effects of the mobile phone conversation. For the elderly, this result is expected due to their higher difficulty to face the more complex situations, especially considering the simultaneous processing of information from different sources. For young drivers, due to the fact of having less automatic processes, the introduction of an additional task will increase their mental workload and degrade the guidance and the driving task. In spite of the expected inferior results for those two groups of drivers in the presence of the mobile phone, it is hypothesised that these declines will be even more evident for the elderly group.

3 Method

Forty eight drivers took part in the experiment. They were distributed in three groups of 16 participants, depending on their age and driving experience: elderly, reference and young drivers. Elderly participants were aged from 62 to 78 years (mean age=69.4; SD=3.9), reference subjects from 34 to 47 years (mean age=39.6; SD=3.9) and novice drivers from 18 to 21 years (mean age=19.5; SD=1). The elderly and reference subjects had possessed their driving licences for at least five years and have driven in excess of 10000 km. Conversely, novice drivers had less than 2 years of driving experience. An equal number of men and women were represented in each driver group.

All drivers had their own mobile phone: in average, elderly drivers possessed it for almost 5 years (m=4.63; SD=3.49), reference drivers for 7 years (SD=2.19) and novice drivers for 5 years (SD=1.26). All but four elderly subjects stated
that they had already used their mobile phone while driving. The majority of elderly drivers admitted to having phone conversations a few times per month while driving. Comparatively, most reference group participants declared having a phone conversation at least several times per week while the majority of young drivers stated to use the mobile phone while driving at least once per day. From the 48 participants only two indicated that they possessed a navigation system, one belonging to the elderly and other to the reference group.

This on-road experiment took place near Lyon (France) with the INRETS vehicle (Institut National de Recherche sur les Transports et leur Sécurité) equipped with sensors that registered the dynamic data of the car. Five mini video-cameras allowed for capturing images from the road environment and the driver and also from the in-vehicle technologies placed in the car. For safety reasons, the car was equipped with another set of pedals in front of the passenger seat and a driving instructor was always seated besides the driver.

A guidance system (Carminat) was fitted as standard to the vehicle and was located on the top of the dashboard to the right of the steering wheel. It displayed schematic guidance instructions throughout arrows (turn-by-turn system) and also transmitted audio instructions some meters prior to intersections.

The recruited participants were asked to drive a predefined course, guided by the instructions of the guidance system and to interact at some specified periods with a mobile phone. Twenty “target intersections” were selected from the course in order to be studied with further detail: 8 turns to the right and 12 turns to the left. To be considered as a “target”, intersections had to allow the driver to make all the decisions as freely as possible; meaning the driver had to decide when to turn and the decision not influenced by traffic lights or other types of vertical signs.

Subjects only drove the course once and for that reason it was designed to have an equal number of situations in each experiment condition: No Phone and Phone. In the No Phone condition, participants were asked to drive the car with the help of the route guidance system. No other in-vehicle systems were connected nor were other tasks asked of the participants to perform. In the Phone condition subjects had to drive the car with the help of the route guidance system and also conduct a mobile phone conversation. Participants interacted with a bluetooth hands-free phone connected to the audio system of the vehicle. Two buttons in the centre of the dashboard allowed them to answer the call (left green button) and to hang up (right red button). During the course half of the target intersections were performed without phone (4 right turns and 6 left turns) and the other half with. The system conditions were balanced over the intersections so that half of the subjects in each group performed a set of target intersections in one condition and the other half in the other condition.

The mobile phone task was compiled of a series of sentences sent by a researcher located at INRETS. The participants had to listen to each sentence, repeat it and then answer “Yes” if it was sensible, and “No” if it was not. For example: “Usually, bicycles are bigger than cars” to which subjects had to repeat and then answer “No”. The rhythm with which sentences were given
depended on the pace of the driver to answer the preceding one. This mobile phone task was based on the “Decision part” of the Working Memory Span Test [32] [33]. A repetition part was added to the test in order to ensure that the correct sentence was heard and to better evaluate the accuracy of the answer. All sentences contained 11 or 12 syllables and took an equivalent duration of time to be said. The test contained 50% of sensible phrases and 50% of nonsense sentences. The order in which they were presented was randomly selected by computer utilising a visual basic program made specifically for ordering the sentences.

At the beginning of the experiment, the main objectives of the study were explained to the participants. They were then submitted to visual and audio tests to ensure they had no related problems that could interfere with the experiment and compromise the results. Subsequently, they filled a questionnaire with personal data and also to investigate their opinion and knowledge about new in-vehicle technologies, especially mobile phones and guidance systems. Before the experiment itself, the guidance system functioning as well as the details of the mobile phone task were explained to the participants. A training period of at least 15 minutes allowed them to get familiar with the car, the guidance system and the phone task. The possibility to extend this familiarization period was given to the driver if needed. The experimental test lasted from 30 to 45 minutes depending on traffic conditions, navigation errors and also on the speed of each driver. During the test, an observational table was filled in by a researcher in order to register aspects regarding navigation, turning indicator signs, driving behaviour, trajectory of the vehicle, interaction with the other road users, respect of road signs, visual behaviour towards the more important areas for collecting visual information from the road environment (such as rear mirrors and the intersections itself). Such a table was based on Risser work [34]. At the end of the experiment, participants filled a questionnaire to investigate the attentional demand according to the experimental conditions (No Phone and Phone).

In spite of several parameters being measured in this experiment (the performance on the primary task, the secondary task and also self-reported measures) only the analysis from the navigation errors and relevant driving errors will be presented in this paper.

4 Results

The variables presented in this paper were only collected at the target intersections because, just in half of those junctions was the mobile phone condition introduced. Due to navigation errors that occurred during the experiment, some participants made small deviations from the original predefined course, resulting in different numbers of target intersections. The allowance for such errors was justified by the fact that drivers should manage their course by themselves in order to find the path and the researcher not allowed to interfere with their decisions. As a consequence, to compare the results, percentages of errors have been computed in each condition. Based on these percentages, results were compared using a statistical test of proportions that was applied in each case (Fisher’s test). A significance threshold of 0.05
was accepted (p<5%). The experimental design included one between-subjects factor: the driver groups (elderly, reference and novice groups) and one within-subjects factor: the driving conditions (Phone and No Phone conditions). Only the statistically significant results are presented.

4.1 Navigation Errors

A navigation error can be considered as a discrepancy between the information sent by the system and the action carried out by the driver. The frequency of such errors was counted and results concluded that from the 843 driven intersections, 42 resulted in navigation errors (approximately 5%). Data showed a higher but non significant percentage of errors in the Phone condition (5.91%) compared with the No Phone situation (4.12%). Similar results were observed for each driver group, where the Phone condition produced a higher percentage of error. Comparing the proportion of errors for the driver groups, elderly drivers made more navigation errors in both Phone and No Phone conditions. Reference drivers were the ones that made fewer errors and novice drivers positioned themselves in an intermediate position, as shown in Figure 1. It is important to point out that, while in the No Phone situation the differences between driver groups are not considerable, for the Phone condition the discrepancies are more pronounced, especially between elderly and reference drivers. Although these differences are not statistically significant (p=0.07 between elderly and reference for the Phone situation) this shows a tendency for elderly drivers to make more navigation errors while at the phone.

![Navigation Errors](image)

Fig.1. Percentage of navigation errors for each driver group

4.2 Turning Indicators

The number of errors for the turning indicators activation was counted with the help of an observational table and afterwards validated using the video recording of the test. This analysis was divided into two major errors: one characterized by the lack of turning indicator sign ("omission" error), and the other considered when the turning indicator was activated too late, i.e., a par of meters or less from beginning to turn the steering wheel ("timing" error).

By comparing both mobile phone conditions it can be seen that in the Phone condition a higher percentage of "omissions" and "timing" errors are observed. It can also be observed that, in this condition, "timing" errors occurred more often
than “omission” errors. In spite of the dissimilarity between both mobile phone conditions not being significant for the “omissions”, for the “timing” errors this difference is statistically significant. Therefore, it can be stated that the Phone condition led to a significantly higher percentage of late activations of the turning indicator sign (p=0.01). When the comparison between groups is made (Figure 2 and 3), it can be seen that elderly drivers are more likely to forget to activate the turning indicator signal while novice drivers have the smallest “omission” errors percentage. However, the difference is not statistically significant within driver group or between them. The only statistically significant difference occurred for the “timing” errors within the elderly group. Those participants made higher percentage of errors in the Phone condition than in the No Phone situation (elderly drivers p= 0.01), meaning that elderly drivers were the ones significantly more affected by the addition of the phone conversation. This performance decrement was characterized by a latter activation of the turning indicators.

Fig.2. and 3. Percentage of “omission” and “timing” errors for each driver group

### 4.3 Visual Behaviour

Similar to the turning indicator sign, the number of errors in visual behaviour was coded through the observational table. This register was also made during the experiment and afterwards validated utilising the video recording of the test. The analysis of the visual behaviour was made based on the assumption that drivers have to attend to specific areas of the road environment in order to capture the crucial information to perform a turn. Whenever a driver does not look to these areas, an error was marked down in the table.

From the analysis of the results it is possible to verify that, in a general way, a higher percentage of “visual behaviour errors” were committed in the Phone condition. When all subjects are taken into consideration this difference is statistically significant (p=0.00). This result is also confirmed for each of the participants’ group where higher percentages of error are observed when a mobile phone conversation is conducted (Figure 4). However, when ages are taken into account, only the elderly and the reference participants reveal a significant difference of errors between mobile phone situations (elderly p=0.015; reference p=0.00). A comparison between driver groups shows that elderly drivers made more “visual behaviour errors” in both mobile phone conditions. Reference drivers made fewer errors in the No Phone situation and their younger counterparts had a lower percentage of error in the Phone condition. However, those differences are not significant.
Near crash situations represent the moments where the driver placed himself into a dangerous situation and the instructor, travelling beside him/her, had to intervene. These interventions aimed at avoiding a critical situation or, in the worse case, a crash between the experimental subject and other road users. The instructor could intervene by means of the double pedals installed in front passenger side of the vehicle and also through the direct control of the steering wheel. Such situations occurred during the present experiment. Video recording analysis showed that all the 5 near crash situations registered concerned elderly drivers Moreover, all but one of these critical events coincided with the usage of the mobile phone. When considering these proportions, the near crash situations in the No Phone condition represents less than 1%, while in the Phone situation represents 3.13%. This suggests that for the elderly drivers, conducting a mobile phone conversation highly increases their probability of near crash or crash situations.

5 Discussion and conclusion

Regarding the navigation errors, when all driver groups are considered, the analysis of this data revealed a slight tendency of an increasing number of navigation errors in the Phone condition. However, contrarily to what was expected, the Phone situation did not reveal a statistically significantly higher number of navigation errors. This may be due to the novelty of the guidance task and to the participants’ inexperience of interacting with this type of system, leading to numerous navigation errors being made even when drivers were not having a mobile phone conversation. However, this could also be related to the imperfect accuracy of the distance given by the navigation system, which was not always accurate when informing about the number of meters for the next turn (higher speeds also decreased the distance precision). This lack of distance precision could have lead drivers to a higher percentage of errors, even when they were not performing the secondary task. Additionally, it should be considered that the nature and difficulty of the mobile phone conversation did not lead to a sufficient involvement of the experiment participants. This supports the statement saying that, if drivers are not really involved in the conversation, no visible behaviour impairments can be seen [35] [36]. On
revealing that the difference between mobile phone conditions was not significant, it cannot be established that the number of errors is directly attributed to the mobile phone conversation. For this experiment, the mobile phone conversation did not lead to higher percentage of navigation errors. In considering the driver groups, elderly drivers made more errors, especially in the Phone condition, where the difference between them and the reference drivers is close to being statistically significant. Thus the elderly show a slight tendency to make more guidance mistakes than reference drivers in a multitask situation.

In considering the turning indicator sign, there was no significant difference for the “omission” errors independently of the mobile phone condition or the driver group. This means that in this experiment, the mobile phone did not produce an important effect by inducing drivers to forget to activate the turning indicators. On the other hand, it can be stated that when all subjects are taken into account, a significantly higher number of late activations of the turning indicator were made coinciding with the phone conversation task. In fact, the detailed analyses of the age groups revealed that elderly drivers were the only group that had higher rates of “timing” errors while using the phone. Neither the reference drivers nor the young drivers drastically changed their “turning indicator” behaviour in the presence of the phone conversation. The data highlights unequal results between age groups and can reveal different ways to process the information. According to Dingus et al. [14] elderly drivers may experience higher difficulties while managing several sources of information and this can lead to a longer information processing. In the present experiment, this higher time to activate the turning indicator sign by the elderly can be considered as the expression of this slowing process.

In the visual behaviour analysis, it is important to highlight that the mobile phone conversation significantly influenced the visual behaviour increasing the percentage of visual errors in this situation. This would suggest that, in the presence of that secondary task, participants more frequently forgot to check some important areas of the environment. The significance of this finding is that dangerous situations could arise as a result of a driver receiving and perceiving less information from the road reducing his/her reactions to an unforeseen event. When age is taken into account, elderly and reference participants committed a significantly higher percentage of errors while using the phone, meaning that the cognitive activity of these two groups of drivers was affected by the presence of the mobile phone conversation. The young driver also made more errors during the phone conversation, but the difference was not significant. According to the literature and supporting the hypothesis in this study, elderly drivers had visual behaviour decrements in the presence of the additional task. Contrarily, the moderate impact of the secondary task on the visual behaviour of the younger drivers’ performance did not confirm the results of other studies. This can be justified by the assumption that this group of drivers is more used to interacting with new technologies, coping better with this multitask situation. This is also supported by a higher reported use of mobile phones by this sample as registered in the questionnaire completed prior to the experiment. Using a mobile phone in the car is more familiar to them and the effect is registered as less important on their driving behaviour. This lack of effects from the additional task registered in the young drivers could also be due
to the presence of the driving instructor whose presence could have caused a feeling of being judged. Additionally, the fact of their relative inexperience to driving and probably not having much confidence in their abilities could induce them to pay extra attention to their driving avoiding making mistakes.

The decrements in performance of elderly drivers are once again highlighted when the results of the near crash situations are analysed. The fact that there is a higher percentage of near crashes for elderly drivers in the Phone condition reveals that they have more difficulty managing guidance and mobile phone tasks at the same time while driving. This assumption supports literature results that indicate older drivers have more difficulties in processing extra information coinciding with some performance decrement. It should be highlighted that the near crash events during the experiment could have become real crashes without the control of the driving instructor.

The conclusions presented in this paper represent a first look to the results withdrawn from the performed tests. An additional and deeper analysis of the other parameters recorded during this experiment will expand conclusions on this topic and allow for an increased knowledge about the influence of additional and competitive sources of information on the performance of the driving task.

As a conclusion, and contrarily to what was hypothesised, the additional task of the mobile phone did not have a crucial impact on the guidance task and the percentage of navigation errors was not significantly different between mobile phone conditions. However, as expected, the influencing factor was more evident in the driving task because, in an overall review, participants activated the turning indicator later while at the phone. An effect was also found in visual behaviour, where drivers paid less attention to the important areas of the road environment to perform an intersection. As hypothesised, when ages are taken into consideration, it is the elderly whose performance levels change the most in relation to the late activation of the turning indicator and also for flaws in checking the road environment. Like the elderly participants, reference drivers also performed significantly worse in terms of visual behaviour. However, in opposition to the hypothesis, younger subjects did not seem significantly affected by the mobile phone conversation, at least when considering the measures used in this experiment.

6 References


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WHAT TOOLS ARE NEEDED TO DEVELOP SAFE AND JOYFUL CYCLING FOR SENIOR CITIZENS

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ABSTRACT: Demographic changes show that the absolute number and portion of the population in Europe that can be categorized as older or very old will continue to grow over the next several years. One aim should be to keep them active and healthy for as long a time as possible. Exercise, for example cycling, plays an important role in this context but data shows that the elderly bicyclists are overrepresented in crashes when compared with their exposure to traffic. Senior cyclists’ needs and preferences should be a base for developing a safe and joyful cycling environment. This project uses literature reviews, in-depth crash data analysis, questionnaires with senior cyclists, questionnaires with experts, and an expert workshop to identify potential ITS applications for improving elderly bicycling. The last tool (the expert workshop) included two group discussions structured according to two philosophically different models: The Diamond model and The Multiple comfort model.

1 Background and purpose

Demographic changes show that the portion of the population in Europe that can be categorized as older or very old will continue to grow over the next several years. The absolute number of older people will also continue to grow and since there will be more old people, one aim should be to keep them active and healthy for as long a time as possible. Exercise, for example cycling, plays an important role in this context – it supports us to stay healthy in all phases of our lives. The health effects of cycling are well documented [1, 2, 3]. Bicycling is possible almost without any limitation of age, so bicycling is an ideal way to stay active at an older age. Apart from the advantages for our physical constitution, cycling could increase mobility at an older age. The bicycle could become an ideal means of transportation for many senior citizens, in order to fulfill their individual needs of mobility, and to stay active and mobile at an older age provided that bicycling is safe. But data shows that the elderly bicyclists are overrepresented in crashes when compared with their exposure to traffic [4]. Maring and Schagen [5] support the findings. Therefore, measures are needed. The following five tools for idea generation were applied for identifying user’s needs and developing countermeasures for safe and joyful cycling for senior citizens:

1. literature review,
2. in-depth crash data analysis,
3. questionnaires with senior cyclists,
4. questionnaires with experts,
5. an expert workshop with group discussions structured according to two different models.
2 An analysis of Finnish in-depth crash data

A set of hypotheses was tested on Finnish in-depth crash data (VALT) to find out reasons behind the higher risks for senior cyclists. The analysis supports the following hypotheses:

- Elderly bicyclists are significantly (p=0.0012) more involved in crashes when intending to turn left compared to other age groups. 22% of elderly in fatal crashes intend to turn left compared to 8% for adults and 14% for children. Goldenbeld [7] found similar results, that elderly bicyclists often have problems at intersections and especially when turning left.

- As expected, elderly bicyclists are significantly more often impaired by bad sight (p=3.52E-05) and/or bad hearing (p=3.52E-05) as well as being impaired from taking medication (p=7.89E-08) in crashes compared to other age groups.

- Elderly bicyclists are less often in a hurry (5%) in crashes compared to other age groups (11%). Of the bicyclists that were fatally injured in 1995-2001, there were a higher percentage of children (18%) that were in a hurry than among other age groups (6%). Differences were not significant.

Somewhat unexpectedly, it was found that:

- Elderly bicyclists obey traffic rules no more and no less than other age groups. However, non-elderly adult bicyclists are significantly more often (p=0.00024) affected by alcohol (50% proven impaired) than elderly bicyclists (9%).

- In darkness (incl. dawn and dusk), non-elderly adult bicyclists are significantly (p=4.1E-10) more often involved in crashes (37%) than elderly (11%).

- There is no significant difference between age groups’ bicycle front light and reflector use, and the footbrake on elderly’s bicycles is not less often in good working order compared to other age groups’ bicycles.

- Child bicyclists are significantly (p=0.00035) more often involved in fatal crashes outside built-up areas (56%) than elderly (39%) and other adult bicyclists (30%).

- Elderly bicyclists are not over-involved in crashes where the road surface is in disrepair.

- Elderly bicyclists are not significantly more involved in fatal crashes on hilly streets than other bicyclists.
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- Adult bicyclists are significantly (p=5.85E-06) more often involved in single-vehicle crashes compared to other age groups. For crashes involving other pedestrians, other bicyclists or mopeds there is no significant difference between age groups.

3 A questionnaire to senior cyclists in Sweden

Interviews with 31 bicyclists (15 men and 16 women), all members of the Cycling Promotion in Sweden (Cykelfrämjandet), were done as a pilot project to test and finalize a questionnaire about needs and safety of elderly bicyclists, see [8]. To gather more extensive knowledge about elderly bicyclists needs, the questionnaire was sent to a sample of more than 500 members of the Cycling Promotion in Sweden (Cykelfrämjandet) in June 2007. The sample was stratified to get a better balance between regions (North, Middle and South of Sweden) and age groups (65-74, 75-84 and 85-89). Altogether, 351 answers were received from members 65+, corresponding to a response frequency of 61%. The answer frequency decreased with increasing age and was 61% in average. 40% of the respondents were female. Seven respondents (2%) were 85+. The oldest one was 89 years.

When interpreting the results below it should be remembered that the respondents are members of the Cycling Promotion in Sweden and have more experience in cycling and matters related to cycling than people in general in Sweden and therefore not representative for all bicyclists of that age. However having experienced respondents can of course be an advantage when gathering background information to be used to develop a strategy and measures to obtain safe and joyful cycling for senior citizens. They are probably also healthier. The share that finds bad hearing a safety problem is small, only 9%, but increases somewhat after age 75. Below follow results.

The foremost reason that elderly ride bicycles is to get exercise, which 94% of the respondents state as a reason. Other often stated reasons are: because it is joyful (84%), because it gives freedom (73%), because it is easy (72%) and because it is easy to park (66%). Note that on this and several other questions respondents are allowed to give several answers. The foremost reason that the elderly leave their bikes at home and use another means of transportation is bad road conditions during the winter (which also is the reason that so many do not bike at all during the winter): slipperiness (81%), bad snow removal (79%) and snowfall (77%). Temperatures below zero Celsius restrain about half of the elderly from cycling.

Also, long distances are a reason that elderly choose not to use a bike. Some leave their bikes at home when the distance in one direction is more than 6-10 kilometers. Two thirds (65%) of the respondents do not like biking if the (one-way) distance is above 15 kilometers. Almost half of the respondents state that their bike usage would increase if there was a possibility to bring the bike onto busses and trains. This view is especially common (57%) among the youngest group (65-69). The most common comment is that such a possibility would facilitate going on bike holidays or longer bike excursions or to use the bike at the destination.
The most commonly used *equipment* is lights, which are used by 81% of the respondents. Most common are battery-powered lights followed by traditional dynamo-operated ones where the generator touches the tire. Some respondents have a dynamo in the hub. The second most common equipment is a helmet, which is used by 80% of the elderly. The remaining fifth does not own one. The helmet use is lower in Southern regions. About two thirds of the respondents use a bicycle-bag or basket *and* reflectors. The use of reflectors increases with the size of the municipality. Contrary, reflective vests are used only by 17% of the respondents, but in rural areas the usage is close to 50%. Rear-view mirrors are used by a few respondents, but are desired by quite many respondents (28%). The age of the respondent does not seem to influence use of rear-view mirrors. Winter tires and winter cycles are desired by one fifth of the respondents. However, more than half of the respondents stated that they do not miss any equipment or that they have no opinion.

The most common *sites or maneuvers* the elderly avoid are roundabouts, left turns and crossing streets without a cycle crossing. Also according to the analysis of Finnish in-depth crash data left-turns were hazardous to the elderly cyclists. Especially the oldest respondents state that they avoid roundabouts. Also cycle tracks with moped traffic are avoided by many. The most common reason that the elderly avoid any site or maneuver is that they feel insecure. Many choose to walk their bike, when they perceive something dangerous such as drivers of cars that do not stop or take cyclists into consideration and cars and mopeds that are driven too fast. However 41% of the respondents do not avoid any site or maneuver.

According to the elderly, the biggest safety problems are potholes, slipperiness and bad snow removal; 76, 74 and 70% of the respondents have referred to these factors as safety problems. However, according to the analysis of the Finnish in-depth crash data, elderly bicyclists are not over-involved in crashes where the road surface was damaged. Possibly the explanations are that elderly ride slower and less in darkness compared to other age groups. Slipperiness and bad snow removal are problems especially in Southern Sweden. Major problems are also curb stones and cars going too fast.

One third of the respondents state that signage and route information for bicyclists is good and another third that it is neither good nor bad. The most frequent comment about posting of signs is that the quality is varying too much. It is good at some sites and bad at others. It is sometimes completely missing and other times damaged.

It is desirable to get information about changes in rules and other news important to cyclists according to almost a third. Especially respondents older than 80 years state that information is important. However, Maring and Schagen [5] conclude that older bicyclists (60+), were deficient regarding knowledge while showing the most positive attitudes. The subjects over 70 performed much worse than the rest of the older group concerning knowledge.

What the elderly say would increase their biking is linked to what they say is important for increased traffic safety. Increased safety would lead to increased biking among the elderly. Requests dealing with the physical design of roads are especially a demand for more and better cycle tracks. Communication
between road users expressed as more and better consideration are also perceived to increase their feeling of security and thereby increase their biking.

4 Expert questionnaire

An expert questionnaire was distributed during the Velo-city 2007 conference. All together, 14 experts answered. At the outset the experts were asked to describe, in their own words, the preconditions for using the bicycle as a means of transport. The most common preconditions mentioned were: safety and a feeling of security when cycling, the existence of a network of roads for cycling including appropriate bike parking facilities and positive attitudes from users and non-users. This is much in accordance with the opinions expressed by the senior cyclists. Some experts stressed the importance of an urban policy for cycle mobility. Reasonable physical and mental abilities of the cyclists were also considered as important preconditions.

According to the experts, the most important needs concerning infrastructure for senior citizens are comfortable, wide bike paths or cycle streets away from main streets, with good directional signage. High curb stones and steep gradients should be avoided. An electric motor could be useful up-hills. Many experts mentioned the importance of detectors well in advance of signalized intersections to give cyclists the possibility to get a green light without having to slow down or dismount their bicycles.

Low motor vehicle speeds achieved by Intelligent Speed Adaptation (ISA) or by other means was by many considered as a prerequisite for safety. Other suggestions to increase safety include warning signals or warning lights to warn cyclists of approaching motor vehicles or vice versa at intersections. Such warning devices could also be useful when a motor vehicle is approaching a bike from behind (or a bike is approaching a pedestrian, but then the sound has to be “gentle” so that pedestrians are not scared). ITS can be used to get better guidance for and visibility of bicyclists at night time, for example through led-lights in the pavements or by increasing the intensity of street lighting at times when cycle traffic is present.

With respect to suggestions to improve the design and equipment of the bike itself, an upright seating position and a low bike frame making it easy to climb on and off the bike was stressed. Some equipment facilitating turning left would be useful as many senior citizens have a stiff neck and bad balance. A rear-view mirror could help, as stated by senior cyclists, but improvements are also possible by designing the infrastructure, so that it becomes unnecessary to merge with motor vehicles when turning left. As mentioned above, cycle tracks are an efficient means to increase safety for elderly bicyclists, as they reduce accidents with left-turning bicyclists [9].

Almost all experts suggested a digital map for on-line route guidance when cycling and also for trip planning before the trip starts. On-line devices like Personal Digital Assistants (PDAs) could also be used, for example, to get local weather information or to find time tables for public transport and especially to see whether it is allowed to bring the bike on the tram or bus. A special design of the devices making it easy for elderly to use them was considered crucial.
The following automatic types of equipment for bikes were considered important to test and further develop: automatic locking and opening e.g. at a distance by using the key as for cars, automatic gears, automatic turning on and off of bicycle lamps (with power supply from a reliable dynamo) and automatic elevating of the saddle after mounting.

5 An expert workshop

The last tool (the expert workshop) included two group discussions structured according to two philosophically different models: The Diamond model and The Multiple comfort model.

5.1 The Diamond model

The Diamond model proposed by Risser [10] includes five areas from which behaviour-steering effects originate and it mirrors also the fact that effects, or areas, are interrelated, see Figure 1. Risser and Ausserer [11] argue that traffic safety experts cannot take decisions that will be accepted by relevant groups, and they certainly will not get their co-operation, without communicating with them in an appropriate way.

The following individual measures were proposed by the group members to develop safe and joyful cycling for senior citizens: Training, Bike pooling and Information & instruction.

Concerning the bicycle e.g.: Easily handable lock, Telematics (GPS), Reflectors and other means to improve visibility, and Assistance for all kinds of communication (e.g. rear mirrors, side blinkers, on-line route guidance).

Concerning infrastructure e.g.: Infrastructure to increase bicyclists' awareness of pedestrians and car drivers' awareness of bicyclists, incl. infrastructure-based
telematics, Awareness raising infrastructure design, including blinking lights, red-coloured lanes, intelligent traffic lights, Sign-posting – big letters and consistent, Route guidance by signs, telematics (GPS), Give space to bicyclists and pedestrians, Places to rest, and Transport on public means.

Concerning society and structure e.g.: Include knowledge about cyclists' needs and characteristics in driving school curricula, Information of the public about rules, health issues, Creating a positive image in the media, Change rules and regulations, and Focus law enforcement on problems of unprotected road users.

And concerning communication between road users e.g.: Infrastructure measures (slow down cars, give place for communication), Laws and regulations enhancing and securing communication, Equipment (rear mirror, Chinese bell), Training and workshops,

5.2 The Multiple comfort model

There are a lot of models to explain driver behavior. Wilde [12] argues that on an aggregated level road users tend to target a certain level of risk (risk homeostasis). This target level of risk can be modified by rewarding safe road user behavior. Summala [13] argues that the following five issues are the most important ones to explain driver behavior on a strategic, tactical and operational (individual) level: safety margins (to survive), good or expected progress of trips, rule following (according to the law and social rules), vehicle/road system (bicycle and infrastructure) and pleasure of driving and pleasure of cycling.

The model is slightly modified to also fit to explain cyclists' behavior. As already mentioned the second group discussion was structured according to this model.

Safety margins imply a concept of available time, which is one basis for the behavioral adaptation phenomenon. One example of this phenomenon is that the safety effect of raising bicycle crossings implying reduced vehicle speeds, were more or less canceled out by increased bicycle speeds [14]. According to the group members it is important to make cyclists and cars visible, for example through warning lights in the pavement, which also was suggested by the experts in the questionnaire. Otherwise, especially in darkness, safety margins tend to be insufficient.

Good or expected progress of trips applies also for cyclists. Cyclists like to maintain their speed and are often hesitating when it comes to braking. As mentioned above many experts mentioned the importance of detectors well in advance of signalized intersections to give cyclists the possibility to get a green light without having to slow down or dismount their bicycles. Gradients, especially downhill, are hazardous especially for cycling children as they were reluctant to brake [15]. Group members suggested rumble strips for cyclists to reduce their speeds at hazardous locations. Cycle infrastructure has to be non-restrictive to be attractive, see [16].

The analysis of Finnish in-depth crash data revealed that 80% of the cyclists had not obeyed some rule. Though this figure is certainly biased due to the fact that the conclusions are often based on the surviving car driver's statements, rule following is obviously critical also for cyclists. Group members suggested
discussions within authorities about rules, for example concerning who should have the right away: driver or cyclists. They also stressed that clear laws for cyclists are crucial to facilitate rule following.

According to Summala [13] the vehicle/road system for cars usually implies smooth car/road performance. This is often not the case for the cycle/road system. A cycle design for elderly cyclists based on new technology is lacking.

Adequate *bicycle infrastructure* is often missing in Europe, except in the Netherlands and Denmark, and if it exists, it often does not comply with the best practise [16]. Cycle tracks in urban areas should be designed *one-directional* [17, 18, 19]. The quality of sign posting for cyclists is varying as stated above. This is not the case for motor vehicles. However, the most stated safety-increasing measure according to the senior cyclists is construction of more *cycle tracks*. More than one third of the respondents want this. Also according to research, cycle tracks are an efficient mean to increase safety for elderly bicyclists, as they reduce accidents with left-turning bicyclists. Jensen [9] concludes that elderly bicyclists (65+) had a significant reduction in injuries, of about 55%, when one-directional cycle tracks (with truncated cycle tracks or raised cycle crossings) were constructed in Copenhagen, though risk increased by 12% if all age groups were included in the analysis. Both European and American experiences show that *bicycle facilities* promote biking [20, 21, 22].

Pleasure of driving will be *pleasure of cycling*, which obviously is an important topic for senior cyclists as 84% of the respondents stated that joyfulness is a reason for them to cycle. Measures should keep or increase the pleasure of cycling.

### 6 Conclusions and discussion

All tools tested here seem to work well together for developing ideas for countermeasures that ensure safe and joyful cycling for senior citizens. With one exception, all aspects mentioned in the expert questionnaire were taken up in group discussions in the expert workshop.

Probably, Intelligent Speed Adaptation on cars is the most efficient measure to provide safe cycling, but other ITS measures are also needed to provide safe and joyful cycling for senior citizens and raise the profile of cycling as such. ITS measures could be linked to, or built into, existing equipment such as navigation systems, cycle computers, and traffic signal control boxes. ITS measures could also increase the comfort for elderly cyclists, *e.g.* automatic locking and opening of bicycles at a distance by using the key as for cars with remote-controlled locks.

### 7 Acknowledgement

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8 References


PRELIMINARY RESULTS OF A STUDY ABOUT THE INFLUENCE OF AN ACTIVE ACCELERATOR PEDAL ON NOVICE AND YOUNG DRIVERS IN AUSTRIA AND THE CZECH REPUBLIC

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ABSTRACT: In this presentation preliminary results of a PhD Thesis carried out in the framework of the NoE HUMANIST will be presented. The thesis itself concentrates on novice and young drivers, their driving behaviour and the possibility to influence them towards a safer driving behaviour. This paper will deal with some descriptive statistics about the first answered questionnaires and the first results about attitudes towards advantages and disadvantages of ISA directly after the use of the system and some months later.

1 Objectives

Novice and young drivers of the age from 15 to 19 are in many countries the group with the highest accident risk in road traffic. In Austria for this age group the risk to get involved in an accident is three times as high as for the general population [15]. Adolescent and young adults are those who are injured and killed mostly on Austrian roads [16]. Additionally it can be stated, that badly adapted speed is the main reason for their accidents [14].

These facts have been the main reasons to focus on this specific driver group, novice and young drivers aged from 18 to 30, and on Intelligent Speed Adaptation, in combination (ISA, see page 2). It is of general interest to learn whether there are methods to make young drivers safer drivers, for instance with the help of telematic devices and/or specific training measures.

2 Methods

The study was based on three important types of methods; driver behaviour observation, psychological group training and questionnaires. The first step was a behaviour observation of novice and young drivers between the age of 18 to 30, using the method of the “Wiener Fahrprobe”, while driving a driving school car along standardise routes in Vienna (Austrian novice and young drivers) and in Brno (Czech novice and young drivers). The observed behaviour at this point can be seen as a kind of baseline reflecting “usual” driving behaviour of the participants.

The “Wiener Fahrprobe” is a standardised observation method that gives a structured impression of an observed individuals driving behaviour. The subjects were observed by one person sitting in the back of the car behind the front passenger seat. The route included sections of different road types, such
as rural roads, motorways, inner city roads, etc., and was divided into sections. For each section the observer had to fill in a sheet concerning standardised, more descriptive variables like lane keeping, behaviour at traffic lights, etc., and non-standardised variables, mostly referring to types of behaviour which could not be predicted a priori for a certain time and space, like communication with other road users.

Additionally, drivers had to fill in four questionnaires. One of them, called “questionnaire for the ISA-study” was developed especially for this study and is based on recent literature [4, 5, 6, 8, 9 & 10], on informal expert interviews, but also on two in-depth interviews with persons belonging to the target-group. Participants had to report about their attitude concerning traffic in general, traffic safety, speeds and ISA. Furthermore the Manchester Driving Behaviour Questionnaire [6] which contains questions about the driving style, risks and mistakes was applied. Another questionnaire was about the type of drivers the subjects themselves though they belonged to. It was developed by the psychonomics AG for the Axa Gruppe and can be found at http://www.autofahrertypen.de/ [17]. Participants had to answer questions about emotions which are important, their attitudes towards the vehicle, which motives are related to driving and so on. The last questionnaire was administered directly in combination with the psychological group training and thus can be seen as an evaluation instrument.

Some months later all participants drove an ISA (Intelligent Speed Adaptation) equipped car along the same standardised test routes. ISA devices have been studied for more than 15 years mostly in Sweden and safety effects are estimated [2, 3 &11]. In those studies it was often pointed out that ISA has a positive influence on the communication of the drivers with other road users. One explanation for this phenomenon is that because of the reduced speed drivers do have more resources to concentrate on the environment, including the social environment. The system used in the study reported here was an Active Accelerator Pedal that gives feedback to the driver by means of pedal resistance as soon as the legal speed limit is reached [12 &13]. During the ride with the ISA equipped car drivers were observed with the help of the “Wiener Fahrprobe”. Again they had to fill in questionnaires; the “questionnaire for ISA-study” and the one about the type of driver one believes one belongs to.

As a next step, a psychological group training was developed where half of the drivers should participate. The goal of the training was to shape participants’ opinion concerning traffic safety in general, speed and speeding but also concerning ISA and the advantages/problems connected to the system. Two sessions were held within two weeks, each of them lasting two hours. The first session focused on motives related to driving and emotions associated to the car. As a consequence of the discussion young drivers should become aware of discrepancies between different motives, like e.g. the need for safety on the one hand and the wish to have fun on the other hand. The second session focused on speed aspects like speed limits, reasons for speeding, problems of speeding, on the advantages and problems of the ISA system, etc..

Finally the driving behaviour of all participants in Vienna and Brno was again observed during a last test ride on the standardised route, so that the practical part of the PhD was finished in August/September 2007.
2.1 Hypotheses

Different Hypotheses have been developed in the frame of this study, mainly based on the assumptions that have been made and discussed before, completed by the preparation work carried out here. The main ones were the following:

Hypothesis 1: The use of an ISA system will improve the communication between the driver and other road users.

Hypothesis 2: Only short-term use of ISA will not be enough to achieve a long term effect on the drivers' attitudes and behaviour.

Hypothesis 3: Special training programs as envisaged in connection with the PhD thesis presented here can change negative attitudes towards ISA and towards speed behaviour in general.

Hypothesis 4: Such training measures have the potential to improve drivers' attitudes and behaviour for a longer period of time.

2.2 Limitations in this paper

There have to be mentioned two limitations of this paper. One limitation is related to the study design. This PhD thesis started as a very ambitious project, with many ideas about how to reach these very specific subjects. In reality it turned out to be more difficult to attract novice drivers to take part in the study. The real number of participants related to answered questionnaires can be seen in table 1. In Austria and the Czech Republic different methods turned out to be successful. In Austria people have been recruited through a webpage where students search for jobs. In the Czech Republic thanks to our partner CDV a driving instructor helped us to search for participants, which was not possible in Austria. That is the reason, why the Austrian subjects are in average older than the Czech ones but also why subjects in Austria have already quite a high driving experience which can be seen in the next chapter. It also has to be noticed that the test and the control group do not have the same size because of practical reasons. It was quite difficult to motivate the young drivers to participate in the group discussion. All results presented here but also those which will be provided in the future will have to be evaluated with respect to these constraints.
Table 1. Study design, pictured by an overview of number of answered questionnaires

<table>
<thead>
<tr>
<th>Steps of the study</th>
<th>Number of people in country</th>
<th>AUT</th>
<th>CZ</th>
<th>Sum</th>
<th>Drop Out</th>
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</thead>
<tbody>
<tr>
<td><strong>Step 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drive in a driving school car</td>
<td>47</td>
<td>27</td>
<td>74</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Fill in &quot;ISA&quot; questionnaire</td>
<td>47</td>
<td>27</td>
<td>74</td>
<td>0</td>
<td></td>
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<tr>
<td><strong>Step 2</strong></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Drive an ISA equipped car on an extra route to get used to the system</td>
<td>40</td>
<td>23</td>
<td>63</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Drive an ISA equipped car on the original route</td>
<td>40</td>
<td>23</td>
<td>63</td>
<td>11</td>
<td></td>
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<tr>
<td>Fill in &quot;ISA&quot; questionnaire</td>
<td>40</td>
<td>23</td>
<td>63</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Fill in MDBQ</td>
<td>40</td>
<td>23</td>
<td>63</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Fill in &quot;Type&quot; questionnaire</td>
<td>40</td>
<td>23</td>
<td>63</td>
<td>11</td>
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<tr>
<td><strong>Step 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Test group</td>
<td></td>
<td></td>
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<tr>
<td>Participate in the psychological group training</td>
<td>15</td>
<td>8</td>
<td>23</td>
<td>5</td>
<td></td>
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<tr>
<td>Fill in &quot;ISA&quot; questionnaire</td>
<td>15</td>
<td>8</td>
<td>23</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Fill in MDBQ</td>
<td>15</td>
<td>8</td>
<td>23</td>
<td>5</td>
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</tr>
<tr>
<td>Fill in &quot;Type&quot; questionnaire</td>
<td>15</td>
<td>8</td>
<td>23</td>
<td>5</td>
<td></td>
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<tr>
<td>Fill in &quot;Training&quot; evaluation</td>
<td>15</td>
<td>8</td>
<td>23</td>
<td>5</td>
<td></td>
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<tr>
<td><strong>Step 4</strong></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Test group/Control group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drive in a driving school car</td>
<td>15/20</td>
<td>8/15</td>
<td>58</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Fill in &quot;ISA&quot; questionnaire</td>
<td>15/20</td>
<td>8/15</td>
<td>58</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Fill in MDBQ</td>
<td>15/20</td>
<td>8/15</td>
<td>58</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Fill in &quot;Type&quot; questionnaire</td>
<td>15/20</td>
<td>8/15</td>
<td>58</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

The other limitation concerns the results presented here. This paper will not yet deal with all of the central hypotheses of the research, but will concentrate on general attitudinal aspects of the subjects whom we have communicated with, concerning their view on what are safe and unsafe drivers, and how an ISA system, according to their point of view, could interfere with the traffic system. The latter aspect was analysed with the help of open-ended questions. The spontaneous answers are summarised in the result chapter. Additionally a first analyse of the answers given concerning ISA will be presented in this paper.

2.3 Participants sample

74 novice and young drivers could be motivated to participate but only 58 finished the study. The others dropped out because of different reasons and at different steps of the study. Out of those 58 just 57 filled in all questionnaires. 34 participants come from Austria and 23 from the Czech Republic. All of them are aged between 18 and 30 years. The mean age in Czech Republic was 19, in Austria 23. The distribution of sex was different in both countries. In the Czech Republic only few women took part whereas in Austria about half of the drivers were female.
Five participants did not have a valid driving licence at the moment of the first ride. 52 had a driving licence allowing them to drive passenger cars and some of them also had a driving licence for other vehicles, like motorbikes or lorries. The driving experience with vehicles of category B can be seen in figure 1.

![Fig.1. Driving experience](image)

The driving experience was in average about 42 months although it has to be said, that the driving experience of the two groups was quite different. In Austria participants had acquired their licence in average 61 months ago, in the Czech Republic this was only about 12 months ago.

3 Results

Concerning their self-perception most novice and young drivers experience themselves as safe drivers but not all of them feel safe in traffic. In the Czech Republic participants feel less safe than in Austria. Good drivers according to participants' view are those, who behave according to the law, who drive anticipatorily and safely, while drivers who endanger others, drive aggressively, do not behave according to the law, drive too fast and reckless. According to the interviewed subjects, speed limits are necessary and are considered as "quite ok" in both countries.

Adolescents in this study have not been aware of ISA that much but all of them have been able to think about advantages and problems of such a system. The most frequent statements (given spontaneously) that reflect advantages of the system were:

- the system makes the driver aware of speed limits
- gives possibility to control one’s behaviour
- can increase traffic safety.

The most frequent disadvantages assumed by novice and young drivers were:

- ISA could be a handicap if someone wanted to overtake
Human Centred Design for Intelligent Transport Systems

- the system would take too much control so that the driver could not behave as he/she likes
- there could be some delegation of responsibility to the system, like speeding when the system was out of function, or speeding in areas where the system would not work
- the system might produce possible errors like setting an erroneous limit, etc.

However, some of the participants believe that ISA does not have any disadvantages at all. All in all, the young drivers that we communicated with are rather neutral concerning the question whether they would use such a system or not. At this point of time it is legitimate to say that their attitude to ISA is not clearly positive, but it is definitely not negative either.

As a next step, the attitudes of novice and young drivers regarding ISA shortly after the use of the system (step 2) compared to their attitude about one year later (step 4) distinguished between the group of subjects with (test group) and without (control group) participating at the group discussion will be reported here as well. The test group consists of 23 subjects whereas in the control group 35 subjects participated. This difference resulted because of practical reasons which already have been mentioned above. It can be seen in figure 2 and 3 that all novice and young drivers assess the advantages of ISA quite positively. On a 5 point scale there are only one to two advantages that are assessed with a value higher than 3 in average (“No control look on speedometer necessary.” and “No control look on traffic signs necessary”). Within the control group, people who did not take part in the group discussion, there are no significant differences between the answers given directly after using the ISA system and those given about one year later after the last test ride. Those participants who underwent the group discussions (test group) assess the advantage “Making aware of speed limits” significantly (t=-2.806; df=21; p=0.011) better directly after using the ISA system (step 2). This result goes against hypothesis 3 at a first step. Further work will have to concentrate on the reasons of that finding.
It is about the same for the disadvantages, shown in figure 4 and 5. Most of the participants agree on the mentioned disadvantages of the ISA system. Within the answers regarding to disadvantages of ISA there is a quality difference. For
instance to realise that ISA might make people rely on the system too much indicates awareness of possible dangerous results. In contrast to this, if ISA is seen as an annoying system it shows that one does not want to renounce fun in order to get safety. In the control group there is one significant difference ($t=2.272; \text{df}=31; p=0.030$) in their rating concerning the reliability of the system. Subjects answered in the last questionnaire (step 4) that ISA users might rely too much on the system, which they thought directly after the use of ISA (step 2) as well. On the other hand there are five significant differences in the attitudes between the two points in time within the test group again. Just two of them “One relies too much on technology. “ and “Uncertainty, if one is unaccustomed to this.” are in the expected direction. The other three statements suggest that the attitudes of the test group towards ISA had deteriorated despite the group discussion in comparison to the control group.

![Disadvantages of ISA without group discussion](image)
Diversity and specificity of road user groups

4 Conclusions

It was found that novice and young drivers in our sample do feel quite safe in traffic and also have many different ideas about attributes of a safe driver and a driver who endangers others. They also have a good imagination about what ISA could accomplish and where the limitations of such a system could lie.

There can be given just few and very restricted answers to hypothesis 3. So far it must be stated that the type of group discussion, realised within this study, did not work in the right way. A reason for this findings might be a group effect of the test group, or it could be that a sensitisation of the test group in regard to problems ISA might have taken place. But this new hypothesis has to be discussed in further steps of analysis. For instance, a comparison of both groups concerning each point in time, broken down into step 2 and 4, will help to find out whether there are significant differences between the test and the control group.

So far it can be stated that a very restricted group discussion in terms of time, as implemented in the frame of the thesis, ad-hoc does not have the potential to change the attitudes towards more traffic safety of novice and young drivers. Maybe this group training at least can cause a sensitisation. Nevertheless for future work a different, “more sophisticated” type of group work has to be considered. Especially, it will have to be more extended in time, as also asked for in connection with legally applied group procedures in, e.g., Austria and Germany [1].
Concerning ISA, in contrast to earlier results, attitude did not change in a positive way after the use of ISA, and those who took part in the group sessions even became more negative, at least in some argument. This might be an effect of age, where one may assume that the attitude towards ISA generally is not that positive and that discussion in the groups even could produce reactance.

To provide comparisons of different nationalities was not possible, due to the differences of the two groups, but this actually never was planned, although it would be interesting. But in any case, the study can provide insight into the structure of attitudes of young drivers and how they can be influenced. But this will only be possible after final provision and analysis of data.

5 References


Internet


COGNITIVE ACTIVITY MODELLING: A CASE STUDY OF LANE CHANGE SCHEMAS AND SENSATION SEEKING

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ABSTRACT: We propose a method to investigate differences of driving at a tactical level, between different categories of drivers. We analysed the naturalistic driving performance of 19 French drivers using an instrumented vehicle. We assessed their sensation seeking scores with the Zuckerman questionnaire. We observed a significant correlation between their sensation seeking score and their mean speed on motorway. We set up a method to model their tactical behaviour and investigate possible correlation between their sensation seeking score and their tendency to perform certain types of behaviour. We applied it to the study of lane changes on motorways. We could model two categories of lane changes but we show that they were not correlated with the sensation seeking score. Despite this negative first result, we are proposing an innovative approach for this kind of study.

1 Introduction

Sensation seeking is a personality trait defined by the seeking of varied, novel, complex, and intense sensations and experiences and the willingness to take physical, social, legal and financial risks for the sake of such experiences [1]. The driving environment is an everyday situation which allows sensation seekers to exhibit typical sensation seeking behaviours. The automobile can provide a variety of intense experiences including: speeding, racing other cars, reckless overtaking [2]. High sensation seekers are more likely to have accidents and receive traffic citations [3, 4] and are significantly more likely to report aggressive driving habits [4].

The habits and preferences of high sensation seekers (HSS) are aimed at maintaining an optimal high level of arousal. Driving is a significant means of achieving this. It is reasonable to assume that accident and speeding ticket prone young drivers are more likely to be high sensation seekers, scoring high on scales that measure attitudes towards speeding and harbouring self-serving attitudes and erroneous beliefs congruent with their higher preferred levels of arousal [5, 6, and 7]. [8] indicated that high sensation seekers were significantly more likely than low sensation seekers to speed, not wear seat belts, drink frequently, drive after drinking, perceive a low risk of detection for impaired driving and perceive that they could drink more beer after being impaired. [9] illustrates that those individuals who score highly on scales which measure
It is apparent that there are substantial differences in the driving behaviour observed in high and low sensation seekers. Questions remain however regarding the differences in the cognitive processes that govern the behaviour of sensation seekers and how these differences can be identified? In an attempt to answer this question we apply the ABSTRACT cognitive modelling approach to data collected using the instrumented vehicle. Firstly we aim to establish that the sample we have selected is representative of sensation seeking behaviour by correlating behaviours that typify the sensation seeker (average speed, maximum speed and Time-To-Collision) with participant’s scores on the general sensation seeking scale. We then used the ABSTRACT methodology to develop a case study comparison to investigate the driving performance of high and low sensation seekers in order to establish differences in cognitive schemas between high and low sensation seekers.

The cognitive modeling of an operator is based on the fundamental notion that they do not act according to the objective status of the world but according to a "mental model" or "representation" that they make of it. Cognitive models are usually constructed by cognitive psychologists or ergonomists. They rely on concepts such as “schemas”, "Scripts" [10], "Scenarios", "Operative Image" [11], or “Situation Awareness” [12]. The latter offers a covering notion by simultaneously addressing the perception, the comprehension and the anticipation for describing how the elements of the situation are “mentally” taken into account by the operators.

The question of knowing which data must be selected to describe “the meaningful (to the subject) aspects of its activity” is a crucial question when one builds cognitive models. Answers to this question can come from both an analysis of the activity and from cognitive theories. To address this question we have developed a method and a tool named Abstract which is described bellow.

This method is based on the collection of behavioral data from driving with an instrumented car. And the transformation of this data to a higher level description of the activity focusing on what is held as being meaningful to the driver. We can so highlight significant patterns of behavior that were actually performed by the subject during the experiment. These patterns can be taken as mental schemas of the activity. It is reasonable to assess that these mental schemas will depend on the subject’s personality. This is this assumption that we would like to investigate here.

2 Method

2.1 Participants

19 (9 male, 10 female) participants were selected at random from an opportunity sample of French drivers. All participants held a French Category B driving license and had normal to corrected vision. The Category B licence permits a driver to drive a vehicle with a maximum weight of 3.5 tons, and seating no more than 9 passengers, including the driver. This includes standard passenger cars, people carriers and microbuses. The average age of sensation seeking are also more likely to commit traffic violations, are more impulsive and are less likely to use their safety belts.
participants was 33 years old (range 25 to 55) and they had held a Class B licence for an average of 13 years (range 2 to 39). They reported an average annual mileage of 12,364 miles per year (range 2,000 to 50,000). Participants received a standard payment of €80 for taking part in this study.

2.2 Instrumented Vehicle

The experiment is run using an instrumented vehicle which is a Renault Scenic. It has a two liter, 16 valve engine. It is fitted with four video cameras that record front view, rear view, side mirrors and the driver and two roof top mounted cameras for obstacle detection. There are a further two cameras linked to an ‘Eyetracker’ system that are responsible for detecting the ‘zone of interest’ towards which the driver has directed their gaze.

![The LESCOT instrumented vehicle.](image)

Fig.1. The LESCOT instrumented vehicle.

It is fitted with a Navteq ADASRP global positioning system (GPS) that is used to compare the recorded data points with the video output. There are four computers located in the rear storage compartment; 1 Pentium III, 1 GHz, P.C. dedicated to collecting vehicle parameters (pedals, steering wheel, speed, acceleration, etc.); 1 Pentium IV 3 GHz dedicated to collecting FaceLab data (gaze detection, direction, etc.); 1 dual Pentium III 1.6 GHz dedicated to obstacle detection and 1 Pentium M 1.6 GHz dedicated to GPS information. It has one point telemeter (LMS) located on the front right of the vehicle and one scanner telemeter (SICK) in front of the car at the centre that works in conjunction with two cameras located on the roof of the vehicle for obstacle detection. The algorithm used in the detection system was developed by INRETS-LIVIC during the ARCOS project (2004). It is equipped with sensors on each pedal, the steering wheel, the indicator and headlights [13].

2.3 The course

The course of the experiment is 50 km long and includes urban, suburban and motorway sections. The urban and suburban sections include numerous junctions, roundabouts and traffic lights. Participants are required to navigate a number of different road types ranging from small roads to large motorways.
This study is primarily concerned with data collected during the motorway section. During the whole course there is a significant interaction with other road users.

### 2.4 Zuckerman’s Sensation Seeking Scale Form V (SSS)

The Sensation Seeking Scale [1] is composed of 40 dichotomous forced choice questions. The forced choice paradigm requires participants to choose the option that most reflects their behaviour. A score of one is given if the sensation seeking option is selected. A score of zero is assigned if the alternative option is chosen. The total score is generated by calculating the number of sensation seeking responses. This scoring system is consistent with other applications of the sensation seeking scale.

Within the general sensation seeking scale there are four contributing factors [14, 15]. Each of these sub-scales is represented by ten questions on the SSS. The dimensions of sensation seeking explored by the SSS are; Thrill and adventure seeking (TAS; Contains questions relating to the participants' attraction to thrill, dread and particularly a willingness to engage in physically risky activities or extreme sports like parachuting, mountaineering and skiing); Experience seeking (ES; Contains questions relating to participants aspirations to undergo a variety of novel experiences through the mind and senses, especially arousing music, art, travel, social non-conformity and the association with fringes of conventional society); Disinhibition (Dis; Contains questions which relate to participants loss of self control and sensation seeking through social activities e.g. drinking, parties, sex) and Boredom Susceptibility (BS; which refers to their intolerance toward monotonous, repetitious or predictable people and events).

### 2.5 Method of behavioural data analysis

For the behavioural data analysis, we have used a methodology and a tool developed at Inrets, called Abstract (Analysis of Behaviour and Situation for menTal Representation Assessment and Cognitive acTivitiy modeling) [16, 17]. It allows us to translate the data collected from sensors in the instrumented vehicle into a higher level of description. This higher level of description highlights patterns of behaviour that can be explained by the fact that the drivers carries out cognitive schemas. These cognitive schemas are shaping the know-how and the reasoning performed by the driver.

### 3 Results and Discussion

The first aim of this study was to analyse the behaviour of participants to ensure that it was consistent with that described in the sensation seeking literature. A key indicator of sensation seeking behaviour in the driving task is speed. In this instance both the average speed and maximum speed were significantly correlated with total sensation seeking score. The presence of this trend in the data is evidence that the sample selected is representative of sensation seekers in general.
There is a significant correlation between sensation seeking total score and mean speed \( r (17) = .550, p< .05 \). This is illustrated in Figure 2 which shows that as sensation seeking total score increases so does the mean speed travelled in the instrumented vehicle. A similar trend is observed between total sensation seeking scores and the maximum speed travelled in the instrumented vehicle. Figure 2 shows that there is an increase in maximum speed as total sensation seeking score increases. This is supported by the statistical analysis of this trend (a significant correlation between sensation seeking total score and maximum speed \( r (17) = .658, p< .01 \)).

A further variable that has been associated with sensation seeking is headway (measured using time-to-collision; TTC); in this instance headway was measured by the forward telemeters. A decline in TTC as shown in figure seven is suggestive of a decrease in the headways maintained by participants scoring high on sensation seeking and although the results of a statistical analysis indicate that the relationship between sensation seeking total scores and TTC is not significant \( r (17) = -.341, p> .05 \). The fact that this is approaching significance is reassuring given the context of data collection. It is possible that there is variability in the TTC measure due to inconsistencies in traffic flow. Differing traffic flow is a key issue in terms of the reliability of results as there are few controls that can limit the impact of this variable. In this study the time of day at which the experiment took place was controlled in the hope that peak traffic flow would be consistent for that particular time, however this does not take into account the impact of school and national holidays, commuters, weekend traffic or other factors that may impact the number of road users during any particular trial.

The weather conditions at the time of the trial can have an impact on the data collection. Rain or overcast conditions can affect the efficiency of the telemeters that measure headway. It can also interfere with the clarity of the video.
recordings provided by the in car cameras. Sunshine can also cause problems with data collection as glare can affect the output of the video recording equipment and can also impact on the accuracy of the eye-tracking data due to reflective glare and the ‘squinting’ of participants. The negative elements of using a naturalistic driving scenario are negated by the rich data that can be collected. When using an ecologically valid experimental paradigm we can be assured that the behaviour observed is realistic.

Fig.3. Correlation of sensation seeking total score with time to collision

### 3.1 Lane change schema

We have focussed our study of tactical behaviour on lane change manoeuvres. We have chosen this type of manoeuvre because it is ubiquitous in the driving environment [18]. It combines many critical features of driving including control, monitoring and decision making. A lane change is defined as a more or less stable sequence of actions that begins with the motivation to change lanes i.e. in the presence of a slow leading vehicle, followed by a gathering of information about the surrounding traffic situation and then the decision whether to change lanes or not. The analysis with Abstract let us [18] identify the two categories of lane change schemas that are explained below.
Fig. 4. Lane_Change_Accelerate

Figure 4 shows a lane change with acceleration. In this situation the driver is impeded by a vehicle slower than his desired speed. He may check his left mirror several times, then, when he decides to overtake, he accelerates while checking his mirror; he switches his blinker on, starts steering, and crosses the line.

Fig. 5. Lane_Change_Stable_Speed

Conversely figure 5 illustrates a lane change where speed is stable, in this situation, the overtaking is done "on the fly" with no speed variation. The blinker is switched on with a good anticipation before the checking to the left mirror and the beginning of the manoeuvre.

Can we therefore, identify differences in the steps (cognitive schema) taken by high and low sensation seekers in a specific driving behaviour (overtaking)? We aimed to do this by identifying differences between frequencies of lane changes by participants with divergent sensation seeking scores. Every participant performs both Lane_Change_Stable_Speed and Lane_Change_Accelerate lane changes, but we could formulate the assumption that high sensation seekers would perform more Lane_Change_Accelerate, because they may have a more dynamic driving style.

However, the relationship between SS-Total and total number of lane changes was not significant, nor did we find evidence to confirm our hypothesis that sensation seekers would perform more lane changes with acceleration than stable lane changes. The lack of a significant relationship between sensation seeking and lane changes is discouraging. However, these schemas were not made with the intention to describe typical low or high sensation seeking patterns of behaviour. We attempted to correlate schema previously defined by [18]. A future direction for this research may involve the analysis of driving behaviour in which participants are pre-selected in terms of their sensation seeking scores. The ABSTRACT methodology could also allow us to model behaviour from the point of view of Sensation Seeking by focussing on indicators that we think may highlight differences with regard to sensation seeking, such as the strength of acceleration or steering.

There are further improvements that could be made to this methodology that may increase the likelihood that we achieve the hypothesised results, they are to increase the sample size and use a simulated driving task. With a larger sample of participants we can increase the power and accuracy of the parameters that we are measuring [19]. It will reduce the variability of measures which will in turn yield more sensitive hypothesis tests with greater statistical
power and smaller confidence intervals. Additionally replication of this experiment in a driving simulator may give us greater control of the experimental context. As suggested in the discussion of the relationship between sensation seeking and TTC the differences in road environment (e.g. traffic flow) may impair our ability to record accurate data. The application of the ABSTRACT methodology in an advanced driving simulator would allow strict control of the driving environment while maintaining the ecological validity of the task. In its current form (instrumented vehicle trial) the Data can be noisy, meaning that the patterns identified are meaningless. Simulation would allow us to replicate the exact traffic flow conditions for each participant so that they are effectively performing the same lane change at the same time which would allow us to better compare the differences.

Given the lack of evidence to support our hypothesis we may have to conclude that sensation seeking is not an important influence on driver’s lane change behaviour. However we believe that we have applied a novel approach to sensation seeking using an innovative methodology and that with further development we may be able to disseminate a relationship between sensation seeking and lane change behaviour.

4 References


Diversity and specificity of road user groups

RISK AWARENESS ANALYSIS: A COMPARISON BETWEEN CAR DRIVERS AND MOTORCYCLISTS

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ABSTRACT: The general framework of this research is about risk awareness through the aspect of cognitive abilities - to perceive and assess the criticality of the driving situation - among motorcyclists versus car drivers. In order to study risk awareness, we have developed some tools based on video films. The experimental task consists in assessing the criticality of dynamic driving situations, via a Likert scale, and qualifying these situations using Osgood’s semantic differential. The results show that riders globally consider our sample of driving situations as less critical than car drivers do. This paper presents the main differences observed between the two populations.

1 Introduction and objectives

This paper deals with drivers versus riders’ awareness of risk while driving. Risk is widely studied in scientific literature as it helps explaining a high proportion of traffic accidents. Risk is then studied from different angles, such as risky driving behaviour through the study of motivations and attitudes towards risk. First of all, risk is more or less linked to human errors problems [1]. Driver Behaviour Questionnaire (DBQ) is one of the tools designed to study this aspect through verbal methods [2]. Risk taking is defined as either a socially unacceptable volitional behaviour with a potentially negative outcome in which precautions are not taken or a socially accepted behaviour in which the danger is recognized [3]. Risk sensation tries to determine the connection between a risky driving behaviour and the driver’s personality factors. Sensation Seeking Scale is one of the tools used to evaluate this aspect of risk [4]. Risk perception refers to the subjective experience of risk in potential traffic hazards or is considered as a precursor of present driving behaviour [5]. Far from tackling every aspect of this concept of risk, our research particularly sets out to understand how a driver becomes aware of risk, and how he / she assesses the criticality of a situation when this situation is likely to turn into an accident. [6].

This work is in line with the research carried out at INRETS (The French national institute for transport and safety research) concerning drivers’ mental activities modelling and simulation [7]. From a methodological point of view, this study continues the experimental protocols developed and validated at the LESCOT (Laboratory of Ergonomics and Cognitive Sciences applied to Transport) for scientific purposes investigating drivers’ mental representations [8], [9]. Indeed, the awareness of risk and the assessment of criticality are two particular aspects of the Situation Awareness [10], mainly focusing on driving situations presenting a risk of collision. Lastly, this research continues the ARCOS project [11] dedicated to the design of “adaptive collision avoidance devices”. Part of the ARCOS project has been devoted to analysing driving
activity when approaching fixed or dynamic obstacles. Within this framework, this naturalistic experiment gathers data collected for twenty-two hours during which 1200 kilometres were covered and over 110 situations with a risk of collision were encountered [12]. All the situations presenting a risk have been analysed. Then, a Driving Activity Model (DAM) in critical driving condition was developed according to these data. When approaching a slow vehicle, the DAM model distinguishes 6 main cognitivo-behavioral phases implemented by the driver in order to avoid an accident [11]:

1. The normal driving situation phase, preceding the occurrence of the obstacle.
2. The realization or risk awareness phase (i.e. the moment when the driver detects the occurrence of an obstacle / the risk of collision and realizes that the situation is critical).
3. The recovery phase (i.e. the driver acts on the situation to avoid collision with the obstacle).
4. The stabilized driving phase, once the driver recovers the situation and controls risks of collision with the obstacle but this does not necessarily mean that the risks incurred are definitively eliminated.
5. The resolution phase, generally amounting to overtaking a slow vehicle when approaching it.
6. Finally, the situation becomes normal again once the obstacle is really out of view.

The focus point of this new research deals with the in-depth analysis of cognitive mechanisms involved during the second phase of this DAM Model: the risk awareness stage. We will thoroughly study the cognitive phase during which the driver realizes that the driving situation, that was normal until then, is suddenly becoming critical. The research aims are the human errors analysis and the cognitive modelling of abilities implemented by the driver/rider to detect or not the critical nature of a driving situation. To study risk awareness, we established a protocol based on 21 ARCOS video sequences (filmed on board a car) and presenting a risk of collision. These sequences are accompanied with a Likert Scale, and with an Attitude Scale in the form of a semantic differential based on Osgood’s work (e.g. [13]) in order to refine the quality of the participants’ subjective assessments. On the base of this methods, it is then possible to study and compare risk assessment performances of different populations of drivers. In this paper, we will present the main results obtained for two categories of drivers: one group of car drivers versus one group of motorcyclists.

The reason why we selected a population of motorcyclists is that over the last 5 years, there has been a significant increase in the number of accidents involving motorcycles on the European roads (+41%). According to the European Road Safety Action Programme [14] 14% of motorcyclists were killed in 2003 although the number of people killed on the road decreased by 12% over this period. Thus, motorcyclists are particularly vulnerable and sensible of risk wherever they are in Europe [15], [16]. In France, 807 motorcyclists were
killed and 17 390 were seriously injured on the road in 2006. Therefore, motorcycle has rapidly become the most dangerous vehicle compared to all the means of transport used on the road [17]. Besides, for each kilometre covered, motorcyclists’ risk of being killed is 20 times higher compared to drivers of standard four-door cars. This leads us to suggest that motorcyclists are forced to show a greater vigilance as they are perfectly aware of their own vulnerability among the other road-users. Although they comply to the same highway code and they resort to the same cognitive processes as car drivers, their vehicle remains more sensitive to weather conditions (rain, black ice…) and infrastructures (slippery road surfaces marking on rainy days, holes or uneven road surface, crash barriers that are dangerous when falling off a motorbike). Moreover, they are more severely injured when they fall off their motorcycle as they have no shell to protect them. The other drivers have more difficulty perceiving them because their vehicle is smaller and faster. They are more fragile within the road network. Nevertheless, according to a study carried out at the French national institute for transport and safety research – INRETS [18] dealing with two-wheelers crashes, motorcyclists have generally more weaknesses during the prognostics and execution phases at the level of cognitive functions while errors made by car drivers rather occur on perceiving and diagnosing situations.

When considering the vulnerability of motorcyclists, they should be more sensitive of risk and should anticipate the evolution of the traffic situation earlier to start a regulation action if the situation worsens. From this fact, it is possible that they do not perceive risks in the same way as car drivers. Certain situations that are considered as not critical by car drivers may be considered as dangerous by motorcyclists owing to a feeling of vulnerability. Conversely, it is also possible that other situations may appear as critical by car drivers, whereas they will be considered as not risky by motorcyclists. In some cases, these last differences could explain the higher level of risk of accident for motorcyclists. This research tries to examine these alternative hypotheses.

2 Methods

The methodology implemented is based on the presentation of 21 ARCOS video sequences (filmed on board a car) of driving situations presenting a risk of collision. These video sequences are divided into 6 categories of situations: approaching fixed obstacles, approaching intersections, changing lanes, following a vehicle, approaching slow vehicles, presence of vulnerable obstacles (pedestrians and cyclists). The participants are asked to stop the sequence when they feel that the situation becomes critical. Moreover, at the end of the sequence, two measurement scales are then submitted to the participants (see figure 1):

- A Likert-type scale [18]: The participants assess the level of risk by moving a cursor sliding along a scale with no graduation. The situation can thus be quantified in terms of criticality on this scale, ranging from 0 % (not critical) to 100 % (high level of criticality).
- Attitude Scale in the form of a semantic differential based on Osgood’s work [13], in order to refine the quality of the participants’ subjective
assessments. This differential is made of 16 antonyms defined for the specific context of driving under critical situation. The use of a semantic differential is complementary to an intensity scale as it helps us investigate the different cognitive dimensions underlying the notion of criticality while driving. This semantic differential is made of 4 dimensions: feelings, predictability, description and implication. Each dimension has respectively 4 antonyms.

Fig.1. Synthetic view of the Risk Awareness Measurement Tool, including a Likert Scale (on the left, below the road scene view) and an Osgood Semantic Differential (on the right)

3 POPULATIONS

We recruited 21 participants altogether. We chose two population samples of drivers in order to check if there were significant differences or not, in terms of risk awareness, between car-drivers and motorcyclists. Owing to the exploratory nature of this study, the size of our samples is limited. We should be cautious about generalizing the results in terms of representativeness of all the French motorcyclists versus car drivers. Nevertheless, we have built two homogenous groups of riders / drivers, regarding their driving experience and age, to increase the interest of the comparison.

Car-driver population: 11 experienced car-drivers (having a category B licence for over 4 years and covering 5000 kilometres per year) participated to the experiment. They have never driven a motorcycle before. They were all about the same age, between 22 and 30 years old (mean age: 28).

Motorcyclist population: 10 motorcyclists participated to the experiment. They all have a Motorcyclist “A” Licence and they rode their bike regularly, in terms of frequency and distance (over 2000 kilometres/year by motorbike). They are between 21 and 52 years old (mean age: 32). Some of them also had a car, but their main means of transport was their motorcycle.
4 Main Results

The first experimental task of the participants was to quantify the level of criticality by means of a Likert scale. This scale had no graduation, but the results were subsequently reported in percentage (from 0 to 100 %). At this stage, we then collected several results:

**Overall criticality values** (via the Likert scale): the criticality average value assessed by all the “car drivers” participants for all the sequences is 57%, against 34% for “motorcyclists” participants. This difference is statistically significant (p< 0,001; T of student test). If we look into the detailed answers given by the participants for each type of sequences, we notice that the category considered as most critical (74%) by the car drivers corresponds to vulnerable obstacles but the motorcyclists considered the same category almost half as critical (38.5%). Moreover, the category considered as most critical by the motorcyclists corresponds to intersections (45%). The car drivers also considered these situations as critical (63%). For this category of situations, the criticality differential for both populations is the smallest (18%). Finally, the categories linked with the presence of an obstacle or depending on an interaction with another vehicle (car, lorry or tractor) are on the whole considered to be not very or not critical at all by motorcyclists (of the order of 20 %). On the other hand, the criticality level of each of these categories assessed by car drivers remains around 50% (from 48% to 56%).

Table 1. Average value of criticality, according to categories of situations

<table>
<thead>
<tr>
<th>Category of situations</th>
<th>Car drivers Crit. %</th>
<th>Motorcyclists Crit. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>category 1: approaching fixed obstacles</td>
<td>56</td>
<td>category 1: approaching fixed obstacles</td>
</tr>
<tr>
<td>category 2: approaching intersections</td>
<td>63</td>
<td>category 2: approaching intersections</td>
</tr>
<tr>
<td>category 3: changing lanes</td>
<td>59</td>
<td>category 3: changing lanes</td>
</tr>
<tr>
<td>category 4: following vehicles</td>
<td>48</td>
<td>category 4: following vehicles</td>
</tr>
<tr>
<td>category 5: approaching slow vehicles</td>
<td>48</td>
<td>category 5: approaching slow vehicles</td>
</tr>
<tr>
<td>category 6: presence of vulnerable obstacles</td>
<td>74</td>
<td>category 6: presence of vulnerable obstacles</td>
</tr>
<tr>
<td><strong>Average value of criticality</strong></td>
<td><strong>58%</strong></td>
<td><strong>Average value of criticality</strong></td>
</tr>
</tbody>
</table>

Criticality values, according to categories of driving situations: We classified our 21 video sequences in categories according to the type of situations that may cause accidents such as approaching fixed obstacles, approaching intersections, changing lanes, following vehicles, approaching slow vehicles, presence of vulnerable obstacles (pedestrians and cyclists). Table 1 present results showing that, by and large, car drivers judged the situations as more critical than motorcyclists. The main significant differences observed between Motorcyclists and Car drivers concern categories 1, 4 and 6.

Categories of situations according to the averages of criticality assessment given by the participants: If we classify the 21 video sequences according the criticality assessments obtained by the two populations, we can see four categories of situations (figure 2). The car drivers and the motorcyclists
feel that 7 sequences out of 21 are critical. They more particularly concern approaches to vulnerable obstacles and one case of failure to give way. On the other hand, 4 sequences are considered as not very or not critical at all by all the participants. Moreover, 8 situations are assessed as critical by the car driver but less critical by the motorcyclist. They more particularly concern approaches to fixed obstacles. Finally, there remain two sequences that the motorcyclists considered more critical in comparison with the car drivers proportionally to their average. Indeed, these two sequences show situations involving a fixed obstacle detected with difficulty and rather belatedly (a lorry parked at the end of a curve) then a sequence filmed in bad weather showing a bus that rapidly enters a roundabout.

![Diagram showing groups of situations according to criticality averages among the two populations.]

**Fig.2. Groups of situations, according to criticality averages among the two populations**

**Early detection:** The car drivers stopped the video sequences from 0.01 to 9.69 seconds earlier than motorcyclists did. However, the motorcyclists stopped 4 sequences out of 21 earlier (from 0.26 seconds to 2.86 seconds).

**Number of sequence-stops:** The car drivers tend to stop the sequences several times (they stop the sequence on risk detection under driving situation). Here is the total number of sequence-stops by all the subjects and of all the sequences: 58 sequence-stops for the car drivers and 21 stops for motorcyclists.

**Results concerning the Osgood semantic differential:** The participants also had to complete the grid of the semantic differential based on Osgood’s approach (table 2) and made of 16 antonyms classified according to 4 dimensions: (1) Predictability (e.g. probability to occur), (2) Feelings (e.g. to be afraid or not), (3) Implication (e.g. to feel responsible or not of the criticality) and (4) Driving situation characteristics (e.g. complexity level of the driving situation). We noticed that all the participants - car drivers as well as motorcyclists - considered the major part of our 21 sequences as Dangerous,
**Fast** and **Abnormal**. However, the car drivers judged these 3 antonyms significantly far more strongly than riders (p< 0.05, T Student test). For instance, the car drivers gave 67% to the antonym **Fast**, against 52% for the motorcyclists. More interesting, we also noticed that the two groups clearly disagree about two antonyms. Indeed, the motorcyclists generally considered the sequences as **Controllable**, and they felt more **Responsible** for the situation. Conversely, the car drivers considered more frequently the sequences as **Uncontrollable**, and they felt less **Responsible** of the criticality of the driving situation.

Table 2. Answers given by the participants to the Osgood semantic differential*

(Shaded items show a significant difference via Student Test: p<0.05)

<table>
<thead>
<tr>
<th>Antonyms</th>
<th>Drivers (%)</th>
<th>Motorcyclists (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe / Dangerous</td>
<td>71.80</td>
<td>57.69</td>
</tr>
<tr>
<td>Stressful / Calm</td>
<td>33.08</td>
<td>42.59</td>
</tr>
<tr>
<td>Disturbing / Reassuring</td>
<td>31.69</td>
<td>40.36</td>
</tr>
<tr>
<td>Difficult / Funny</td>
<td>67.52</td>
<td>65.74</td>
</tr>
<tr>
<td>Soliciting / Ordinary</td>
<td>44.12</td>
<td>49.56</td>
</tr>
<tr>
<td>Irresponsible / Responsible</td>
<td>39.25</td>
<td>58.42</td>
</tr>
<tr>
<td>Brought about / Suffered</td>
<td>57.44</td>
<td>68.75</td>
</tr>
<tr>
<td>Uncontrollable / Controllable</td>
<td>45.21</td>
<td>64.92</td>
</tr>
<tr>
<td>Probable / Improbable</td>
<td>56.65</td>
<td>51.21</td>
</tr>
<tr>
<td>Rare / Frequent</td>
<td>73.62</td>
<td>67.10</td>
</tr>
<tr>
<td>Abnormal / Normal</td>
<td>35.35</td>
<td>46.96</td>
</tr>
<tr>
<td>Unpredictable / Predictable</td>
<td>56.72</td>
<td>59.43</td>
</tr>
<tr>
<td>Slow / Fast</td>
<td>67.47</td>
<td>52.67</td>
</tr>
<tr>
<td>Complex / Simple</td>
<td>51.51</td>
<td>57.15</td>
</tr>
<tr>
<td>Dynamic / Static</td>
<td>38.52</td>
<td>36.60</td>
</tr>
<tr>
<td>Forced / Open</td>
<td>64.74</td>
<td>70.55</td>
</tr>
</tbody>
</table>

(*NB: note that for this Osgood’s scale, a value of 50% is the “origin” and means that not any of the 2 antonyms is chosen. If % value is < 50%, the situation is then defined by first antonym (like “Safe”). If % value is > 50%, it means that the 2nd antonym (like “Dangerous”) is assessed as more relevant to describe the driving situation

**Typical example of diverging answers between the car drivers and the motorcyclists:** To conclude this part dedicated to the results presentation, we would like to present detailed data collected concerning a typical case of diverging answers between the two populations (see Figure 3). The case (Sequence n°21) corresponds to a situation assessed as very critical by the car drivers (69%), but not critical at all by motorcyclists (18%).

Diverging answers between drivers and riders for this sequence could be explained like that. During this situation, after having passed a bend in a roadwork zone, the participants see a pedestrian finishing crossing the road (20 meters in front of our vehicle). For the car drivers, this situation is critical due to
the combining effect of the pedestrian presence on the left (after he crossed the road) and the car incoming in the opposite direction. Consequently, they must reduce their speed to avoid an accident. Conversely, it is easier for motorcyclists to manage risk in this case: only the pedestrian’s crossing behaviour could be potentially critical, but as he is now walking on the left side along the road, the criticality is low for riders and it is possible to bypass him without any interference with the incoming car on the opposite way. Semantic differential results show that this situation is assessed as highly Dangerous (83.91%), Fast (89.09%), Stressful (29.45%), Uncontrollable (33.09%), Disturbing (21.27%), Abnormal (26.82%) and Irresponsible (17.27%) by car drivers. On the contrary, this situation is identified as not Dangerous (54.5 %; reminder: the “0” value for Osgood scales are 50%), but very Frequent (70%), Predictable (70.70%), Simple (61.80%) and Controllable (59.30%) by motorcyclists. These results clearly confirm the interest and the validity of our “Risk Awareness Measurement” methods for studying and understanding the nature of divergences between different populations of road users, concerning risk assessment.

SEQUENCE n° 21:

<table>
<thead>
<tr>
<th>ANTONYMS</th>
<th>Driver (%)</th>
<th>Rider (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe / Dangerous</td>
<td>83.91</td>
<td>54.50</td>
</tr>
<tr>
<td>Stressful / Calm</td>
<td>29.45</td>
<td>46.70</td>
</tr>
<tr>
<td>Disturbing / Reassuring</td>
<td>21.27</td>
<td>42.10</td>
</tr>
<tr>
<td>Difficult / Funny</td>
<td>66.82</td>
<td>57.10</td>
</tr>
<tr>
<td>Soliciting / Ordinary</td>
<td>36.00</td>
<td>43.90</td>
</tr>
<tr>
<td>Irresponsible/Responsible</td>
<td>17.27</td>
<td>53.00</td>
</tr>
<tr>
<td>Brought about / Suffered</td>
<td>38.82</td>
<td>48.80</td>
</tr>
<tr>
<td>Uncontrollable/Controllable</td>
<td>33.09</td>
<td>59.30</td>
</tr>
<tr>
<td>Probable / Improbable</td>
<td>54.82</td>
<td>54.70</td>
</tr>
<tr>
<td>Rare / Frequent</td>
<td>62.64</td>
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<tr>
<td>Unpredictable / Predictable</td>
<td>59.00</td>
<td>70.70</td>
</tr>
<tr>
<td>Slow / Fast</td>
<td>89.09</td>
<td>67.30</td>
</tr>
<tr>
<td>Complex / Simple</td>
<td>48.36</td>
<td>61.80</td>
</tr>
<tr>
<td>Dynamic / Static</td>
<td>36.64</td>
<td>35.20</td>
</tr>
<tr>
<td>Forced / Open</td>
<td>49.27</td>
<td>47.00</td>
</tr>
</tbody>
</table>

Osgood semantic differential results for the each population (Shaded items show a significant difference: p<0.05)

CAR DRIVERS
Criticality score for Car Drivers (Likert Scale): 69%

MOTORCYCLISTS
Criticality score for Motorcyclists (Likert Scale): 18%

Fig.3. detailed results collected for sequence n° 21
5 Discussion

The purpose of this research was to elaborate a methodology allowing us to collect assessments of risk and to evaluate traffic situations presenting a risk of collision among two populations of experienced drivers (11 car drivers and 10 motorcyclists). Motorcyclists are supposed to be more aware of risk as they are very vulnerable on the road in case of accident. From this point of view, they should judge “risky” situations as more critical and be aware of risks earlier.

As far as criticality assessment is concerned (grade given in percentage between 0 and 100), the results show that, on average, the car drivers consider the situations presented as more critical than the motorcyclists (reminder: 53% for the car drivers and 34% for the motorcyclists). Moreover, the car drivers stop the sequences more often and earlier on average. Nevertheless, we may say that some of our driving situations represent a minimal risk for a motorcyclist while they are perceived as risky by a car driver. For instance, we had 4 video sequences showing approaches to fixed obstacles which are very easy to manage for a motorcyclist but more difficult for a car driver. Consequently, the average value of criticality for all the sequences is not the main relevant result in this experiment. The most interesting results concern in-depth analysis according to the type of traffic condition and driving context.

Indeed, a thorough analysis of our results shows that the risk assessments of our video sequences between the two populations are not homogenous according to our different categories of situations. There were 6 different categories of situations. Approaching fixed obstacles or approaching slow vehicles are not considered as critical by motorcyclists since it is easier for a motorbike to bypass these obstacles when a car driver should slow down or stop. On the other hand, approaching vulnerable obstacles (pedestrians, bicycle, etc.), and more especially crossing intersections is on the whole assessed as far more critical by the motorcyclists in comparison with their overall criticality value of all the situations in so far as they fear that the car drivers may not adapt their speed correctly. More simply, they fear that car drivers may not spot them in time. Besides, accidentology data show that half of the accidents involving a PTW and a car on an intersection are due to the car’s failure to give way in 55% of the cases [19]. It is interesting to notice that motorcyclists often considered our situations as critical when they took place in unfavourable weather conditions. But generally, what is often considered dangerous for motorcyclists is the quality of road surface, holes, gravels, rain which is normal since the security of the motorbike is mostly ensured by the grip of the machine on the road.

Concerning the semantic differential, it is interesting to mention that the situations are judged as “controlled” and “responsible” (i.e. involving the rider / driver’s responsibility) by motorcyclists, while it is the contrary for car drivers. These 2 antonyms refer to the notion of involvement: the fact of feeling “responsible” for what is happening and the fact of feeling able to “control” the situation. Those last results are interesting. Indeed, being perfectly aware that they are very vulnerable in case of accidents, this awareness tends to make motorcyclists more aware of risks. That is what the differences observed for these two antonyms seem to reveal.
6 Conclusion and perspectives

The general framework of this research was to analyse the cognitive mechanisms involved in the assessment of collision risks when approaching fixed or dynamic obstacles. We compared two populations of road users, one of which being particularly exposed to risk (motorcyclists).

As the size of our driver samples is limited, we should be cautious about generalizing the results in terms of representativeness of all the French motorcyclists versus car drivers. Nevertheless, the protocol developed during this experiment appeared to be very discriminating since it enabled us to collect very different data between the two populations. We can also notice that criticality assessment differences, observed between car drivers and motorcyclists, differ or not according to the various categories of driving situations.

Within the framework of a current research, we will question more car drivers and motorcyclists. Concerning riders, more specifically, a new research is in progress at LESCOT with the aim to compare risk awareness abilities for different profiles of motorcyclists (e.g. novice versus experienced riders, motorcyclists who like sport motorbikes, versus Harley Davidson or Scooters). In this work, the characteristics of the riders’ personality are also assessed by studying Zuckerman Sensation-Seeking Scale [20].

We will also draw a parallel between our video methods and other more classic verbal methods implemented for Driver’s attitudes towards risk study and/or human errors analysis (like the DBQ questionnaire; e.g. [2, 16]), with the aim to evaluate correlations between social cognition on one hand, and risk awareness abilities, on the other.

7 References


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SESSION 6: DRIVERS’ ACCEPTANCE OF ASSISTANCE FUNCTIONS
DRIVERS’ RELIANCE ON LANE KEEPING ASSISTANCE SYSTEMS: EFFECTS OF DIFFERENT LEVELS OF ASSISTANCE

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ABSTRACT: Overreliance on Advanced Driver Assistance Systems (ADAS) and a lack of involvement in the driving task reflect current safety-concerns in connection with the increasing automation of the driving task due to ADAS. It is hypothesised that those effects gain relevance the more ADAS intervene in the cognitive and regulatory processes underlying driving. In a driving simulator study drivers’ preparedness to divert attention away from the driving task was investigated as a function of the level of assistance. Forty-five drivers drove 55 km on a simulated rural road with either one of three levels of lane keeping assistance: (1) a high level of assistance realised by a Heading Control system, (2) a low level of assistance realised by a Lane Departure Warning system, and (3) no assistance (control condition). Drivers’ attention allocation to a visually demanding secondary task served as a measure for their reliance on the systems.

1 Introduction

In an attempt to increase road safety and to reduce the number of traffic deaths and injuries, active safety in-vehicle technologies gain more and more importance as a complement to passive safety technologies. The main aim is not only to reduce actual crash consequences, but also to minimise crash risk. Advanced Driver Assistance Systems (ADAS) are electronic in-vehicle systems that offer support to the driver while driving and aim at enhancing driver (and traffic) safety and comfort. ADAS intervene to different degrees in the driving task and in vehicle control. Although ADAS are supposed to positively influence driver behaviour and safety, the full range of possible adaptation effects in response to the introduction of these systems is at present difficult to predict (e.g., [1]). Safety concerns with ADAS are primarily related to possible negative human performance consequences that arise in conjunction with the automation of task processes, as extensively studied in other domains like aviation ([2]). Because ADAS - according to their type and functionality - intervene in different levels of the control processes involved in driving, they change the way the driving task is performed and affect the information processing and action regulation processes involved in driving. The “relieving” function of ADAS may indeed positively influence driver performance and comfort in non-critical (“normal”) driving situations, but may have negative impacts in situations that suddenly demand for drivers’ intervention; for instance situations that lie beyond
the ADAS’ functional scope or disturbing events such as system failures or malfunctions.

In aviation research, evidence was found for problematic adaptation effects such as overreliance on systems and inappropriate trust in system capabilities ([3, 4, 5, 6, 7, 8, 9]), complacency ([10, 11, 12]), vigilance problems and high mental workload due to system monitoring demands ([13, 14, 15, 16, 17, 18]), underload ([19, 20, 21]), and reduced Situation Awareness ([22, 23, 24, 25, 26]).

It is suggested that the occurrence and size of possible problematic adaptation effects is related to the degree the operator is taken “out-of-the-loop” from the controlled processes (e.g. [25, 27, 28]). Thus, system characteristics like the design of the human-machine interaction and the systems’ performance (e.g., reliability) play an important role in the evolution of adaptation effects. A number of studies demonstrated the strong relationship between system reliability and its effects on human trust and monitoring behaviour ([29, 30, 4, 6, 7, 9, 10]). People tend to rely on and to neglect monitoring of highly reliable systems, after they have gained a sufficient level of trust in their performance. Highly reliable systems reduce the necessity for human intervention in the automated processes. A reduced involvement in the task, coupled with changes in cognitive (information processing) and regulatory processes (e.g., vigilance) are most likely consequences. Similar effects are predicted for the impact of the level of automation, i.e. the level of control the operator has in the human-machine interaction (e.g. [22]). In the automotive area, overreliance on ADAS and a lack of involvement in the driving task (e.g., reduced Situation Awareness, attention shifts to driving-unrelated activities) reflect major safety-concerns in response to the introduction of ADAS. In this study drivers’ preparedness to divert attention away from the driving task is investigated as a function of the level of (lane keeping) assistance. Thereby the focus laid on an initial interaction with a system under high demanding conditions that were designed to promote reliance on the system. Of special interest are potential changes in drivers’ reliance after encountering critical situations where they have to override the system or to ignore the system’s actions.

2 Methods

The VTI advanced moving base driving simulator III in Linköping, Sweden, with a 120 degrees horizontal field of view was used in this study (Figure 1). Participants drove six times on a rural road of 11 km length with one driving lane in each direction. The lane width was 3,5 m. The speed limit during the study was 70 km/h.
2.1 Participants

Forty-five participants (23 male, 22 female) aged between 25 and 45 years ($M = 33.7; SD = 6.4$) took part in this study. They had been driving at least 5000 km during the last year. Most of them had been driving in the VTI driving simulator before.

2.2 Levels of lane keeping assistance

The 45 participants were randomly assigned to one of three experimental conditions (15 participants in each condition) representing three different levels of assistance in lane keeping: (1) Driving with a Heading Control system (HC condition) corresponding to the highest level of lane keeping assistance, (2) driving with a Lane Departure Warning system (LDW condition) corresponding to a low level of lane keeping assistance, and (3) driving manually (MD condition) without any assistance in lane keeping (control condition). The LDW system warned the driver via a vibration in the steering wheel when he or she crossed the lane markings. The HC system guided the drivers within the lane by applying counter forces on the steering wheel as soon as they were approaching the left or right lane marking. Both systems were 100% reliable during the whole study.

2.3 Secondary Task

Concurrently to driving participants performed a visually demanding secondary task: The Arrows Task developed in the European HASTE project. The visual distraction caused by this task should provoke lateral path deviations and thus enable drivers to experience the actions of the lane keeping assistance systems and to develop trust in the system. Furthermore, drivers’ attention allocation to the primary driving task and the secondary task was used as an indicator of their reliance on the assistance systems (compared to non-assisted driving).

The Arrows Task was presented on a 7 inches TFT touch screen mounted in the centre console of the simulator vehicle. The secondary task display was positioned on a horizontal eccentricity of about 22 to 37 degrees visual angle to the left of the driver’s straight-ahead line of sight and on a vertical eccentricity of about 13 to 22 degrees visual angle below the driver’s straight-ahead line of sight. The Arrows Task started on certain road marks which were the same for
each driver in each condition. The duration of one Arrows Task was 30 s. One Arrows Task consisted of a series of displays presenting different configurations of 16 arrows pointing in different directions. For each display drivers had to decide if there was an arrow present pointing upward and to accordingly press the "yes" or "no" buttons in the upper or lower part of the screen, respectively. The time out for each display was 5 s. Response times above 5 s were recorded as missing responses. Each presentation of a new display was signalled by a sound. Additionally, drivers got an auditory and visual performance feedback.

2.4 Procedure

Participants were instructed to drive as they would usually drive on a real road with corresponding character concerning interaction with other traffic participants, speed choice, manoeuvring, and time gaps. Participants were instructed to use the turn indicator to signal their intention to depart from the driving lane, e.g. during lane change manoeuvres. They were informed that the activation of the indicator would suppress the lane departure warning and deactivate the HC system’s steering torque. Participants in the HC condition were additionally told that they could principally override the system if they applied a counter force to the steering wheel greater than the maximum steering force of the HC system.

Participants started with a training session in order to become accustomed to driving with the simulator and with the LDW and HC system. During the training session participants were instructed to perform some lane change manoeuvres in order to experience the systems’ functionality. After that participants practised the secondary task while the simulator vehicle was parked. Participants were instructed to perform the Arrows Task as well and as fast as possible while driving, but without jeopardising traffic safety.

Subsequently participants performed two experimental drives. During the first drive (about 15 min.) participants were supposed to build up a stable level of trust in the system and adapt their time-sharing strategies accordingly. During the second drive (about 25 min.) drivers encountered eight critical situations in which they had to react accordingly in order to not compromise traffic safety or violate the traffic rules. The LDW and the HC system were 100% reliable during the whole study (no system failures occurred). However, the critical situations lay partly outside the systems’ functional limits and thus, drivers had to override the systems. Of special interest are the potential changes in drivers’ trust, reliance, and workload as a function of their experience of these critical situations.

2.5 Dependent Measures

Performance-based measures of drivers’ time-sharing strategies (eye glance behaviour, secondary task performance) were used as indicators of their reliance on the lane keeping assistance systems. Additionally various subjective measures were collected after the two experimental sessions in order to assess amongst other things drivers’ alertness and mental workload, their perception of
system performance, their trust in the systems, and their opinions about how such systems may influence their safety and driving behaviour.

3 Results

All measures were subject to a 3 x 3 factorial repeated measures ANOVA with the level of assistance (Heading Control, Lane Departure Warning, No Assistance) treated as between-subjects factor and the session/criticality of driving situation (session one – no critical driving situations, session two – no critical driving situations, session two – critical driving situations) treated as within-subjects factor. Some first results of the analysis are presented below.

3.1 Secondary Task Performance

Drivers performed 19 Arrows Tasks in the first experimental session and 25 Arrows Tasks in the second experimental session.

3.1.1 Response Accuracy

Response accuracy was generally very high for all experimental conditions. Unassisted drivers had a higher percentage of correct answers and a lower percentage of false and missed responses in the Arrows Task than LDW drivers and HC drivers in both experimental sessions. This difference was however not significant. The performance of the unassisted drivers improved from session one to session two (in terms of percentage of correct and false responses), whereas the performance of the LDW and HC drivers deteriorated from session one to session two. The interaction between level of assistance and session/criticality of driving situation was not significant. HC drivers generally missed more responses than LDW and unassisted drivers (n.s.). There was a highly significant effect \((p < 0.001)\) for the occurrence of critical driving situations, in that response accuracy deteriorated considerably in critical situations compared to non-critical driving situations in both sessions.

3.1.2 Mean Number of responded displays

Each Arrows Task lasted for about 30 s. During one Arrows Task a number of displays representing different arrows configurations were shown. Dependent on how fast drivers responded to each single display, more or less displays were presented during the whole duration of one Arrows Task. Drivers in the HC condition on the average answered the smallest number of displays and LDW drivers answered the largest number of displays during one Arrows Task in non-critical driving situations. For HC and LDW drivers, performance in critical situations in session two was better than performance in non-critical situations in session one; whereas the performance of unassisted drivers was worse during critical situations in session two compared to non-critical situations in session one. There was neither a significant main effect for the level of assistance nor a significant interaction between the level of assistance and the number of session/criticality of driving situation. There was a significant performance improvement for drivers in all conditions in non-critical driving situations from session one to session two \((p < 0.001)\).
3.1.3 Reaction time

Reaction times were calculated for all displays except those drivers missed to respond to within five seconds (recorded as missing responses). LDW drivers and drivers in the no assistance condition reacted faster than HC drivers in non-critical driving situations. This effect was not statistically significant. There was a significant main effect for the session/criticality of driving situation factor, in that reaction times were significantly longer during critical situations compared to non-critical situations in both sessions for all levels of assistance ($p < 0.001$). Reaction times decreased from session one to session two but this effect was not significant.

3.2 Eye glance behaviour

This analysis is based on a total number of more than 13000 display glances.

3.2.1 Mean single glance durations to the secondary task display

HC drivers had the longest mean single glance durations to the display in session one and the shortest mean single glance durations in session two. Mean single glance durations to the display decreased from session one to session two, but this difference did not yield statistical significance in post-hoc analyses. However, there was a significant effect for the criticality of the driving situation, in that mean single glance durations to the display were significantly shorter during critical situations compared to non-critical situations ($p < 0.001$). During critical situations, unassisted drivers had the longest display glance durations compared to HC and LDW drivers.

3.2.2 Mean display glance frequencies

LDW drivers had the highest frequency of glances to the display; and HC drivers had the lowest display glance frequency in session one. During session two, HC driver looked less often to the Arrows Task display than LDW and unassisted drivers. Unassisted drivers looked most often to the display in session two. There was no significant effect for the level of assistance and no significant interaction between the level of assistance and session number/criticality of situation.

There was however a highly significant main effect ($p < 0.001$) for the session number/criticality of situation factor: Drivers in all conditions looked significantly less often to the display in session two (compared to session one), and looked least often to the display during critical driving situations.

4 Discussion

The results show that drivers adapted their task related effort to driving task demands. In critical driving situations, drivers allocated fewer resources to the secondary task, confirmed by a significantly worse secondary task performance and significantly shorter and fewer glances to the secondary task display in critical driving situations.

There is also evidence for a general training effect for drivers’ performance in the secondary task. Drivers answered more displays in session two than in session one, and reaction times slightly improved. Furthermore, drivers needed
significantly fewer glances to extract the relevant information from the secondary task display in session two compared to session one.

The results for the different levels of assistance show a more complex picture. There was no significant main effect of the level of assistance for any of the measures.

For the Arrows Task performance, there was a surprising finding in that unassisted drivers performed better than HC and LDW drivers in terms of response accuracy. This difference was also obvious in critical driving situations. A further interesting finding was that HC and LDW drivers’ Arrows Task performance deteriorated from session one to session two (in terms of percentage of correct and false responses), whereas performance of unassisted drivers improved. HC drivers had the highest number of missing responses during both sessions and especially in critical driving situations. In critical driving situations there seems to be a tendency for LDW drivers of tempting to respond to displays rather than to omit them (even when the answer is false), whereas HC drivers rather drop the secondary task. One possible explanation for these findings could be that HC drivers had to invest some additional resources in system control, which was particularly necessary in session two when they had to recognise critical driving situations which required them partly to override the HC system.

There seems to be some further evidence for interpretation in the results of the eye glance measures. For HC drivers both duration and frequency of glances to the secondary task display decreased from session one to session two. HC had the longest display glance durations in session one, and the shortest display glance durations in session two. For LDW and unassisted drivers there was mainly a difference in glance frequencies from session one to session two (less frequent display glances in session two), whereas display glance durations were similar in both sessions. Unassisted drivers had the longest and also the most frequent glances to the display in critical driving situations.

Further analysis of other glance behaviour measures (e.g. the percentage of time spent looking to the display during one Arrows Task) and the relation of the behavioural measures with the subjective data (e.g. mental workload) will complete the picture of drivers resource allocation strategies when driving with different levels of lane keeping assistance.

5 Acknowledgements

This study was funded by a grant for infrastructure-sharing from the HUMANIST Network of excellence (HUMAN centred design for Information Society Technologies; www.noehumanist.org). We would like to thank the following persons at VTI for their overwhelming support in conducting this study: Anne Bolling (for a lot of fruitful discussions and the timely management of the study), Beatrice Söderström, Birgitta Thorslund and Jerker Sundström (for being experimental leaders), Håkan Jansson and Laban Källgren (for realising the simulator scenarios), Göran Palmkvist (for implementing the lane keeping assistance systems), Mikael Adlers (for implementing the secondary task), and
6 References


USER ACCEPTANCE AND EFFECTIVENESS OF WARNING AND MOTOR PRIMING ASSISTANCE DEVICES IN CAR DRIVING

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ABSTRACT: This paper deals with driving assistances that intervene when a lane departure is imminent. Previous work [1] showed that motor priming devices (devices prompting the driver to take action by means of an asymmetric steering wheel vibration) were the most effective warning systems. The present experiment tries to qualify the different lane departure warning systems not only in terms of effectiveness but also in terms of acceptability. For this, both objective and subjective data were collected. Firstly, the study shows that acceptability and effectiveness are not necessarily correlated, and can even be contradictory. From an ergonomics point of view, we claim that a compromise should be reached between those criteria. Secondly, we show that a combined mode (sound and motor priming) could be a solution to find such a compromise. Finally, a perspective for further research is to better combine the modalities, through improved synchronization of the driver sensations.

1 INTRODUCTION

In order to contribute to the ergonomic design of safety devices for critical situations in cars, a research project on Human-Machine cooperation (Predit-Prevsensor) deals with lateral control situations where additional devices are assumed to enhance safety. For Hoc and Blosseville (2003), safety devices in car driving can be classified into four levels of Human-Machine cooperation [2]: (1) perceptive mode, (2) mutual control mode, (3) function delegation mode and (4) fully automatic mode. In the particular case of lateral control, some proposed safety devices belong to mutual control mode. This means that drivers have full control of their vehicles, but their driving behavior can be criticized (warning mode devices). Moreover, safety devices can lead drivers to correct their trajectory (motor priming) by inducing asymmetric vibrations in the steering wheel for example.

Previous studies on safety devices applied to lateral control show ambivalent results. The effect of motor priming in steering wheel was found to depend on inter-individual variations ([3]; [4]), and in some cases, driver response went opposite to the suggested action [3]. However, [1] demonstrated by a comparative evaluation technique that, among five driving assistance devices, all belonging to mutual control mode, motor priming was found to be superior in terms of effectiveness. Indeed, the asymmetric vibrations on the steering wheel seem to guide the driver to take the correct action. Nevertheless, acceptability of such vibrations was not discussed.
In accordance with this finding, the present study aims at checking advantages of the mutual control mode for lane departure prevention, and particularly the superiority of motor priming when induced through the steering wheel. Beyond effectiveness measures and theoretical utility [5], the users point of view regarding similar driving assistances is assessed. Investigating drivers’ subjective side is particularly justified by the fact that Human-Machine cooperation is considered as a management of interferences between different agents [6]. Actually, the study of the representations of the system, the attitudes and the motivations are crucial to understand how and why the human feels either comfortable or reluctant to cooperate with the machine, in order to control the dynamic driving situation. In other words, what the users think and expect from the device, as well as how they perceive it, needs to be evidenced. More generally, comfort or discomfort, pleasure or displeasure, satisfaction or dissatisfaction ([7]; [8]) constitutes the heart of this framework.

In this paper, motor priming through the steering wheel is presumed to be more effective than a warning, because the direct intervention on the action level should improve corrective maneuvers and situation diagnosis. However, for the same reasons, drivers could reject this assistance. Besides, a study on social acceptability of driving assistance devices showed that users’ judgments are unfavorable when the assistance takes more or less control of the driving situation [9].

Following this idea, a mode that combines motor priming and auditory warning is proposed. In this case, it is assumed that a sound reminding driving on rumble strips is potentially acceptable. Furthermore, [10] showed that when preexisting or direct association between the sound and the event is strong, this pairing tends to be learned and retained more readily. This may induce that auditory warning implying strong or direct association with the event should be more understandable and thus acceptable. The aim of this paper is therefore to check whether combining motor priming with auditory warning improves driver acceptability along with keeping device effectiveness.

2 METHOD

2.1 Participants

Twenty participants (16 men and 4 women) ranging from 23 to 52 years old (mean = 34) took part in this study. Sixty percent of them cumulated more than 10-years driving experience. Participants were volunteers from Renault workers and none of them was involved in the design process of driving assistances.

2.2 Material

2.2.1 Simulation

Experimentations took place on a dynamic driving simulator (Cards2, developed by the Technical Centre of Simulation of Renault). The platform consists of a driver's cabin (on top of an hexapod) with a manual gearbox and a 150° vision of the driving scene. The cockpit was specifically equipped with the following devices: (1) haptic seat, (2) haptic steering wheel (vibration or asymmetric
oscillations) and (3) 3D sound. Simulated driving scene was a country road, where “legal” speed limitations were fixed at 80km/h on straight lines and 70km/h in curves.

2.2.2 Interview
An open interview inspired by explicitation interview techniques ([11]; [12]) was performed. These techniques aim to explore implicit, pre-thought-out aspects of a physical or mental action. The objective of the interview was to collect the description of the action (effectively) realized by the driver. Interviewer has to guide drivers to operate a thinking-out of their experience and to put it into words. Techniques of explicitation allow « to help the user to describe his activity such as it took place in this situation, such as what he did, perceived, thought and felt during that specific situation» ([7]; [8]). Although we did not perform a real explicitation interview as defined by Vermersch, we were strongly inspired by those techniques by using non-inductive questioning. The aim was to collect verbal reports on feelings, senses, internal states, thoughts that were lived by the driver with a driving assistance device.

2.3 Driving assistances
Five driving assistance devices were assessed in this study. All these devices were activated in case of imminent lane departure (with axial line or bank line).

- The auditory warning mode consisted of a lateral 3D sound coming from the side where lane departure occurred. The emitted sound was similar to a rumble strip noise.
- The wheel vibratory warning mode was produced by a lateral haptic vibration from the side where lane departure occurred.
- The motor priming mode was generated by an asymmetric haptic stimulation on the steering wheel. In other words, jolts on the steering wheel indicated the direction of the trajectory to adopt. The stimulation was not sufficient in itself to correct the trajectory.
- The seat vibratory warning was produced by a lateral haptic stimulation from the side where lane departure occurred.
- The combined mode consisted of a combination between the auditory warning mode and the motor priming mode.

2.4 Procedure
After a familiarization phase with the driving simulator, participants performed ten laps, of five minutes each. Runs were alternated between lap, with and without assistance. After assisted laps, the experimenter interrogated briefly the driver about what he or she had just experienced. To control any order effect, presentation of various assistances was counterbalanced among the participants.

Driving scenarios were defined to control lanes departures. Every assisted ride consisted of four critical events, two before the curves’ entry and two on straights lines. The non-assisted ride also consisted of two to four critical
events. For each critical event, a slight gusts of wind occurred (drivers were unaware of this occurrence) in parallel with a distraction task to provoke lane departures. This relatively “ecological” secondary task was supported by a screen placed in the driver's cockpit at the usual place of the radio and was set up in order to distract the driver by means of a “reading task” (scrolling of a list of three words per second).

Drivers had been instructed to adopt a "laid-back" driving attitude and to keep both hands on the steering wheel in “10:10” or “9:15” time position. They were informed that the beginning of the reading task would be randomly indicated by a beep sound for several times. The importance to maintain attention on reading while maintaining steering wheel angle was strongly emphasized until the end of secondary task (which was synchronized with the assistance onset if present). At last, drivers were invited to maintain speed driving as far as possible with speed limit standard and to respect those standards. Experimenter reassured participants that these experimental conditions were made to provoke lanes departures.

After each lap, participants were asked to describe their own personal experiences when lane departures occurred: what happened for them? What were their feelings or thoughts? At the end of the experiment these short descriptions were re-examined with the subject in a way to avoid inductive questioning. These post interviews took place in the simulator's cockpit to facilitate drivers' remembrance of the assisted driving. Afterwards, subjects were invited to classify the assessed modalities in order of preference (without ex-aequo).

2.5 Data analysis

Three types of data were analyzed: performance measures (lane departure durations), rankings and verbalizations. Only rankings and verbalizations are detailed in this paper for eighteen participants out of the twenty original because of a destroyed tape. Further details about performance values can be found in Navarro et al [13].

2.5.1 Ranking

Assistance devices were statistically analyzed in terms of order of preferences. Ranking results were used to find which modality was the favorite and which one was unfavorable. In addition, Friedman non-parametric test was used to highlight, if applicable, significant differences between modalities.

2.5.2 Analysis of contents

The detailed analysis of verbalizations underlined four discursive categories: a) Sensory sensation (pleasantness, inconvenience, unpleasantness, etc.); b) Interpretation of the type of alert (lane departure), of its location (side departure), and the corrective action required (towards the lane centre); c) Perceived utility; d) Attitudes (satisfaction, dissatisfaction, etc.). Those categories were evidenced thanks to content analysis methods. First, we categorized participants’ speech in positive and negative dimensions; then we extracted and classified spontaneous verbal reports able to describe drivers’ acceptability. In addition, the previously mentioned emergent categories are
Drivers’ acceptance of assistance functions

close to some well-known acceptability criteria in Human-Machine Interaction field ([5]; [14] for instance). Through this analysis we wanted to identify in details, from actual experiences of the subject, the inherent reasons for approving or rejecting such or such modality.

2.5.3 Driving performances

The variable retained was the lane departure durations. Values were interpreted in terms of effect of the assistance device on lateral departure. In other words, we were interested in the time saved thanks to the assistance device.

3 RESULTS

3.1 Rankings

The rankings (fig.1) show a first approach of the compared levels of systems acceptability.

![Fig.1. Proportion by rank of the relative classification in order of preference](image)

Figure 1 illustrates participants’ relative preferences for auditory warning. It appears mainly as a second choice (50% in rank 2). While sound is globally preferred, results regarding vibratory warnings (seat and steering wheel) are scattered. In addition, combined mode is rather scattered (39 % in rank 1 and 2 and 34 % in rank 4 and 5). Finally, motor priming device obtained the worst results, mainly classified between rank 4 and 5. Friedman test did not reveal significant global differences of driver’s assessment of the modalities, probably due to the few number of participants. Moreover, figure 1 shows that differences between auditory warning and motor priming are sensible (tendency). Furthermore, verbal reports (§ 3.2) corroborate this idea.

3.2 Analysis of content

- Auditory warning appeared to be the least intrusive modality. Indeed, some positive comments underline the non-aggressive aspect of this modality: “this one is really soft”; “this one is probably the least violent”… Analogy of the simulated noise along with perceptible noise of real driving (rumble strips) enabled drivers to represent themselves as having a lane departure. Attitudes were rather favorable, but many drivers had some doubts about discriminating
this sound in real vehicle’s sound environment: “I thought there were a lot of signals in the vehicle, so how can I distinguish this one from another one”…

- Motor priming device was outlined as the most intrusive modality. Globally lateralization was generally not well perceived: “the jolts are not indicative, it’s like a back and forth movement”... In addition, jolts in the steering wheel disturbed some drivers who confused it with their usual driving sensations on the steering wheel. This confusion could have caused troubles such as a feeling of trajectory lost of control for example: “I have the impression not to control the car”…

- Combined device presented different perceptive representations. Two perceptive profiles were evidenced: those who used both signals and those who used one of the most salient signals according to the individual’s sensibility: “I had the feeling to react because of the sound and not because of the sensation detected by my hands” or “the sound, it is like I did not hear it because there is a lot of things”. Additionally, risks of confusion inherent to stimulation in the steering wheel were evoked.

- Vibration warning on the steering wheel caused various representations. First, lateralization was not well perceived (felt on both hands) but some drivers reported that the signal allowed them to anticipate correction. Besides, many participants were confused and annoyed.

- Vibration warning on the seat revealed a scattering of preferences. Globally, lateralization was perceived without ambiguity but it was not systematically associated to lane departure side. Furthermore, the location of the vibrations can be annoying.

### 3.3 Acceptability vs. effectiveness

Auditory warning was generally preferred, without being ideal as reported by some drivers. In addition, drivers rejected motor priming device whereas opinions relative to combined device were scattered. Figure 2 shows driving effectiveness with respect to tested modalities.

![Level of acceptability](Image)

Fig.2. Effects of the auditory warning [high acceptability] and the motor priming [low acceptability] on lateral lane departure durations (normalized against control condition)

For further details regarding performance measurements, see Navarro et al [13].
Drivers’ acceptance of assistance functions

Statistical analysis revealed that motor priming device had a significant effect on lane departure duration compared to control condition in straight lines as well as in curves. Nevertheless, the majority of drivers significantly rejected this device. The auditory warning also tends to decrease lane departure durations but not significantly. Furthermore, compared with other assistance devices, performance (duration of lateral excursions) was among the worst, although paradoxically, it was significantly preferred than motor priming. Combined mode allowed driver to be more successful with respect to other devices while subjective judgments were scattered. Moreover, effectiveness and preferences of vibratory warning on seat as well as on steering wheel presented scattered results and thus were hardly distinguishable.

4 DISCUSSION

In this paragraph, the results are interpreted with respect to the hypothesis and the general aim of this study. More specifically, integration of an acceptable and effective driving assistance device for safety applied to lateral control is discussed.

First, the experimental protocol was quite ecological and therefore relatively close to a real driving situation, thanks to methodological choices. Dynamic driving simulation has the particularity to immerse the driver in driving situation and thus to preserve most of his usual driving task, at least at the operational level considered here. Besides, simulated distraction task, defined as a punctual appearance of a reading task, is quite close to real distractions sources (navigation tasks, audio, inattention, etc.). Thus, in spite of the simulation bias, the representativeness of the experimental situation allows to access, to some extent, to the drivers subjective point of view.

Study of acceptability of driving assistance devices through the evocation of lived experience was particularly rich. In particular, the several dimensions of acceptability (Feeling/Interpretation/Utility/Attitude) underlined were useful to compare modalities in details. For example, the speech relative to feeling and interpretation were widely positive for sound, and negative for motor priming; while the perception of utility was lightly positive for both sound and motor priming.

Overall, assistance devices comparison shows the superiority in terms of acceptability of auditory warning with respect to motor priming. On one hand, ideal experimental conditions permitted to perceive the sound well and therefore auditory warning was ranked at the head of preferences. Nevertheless, participants had some doubts regarding “easy” perception of sound when driving in a real car, and in real conditions; this may explain why auditory warning appeared mainly in second choice (50 % in rank 2, fig.1.). On the other hand, reproduced sound, which reminded of noise induced by driving on rumble strips, strongly contributed to the acceptance of tested auditory warning. These findings confirm the influence of sound design on acceptability.

Nevertheless, asymmetric steering wheel vibration (motor priming), which was supposed to be more efficient was confirmed as it induced the best successful correction. However, this assistance was not fully accepted by drivers, due to
the location of the stimulation. Indeed, most drivers believe that steering wheel represents a prominent component to control vehicle and they were not very confident in the use of this device in real driving conditions: in a real car, vibrations are transmitted to steering wheel, and their amplitude and frequency depend on road type, speed, vehicle, etc. This may induce unsafety feelings and discomfort when using motor priming because drivers could not only confuse whether vibrations are related to infrastructure or to assistance device, but also lose control of their car.

Concerning the combined device, results in terms of effectiveness are equivalent to those found with the motor priming device alone. In terms of acceptability, some subjects declared that auditory warning helped them to better interpret motor priming stimulation: “I do not know if it is the combination of sound and steering wheel, but it seemed for me easier to manage”; “maybe thanks to sound, I was able to distinguish the first priming vibration. I do not know why it was easier for me to feel it”. Nevertheless, for others, non-synchronization signals, bad laterализation of motor priming device and confusion risks influenced negatively their user’s representation.

To conclude, the initial hypothesis on the combined mode is still reliable because the association of a sound, accepted by the majority of drivers, with efficient asymmetric vibrations on the steering wheel, seems to be a good compromise to combine effectiveness and acceptability. Nevertheless, a better integration of these assistance devices (by improvement of the synchronization frequency between sound and haptic stimulation for example) is still necessary to improve acceptability with preservation of device effectiveness. It should be noted that this compromise is difficult to obtain.

Effectiveness, which has generally been considered as a fundamental criterion for acceptability and usability in the Human-Machine Interaction domain\(^1\), appears not to be the most important factor for Human-Machine cooperation. Indeed, driver did not immediately perceive the beneficial effect of the assistance, and thus acceptability was not influenced. Besides, interferences management, one of the important criteria of Human-Machine cooperation, can induce annoyance even if performances are raised. However, this criterion of effectiveness is essential in conception choices. This paradox makes important to discuss where to place effectiveness in the user-centered conception loop. It could be overcome by a compromise between device effectiveness (performances measures for example) and acceptability criteria as defined in this study.

5 CONCLUSION

Evaluation of acceptability in mutual control modes, through the analysis of spontaneous and provoked verbalizations, evidenced which modality was preferred and which one was rejected. In addition, these data permitted to understand individual and collective reasons of these differences. None of all assessed modalities was found to make unanimity of preferences, and drivers’

\(^1\) Because of the narrow link between perceived and real effectiveness.
opinions were various. However, it clearly appeared that: (1) auditory warning device was preferred although classified as second choice and (2) motor priming device was massively rejected because of various reasons, such as the location of the stimulation. Assistance devices' effectiveness did not influence drivers' choices in terms of acceptability, and hence effectiveness could not constitute the only criterion to choose cooperation mode.

In this paper, we underlined the potential gap between acceptability and effectiveness. This point can be a crucial one for an efficient design of the assistance. Consequently, we have to find the best compromise between these criteria. In our study, the results of the combined device (sound and motor priming) could be a possible solution for such compromise: the result of effectiveness is good in terms of effectiveness and quite good in terms of acceptability.

Furthermore the detailed analysis of verbalizations showed that for a majority of subjects the combined device was not felt as a unified sensation but as two distinct ones. This is the main explanation for the relative poor result of the combined device in term of acceptability. Further studies should address this major point by improving the accuracy of the synchronization of those sensations.

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7 References


REFLEKTAS – USAGE OF REFLEXIVE DRIVER REACTIONS IN ADAS-DEVELOPMENT

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ABSTRACT: In common lane-keeping systems drivers are warned of lane-departures by acoustic, visual or haptic devices. Thus, an association between the signal and the desired action has to be established. Because the association is vulnerable to interference and decay, the functionality of cognitive systems is suboptimal. The new approach uses behavioural strategies. By eliciting a steering-reflex, the attention of the driver is attracted and the correct reaction is initiated. This principle was explored with 23 participants in a driving simulator. First results already demonstrate the functionality of the principle. Eliciting the appropriate reaction prevented road departures.

1 Introduction

One goal which was set by the European Commission is to halve the number of road fatalities between 2000 and 2010. They want to achieve this by harmonisation of penalties and they promote new technologies to improve road safety [1]. Other countries have their own, smarter goals like the “Vision Zero” in Sweden [2]. One way to improve road safety is to develop new driver assistance systems in order to prevent fatal crashes. Because lane departures are a major cause of fatal crashes, many lane-keeping systems are developed.

2 The cognitive and the behavioural approach in the design of Lane Keeping Assistance Systems

Classical cognitive systems use acoustic, visual or haptic devices to warn the driver. Visual information of the vehicles status could be found everywhere in the cockpit and centre console. Different blips are used for different acoustic information or warnings. In case of the haptic devices, for example some car manufacturers produce a vibration at the steering-wheel [3] or on one side of the driver’s seat [4]. And there are some researches on assistants which use a smooth force on the steering wheel in the direction of the middle of the lane.

In doing so an association between the signal and the desired action has to be established in the context of learning processes. The drivers have to learn the different associations. These also vary between the different car manufacturers. The associations are subjected to interference and decay. Therefore the functionality of these cognitive systems is suboptimal.
In contrast, our new approach uses behavioural strategies to prevent road departures. Established, stable and irreversible stimulus-reaction links which are involved in reflexes are used, which lead to a better reliability, even in situations with a higher workload. There is no need for extra attention to process the new incoming information by the driver.

Furthermore the reaction times are much shorter – reflexes have the shortest latencies with 20-120ms – as reflexes involve other neural structures than cognitive processes. There is no moment of shock which delayed a driver’s reaction, because the reaction is reflexive.

As Figure 1 illustrates, reflexes comprise the brainstem and spinal cord, whereas consolidated behaviour and intended actions involve higher regions like the cerebellum or the association cortex. Consequently cognitive information processing requires more time to produce an action in comparison to reflexive reactions.

Fig.1. Scheme of the different levels of the sensomotor process and neural structures, which are involved in these processes. The suggested hierarchical order is simplified. In favour of a better illustration many afferent and efferent connections are ignored [5]

3 The new approach of Lane Keeping Assistance

The aim of the development of the new lane keeping assistance is to overcome the disadvantages of conventional cognitive systems. Primarily we want to achieve faster reaction times and less incorrect reactions. The innovative idea is to elicit a steering-reflex by a jerk at the steering wheel to initiate the correct reaction and simultaneously enhance the driver’s attention. The drivers’ reflexive response starts even before he recognises what he is doing. But at this
moment of recognition he is still turning the steering wheel in the right direction. He has only to control the end of the reaction and fulfil the task.

The jerk is triangular and symmetric and proceeds into the same direction in which the driver begins to leave the lane, thus a reflexive reaction against the deviation is provoked. This principle was successfully analysed in several studies in a driving simulator at the German Aerospace Center.

4 The Studies

The first of a number of studies explored systematically different adjustments of the jerk to find the most effective one. Therefore a high number of variations between the strength and the duration of the jerk have been tested. Afterwards the jerk which was identified as the most appropriate was further examined. A total of 23 participants took part in the study. The average age of the sample was 40 years (SD=11). They drove for about one hour on a simulated rural road.

Figure 2 shows the HMI-Lab at the German Aerospace Center which is used in the studies.

![Fig.2. The HMI-Lab at the German Aerospace Center](image)

The usual cause for failures in lane keeping is distracted attention of the driver. Thus, we simulated such a condition by presenting a distracting task to the driver. While the drivers worked on this task, the system simulated a tendency of the car to leave the lane on one side by means of adding a defined steering angle. The distracting task was realized in two different forms, simulating different forms of impaired attention.

One half of the participants had to track a ball which moved across the scene with their eyes. The ball changed its size from time to time. The participants
were asked to indicate such an event by means of two buttons on the steering wheel.

The other half of the participants had to solve easy mathematical tasks which appeared on a screen in the centre console. These drivers had to indicate if a presented solution was right or wrong with the same two buttons on the steering wheel. Due to the distraction tasks, the participants did not recognise the tendency of the car to leave the lane. As the car reached a pre-defined distance to the lane-edge, the assistant was activated.

Afterwards the additional steering angle was deactivated in order to avoid any artefact in the steering movements due to it. The subjects continued normal driving and after a few minutes, the process started again.

5 Results

All studies which have been carried out demonstrated the functionality of the principle. The jerk produced the reflexive response regularly and immediately after the assistant has been activated. The participants reacted with a reflexive steering-movement directed to the correct side. The compensatory corrective actions following the reflex did not build up and the participants did not overcompensate. Moreover there was no steering in the wrong direction. This also indicates that the jerk that was used was able to evoke the desired reflex.

Figure 3 shows an idealised reaction pattern for a departure to the right side of the lane.

![Idealised reaction pattern](image)

**Fig.3. Idealised reaction pattern, explanation of the different measures**

In order to better characterise the reaction, different measures were calculated. A difficulty in the analysis of the reaction is that the participants react so fast that the reset of the steering wheel produced by the system merges into the start of the participant’s reaction. Therefore no exact reaction time can be
calculated but only the maximum of the reaction time, which surely describes an event quite a while after the reaction started. The maximum reaction time of course is a very conservative measure and heavily overestimates the actual reaction times.

Another important measure is the time from the onset of the assistant until the car changes the direction. Furthermore the primary reaction (the reflex) and the secondary reaction (compensatory reaction) have to be described. At the end of the second component of the compensatory reaction which could be described as an idealised damped oscillation the car follows its usual track in the middle (or nearly in the middle) of the lane.

In addition to the objective data from the simulation, subjective data was collected. After each study the participants were asked if they liked the system and felt comfortable with it. In the first studies the participants stated that the system helped them not to leave the roadway and that they felt safe with the system.

Detailed analyses of the gathered data are under way.

6 A look into the future

Further studies will examine the reactions of drivers with different steering modalities, like holding the steering wheel with only one hand.

Also the status of the drivers’ vigilance will be varied. Could the reflex triggered with the accurate result during microsleeps?

The usefulness of a number of systems designed to apply principles of our behavioural approach is currently under examination and will be presented in the future.

7 References

MEET THE DRIVER NEEDS BY MATCHING ASSISTANCE FUNCTIONS AND TASK DEMANDS

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ABSTRACT: Test drivers drove in fog as well as with clear visibility. They were assisted with informing, warning or intervening Driver Assistance Systems or drove without assistance. Driving data and acceptance judgments show the best safety and acceptance values for the Info-Assistant. The Info-Assistant allowed the consistent driving behavior, the safest headway parameters and the shortest danger exposure. Acceptance evaluation showed that the Info-Assistant provided the most relief and maintained control over driving at the same time. Paying attention to task demands gives some useful information about the user needs. Matching of task difficulty and assistance functionality seems to be a useful step within the development of Driver Assistance Systems.

1 Introduction

Advanced Driver Assistance Systems (ADAS) are supposed to increase traffic safety. Although a lot of systems are available the take rate with 1% of all cars is low [1]. Therefore positive consequences for traffic safety are small and should be enhanced. Maybe car drivers don’t know the advantages or the functionality of these systems. At the same time with the introduction of active systems (such as lane departure warning) there will be more and more systems that involve the driver and need his understanding of their functioning. This requires more precise knowledge about the cooperation of driver, car and ADAS than with passive systems (ABS e.g.). The development of ADAS motivated by economic or technical aspects doesn’t seem to be very useful. Instead, the development process should focus on the driver and his needs to get some assistance. This assistance needs arise mainly from the difficulty of the driving task since task difficulty is a main determinant of driver behavior [2]. According to the Information Processing Approach (e.g. [3]) the difficulty can consist in perceiving the relevant information, deciding or executing the action correctly. ADAS could then assist through information, warning or intervention. For example, if perception in fog is difficult an ADAS could inform you about relevant things in your near environment, could warn you and facilitate your decision or could brake by itself. It would be useful to know if matching of the functionality of ADAS (informing, warning, intervening) with task difficulty (perception, decision, action execution) results in better driving performance and system acceptance. Traffic safety could profit because systems would be more efficient and then maybe more systems would be used because of the better acceptance. Therefore this knowledge could be useful for the development process of future ADAS.
2 Method

We examined this question with the Dynamic Driving Simulator of the DLR. 16 test persons participated aged between 24 and 39 years (mean = 30.1 years, STD = 4.85 years). Participation was voluntarily and compensated. Before the experiment each driver completed a training session in the simulator. In the experiment the subjects had to drive on a straight road for 10 minutes and repeatedly approached a lead car which drove with a constant speed of 50 km/h. After at least 20 seconds each lead car pulled off the road and the participants had the chance to drive unaffected until they approached the next lead car. The distances between the cars within one trial varied between 900 und 1600m. The order of the distances varied from trial to trial to inhibit that the drivers build some expectations about the appearance of the next car.

As independent variables we varied the task difficulty and the functionality of assistance. Task difficulty was varied by creating two different perceptional conditions. In the easy task condition the drivers had clear visibility conditions. In the difficult task they drove in fog. In both conditions they were instructed to drive safely and as fast as possible. To prevent any velocity reduction especially in the difficult condition which might reduce task difficulty we additionally motivated the test persons to drive fast by time measurements. The assistance functionality was varied by supporting the drivers either by an informing, warning or braking Assistant or let them drive without assistance. The experiment was designed as a within-subjects design. Thus each driver drove in clear visibility with either an informing, warning or braking Assistant or without assistance and each driver drove in fog with either an informing, warning or braking Assistant or without assistance.

To let the test drivers familiarize themselves with the Assistants and to minimize any carry-over effects each trial was performed twice and just the second trial was used for the analysis. Half of the participants started with the easy task, the other half started with the difficult task. The order of the assistance conditions within the difficulty condition was counterbalanced.

The different Assistants were supposed to support different parts of the driving task. The Info-Assistant is supposed to support the perception of the headway to a lead car since it always shows a topview of the road and a possible lead vehicle in a head-up display. The Warning-Assistant gives an auditive and visual signal depending on the collision risk (based on the Time-To-Collision) and is supposed to facilitate the decision to brake. The Brake-Assistant brakes if the collision risk is imminent to prevent any collision and gives some visual and auditive feedback. Figure 1 shows the three Assistants.
The three Assistants were activated at different times. The design emerged from preliminary expert tests. The Info-Assistant was always present and started to display the lead car very early to give the driver enough time for the next steps to take. The Warning-Assistant was active when a certain threshold for the time-to-collision was reached. It warned early enough to allow the driver a moderate braking action but it warned late enough not to anticipate the driver's decision to brake. The Brake-Assistant intervened as the latest when the time-to-collision was small. It braked early enough to avoid a collision but late enough to allow the driver braking by himself.

3 Results

Three of the ten approaching events of each trial were chosen because then the distance to the next lead car was large enough and there were no missing data. For each of this three events the driving behavior before the approaching (phase 1) and during the approaching process (phase 2) was examined. Phase 1 lasted 7 seconds and ended when the lead car was 6 seconds (time headway) away. Phase 2 lasted at least 20 seconds depending on the driving behavior and ended when the lead car left the road to the right. The activities of the Assistance Systems started during phase 2, the always present Info-Assistant just showed an empty road in phase 1. The results were analyzed using a Two-Way Analysis of Variance with repeated Measurements with the factors task difficulty (clear visibility and fog) and Assistance System (without assistance, Info-Assistant, Warning-Assistant and Brake-Assistant).

First I will focus on phase 1 and start with the speed behavior. As desired there were no velocity differences between difficulty conditions and Assistance Systems in phase 1. Thus the drivers didn’t reduce the task difficulty of the fog condition by reducing the velocity. Also no Assistance System induced a lower or higher velocity either. A meaningful variable of the speed behavior is the speed variability. It describes how much the drivers changed their speed and showed a main effect of the task difficulty (F(1,14) = 14.97, p< .05). With clear visibility velocity changed more. Mean deceleration showed the same effect which means that there was more braking activity under clear visibility conditions. A reason might be that the lead car in the clear visibility condition was already visible in this phase and the drivers started decelerating. Furthermore speed variability showed a main effect of the Assistance System (F(3,42) = 5.37, p< .05) with the Info-Assistant leading to the most constant speed behavior. Again, mean deceleration was responsible which was the
lowest with the Info-Assistant. Driver behavior in phase 1 is also useful to examine possible behavioral adaptations since drivers in this phase drove unaffected by any lead car. Therefore we compared the mean velocity of the first event with the mean velocity of the third event and found no differences ($F(1,13)= 0.396, p= 0.54$). Thus there were no short term behavioral adaptations.

Phase 2 showed no velocity differences between the visibility conditions or the Assistance Systems as well. As instructed the test persons drove with similar velocity in clear visibility as well as in fog. This time speed variability in fog was higher than with clear visibility conditions ($F(1,14) = 8.92, p< .05$). This again resulted from the deceleration behavior which showed the same main effect. In phase 2 braking in fog was more severe than in clear visibility and the drivers decelerated to a lower velocity. The speed variability depended also on the Assistance System ($F(3,42) = 3.06, p< .05$). The Info-Assistant allowed the smoothest speed behavior. Especially in fog drivers reduced their speed with the Info-Assistant not to the same extent as with the other Assistants. Figure 2 shows speed variability as a measure of driving behavior.

This speed behavior can result in safe or unsafe traffic situations that are especially in phase 2 a matter of interest. An important safety indicator is the time-to-collision (TTC) that contains the time until a possible collision occurs and measures therefore how dangerous a situation is. Traffic situations with less than 4 seconds TTC are considered to be dangerous. The proportion of the dangerous time (TTC) to the time of the whole phase describes how long danger existed. This time-exposed TTC shows a main effect of task difficulty ($F(1,14) = 26.94, p< .001$), which means that the danger in fog existed for a longer period of time than with clear visibility. Other safety indicators showed the same effect. Distance headway or time headway describe how closely the driver followed the lead car. In fog the mean time headway and the mean distance headway were smaller than with clear visibility. Furthermore the time-exposed TTC depended on the interaction of visibility condition and Assistance System ($F(3,42) = 5.34, p< .05$). With the Info-Assistant in fog drivers were not as long exposed to the danger than with the other Assistance Systems.
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Distance headway and time headway were the safest for the Info-Assistant as well. However, the duration of lane exceedences was the longest with the Info-Assistant \( (F(1.5, 21.1) = 4.95, p< .05) \) but happened mainly with clear visibility. Figure 3 shows time-exposed TTC and lane exceedences as measures of traffic safety.

Acceptance was measured with questionnaires after each trial. Driver judged the speedometer in the trial without assistance instead of an Assistant System. With judging the content of the Assistant drivers evaluated how useful information about the distance to the lead car is compared to a collision warning or a collision-dependent intervention. Results showed an interaction of task difficulty and Assistance System \( (F(3,42)= 4.67, p< .05) \). With clear visibility information about the distance made no sense, but in fog it’s usefulness was similar to a warning or intervention. Evaluations of the user interface tended to depend on the interaction of both factors \( (F(3,42) = 2.61, p= .064) \). The user interface of the Info-Assistant performed poorly with clear visibility but as good as the other Assistants in fog. The relief through the use of assistance showed an interaction, too \( (F(3,42) = 2.9, p< .05) \). The test drivers evaluated whether distance keeping to the lead vehicle was easier or more difficult when using the Assistant. The Info-Assistant made this task easier, especially in fog. Control over driving is another important variable and describes how the use of an Assistant changes the own control over driving. It was evaluated dependent on both factors \( (F(3,42) = 4.85, p< .05) \), which means that the Info-Assistant in fog reduced the control least of all. However, the distraction through assistance showed a main effect \( (F(1.7,23.8) = 9.94, p< .001) \) with the Info-Assistant distracting most. Figure 4 shows the important evaluations.

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Fig.3. Time-exposed TTC and duration of lane exceedences
4 Discussion

In the experiment the participants drove on a straight road with good or bad visibility conditions and therefore different task difficulties. They were supported by one of three Assistance Systems that differed in the kind of functionality or they drove without assistance. Following our instruction they drove in both task difficulty conditions with the same velocity. Thus the drivers didn’t reduce task difficulty of the fog condition and they experienced a more difficult driving task in the fog condition than with clear visibility. Task difficulty further resulted in different driving behavior. In phase 1 deceleration was stronger with clear visibility since they already saw the lead car, whereas in phase 2 they had to decelerate stronger in fog. The difficult fog condition resulted also in less safe traffic situations. Drivers then had lower safety margins and dangerous time periods were longer. More relevant than task difficulty effects are the effects of the different Assistance Systems. No Assistance System tempted the drivers to drive faster. The test persons drove more consistent with the Info-Assistant than with the other Assistants since they didn’t have to decelerate so much. In phase 2 the Info-Assistant especially in fog generated less deceleration. Thus the Info-Assistant allowed a very smooth driving behavior with early and weak decelerations. The Info-Assistant also resulted in the best traffic safety values especially in fog. Dangerous time periods with the Info-Assistant were shorter. Distance and time headway were safer. Acceptance evaluation in the fog condition didn’t differ between the Assistance Systems regarding the delivered content (distance information, collision warning or collision-dependent intervention) and the user interface. The major subjective advantages of the Info-Assistant consisted in the usefulness. The Info-Assistant allowed the most control over driving which corresponds with the better anticipative abilities in driving behavior. In addition the Info-Assistant facilitated distance keeping most which corresponds with higher traffic safety in driving behavior. However, drivers evaluated the Info-Assistant as most distractive which is supported by the time of lane exceedences. Since the Info-Assistant doesn’t result in more variation in the lateral position than the other Assistance Systems, the distractive effect should be of more subjective than objective nature. Overall the
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Info-Assistant shows the best driving behavior, the highest traffic safety and the best acceptance evaluations.

Our study shows that the longitudinal control in a perceptually difficult driving task is best assisted by an Assistant that provides early information about a lead car. The Warning-Assistant which gave a warning about some danger with the request to brake or the Brake-Assistant which intervened in case of an emergency resulted in less safe traffic situations and these Assistants were also less accepted. This happened despite the fact that these systems also gave the driver enough time to brake, thus didn’t induce any time pressure. Apparently it is most useful for the driver in this situation to get some information about future events which allows the driver to anticipate his behavior. With the different Assistance Systems we also tried to vary different Levels of Automation. The Info-Assistant represents the lowest level since it just gives some relevant information about the environment and the driver has to deal with the consequences. The Brake-Assistant represents the highest Level of Automation since it acts for the driver. The study shows that the highest degree of automation is not always desirable. One has to consider also the task difficulty.

On the other hand we do not know if the drivers really used the Assistance Systems as they were intended to use. For example it is quite possible to use the Brake-Assistant as a warning when the start of the system’s activity is used as a hint to start with braking. Similarly it is possible to use the Info-Assistant as a warning when one specific status of the display is used to start braking. We hope to get some insights into this issue when we evaluate the interviews where we asked the participants how they used the systems. Another weakness of the study is that the functionality of the Assistance Systems is confounded with the kind and number of the used sensory channels. The Info-Assistant just uses the visual channel, the Warning-Assistant additionally uses the auditory channel. The Brake-Assistant uses the visual, auditory and the haptic channel. However, the used channel results from the functionality of the assistance. One cannot combine each functionality with each channel, e.g. an intervention must use the haptic channel and can’t be visual. This restriction means that we can’t be sure that the advantages of the Info-Assistant only result from it’s informing character, maybe the used channel is also responsible. However, we found no differences in the acceptance evaluations regarding the used channels. As another possible weakness the functionality of the Assistance Systems is confounded with the different times they started to be active. Again this results from their functionality. The Info-Assistant has to be active early to allow the driver all the other steps to take. A warning as early as this information would have been considered as a false alarm since the lead car was far ahead. A braking at this early time would be completely senseless. There exists no common point in time to start the activity of the different functionalities. The functionality cannot be separated from the starting point. In other words – the starting point is in addition to the functionality part of the Assistance System. One might argue that the smoother and safer driving behavior of the Info-Assistant results from it’s earlier activity. Of course it allowed an earlier reaction of the driver but this earlier reaction wouldn’t have happened if the drivers hadn’t thought that an anticipative behavior is useful. Finally we have to consider that the identified effects of the Assistance Systems may change with longer use. We found no short-term adaptations in terms of velocity changes.
after the participants had used each system at least 20 times. Longer term adaptations can usually be measured only after a familiarization period. Possible determinants of behavioral adaptations are the influence of the system on the way the driving task is performed, the drivers’ possibilities to change their behavior and the presence of competitive motives for changing behavior [4]. Maybe it can be hypothesized that a lower Level of Automation changes the way a task is performed to a less extent and therefore induces less behavioral adaptations than higher Levels of Automation. But this has to be examined in a long-term study.

5 Acknowledgements

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6 References


ABSTRACT: This paper reports on a part of a larger study carried out within the HUMANIST network for excellence, within the remit of a post-doctoral research project. It examines the relationship between driver perceptions of risk and control, and the influence this has on their acceptance of advanced driver assistance systems. The paper describes in depth the unique methodology employed, the experimental design and the analytical framework used. It builds on current knowledge in the area of ADAS acceptance and behavioural adaptation resulting from it.

1 Introduction

With a marked increase in advanced driver assistance systems (ADAS) being designed and deployed for cars, there is a logical emergence of studies that critically examine the influence these have on driver behavior and attitudes towards risk and safety. The research question addressed within this paper asks to what extent the level of perceived criticality or risk on the part of drivers influences their acceptance of advanced assistance. The hypothesis thus tested the relation between increased perception of personal control in a given situation and the influence this has over the acceptance of risk by individuals, as well as on their subsequent acceptance of ADAS. In relation to driving behaviour, by risk perception here we refer to “the subjective experience of risk in potential traffic hazards” [1]. Individual road users experience or anticipate, at any moment in time, a certain amount of loss of control, and they compare this with their target level of risk.

Different research traditions have attempted to explain individual differences in risky driving behaviour and accident involvement. Presently, the technological feasibility of most ADAS is not the main issue for implementation anymore [2]. In fact, the first ADAS applications have already entered the market, such as adaptive cruise controls and collision warning systems. The focus in scientific research on ADAS in the past years has shifted from basic technology research and development towards the complexity and impacts of implementation of ADAS [3]. The present study contributes to this by undertaking an analysis of driver identifications, motivations and preferences with regard to risk-taking behaviour, and subsequently their acceptance of ADAS. The analytical framework of Activity Theory was employed to systematically investigate the complex relationships and tool-mediation that emerge within the present-day augmented environment of intelligent transport. By focusing on the tools (both...
technological and conceptual) that mediate between our subject group of drivers and our augmented driving environment, this paper attempts to critically examine how diverse driver attitudes towards risk and control can be factored into the design of intelligent in-car systems.

2 Methodology

This paper reports on the findings from a two-year research collaboration within the HUMANIST network\(^1\). The research took place over a period of a year and a half, with the support of infrastructure sharing in terms of both equipment and knowledge expertise. An extensive literature review was conducted on the area of ADAS assistance. The development of analysis tools, thereby allowing for a deeper, richer understanding of driver decision-making behaviour and subjective attitudes towards risk and safety.

2.1 Participants

A total of 20 subjects participated in our study, who were selected from a diverse background, cutting across gender, age, driving experience, and license history. With regard to the novice-elderly distribution, the subjects covered ages ranging from 24 to 66 (see fig.1), their experience ranged from 1 to 48 years (see fig. 2). In terms of mileage the subjects varied from below 3000 kms to 100000 kms. Finally, we had a mixture within the group of subjects that had points on their license and those that held a clean license history.

![Age/Gender distribution](image1)

![Experience distribution](image2)

2.2 Simulator

The simulator we used was a static base one, with a vehicle interface driven by a microcontroller, steering wheel, brake and accelerator with driven torque and effort. The computers used for the simulation were 4 PC:

\(^1\) Between ICCS, Greece and INRETS, France {April 2006 – April 2008}
• 1 PC for dynamic models of the vehicle and the traffic: PC 300Mhz
• 3 PC with high performance graphic card for the visuals (front views and rear views of the road scene): PC 300 Mhz

The front field of view for the Bron simulator was 150° horizontal (on 3 screens) and 40° vertical. The rear-view was embedded in the front view.

2.3 Experimental Design

The simulator part of the experiment was divided into three main stages. These were: Orientation, Non-assistance and Assistance. As the name suggests, during the first stage, we oriented the subjects with the two road environments (i.e. urban/motorway) and allowed them to familiarise themselves with the car and the simulator itself. This was followed by two series (1&2) where the driver experienced a range of critical and non-critical situations, but without any automation or assistance from the intelligent vehicle. Then in series (3&4) they once again experienced a range of critical driving condition, with assistance in the form of automatic breaking, steering control and speed reduction. Warning assistance was given by way of audio (beeps) and visual (flashing diode) signals. Finally the last section of series 4 ended with a near-collision scenario.

In addition to variation in terms of degree of criticality, type of assistance, and road environment, we also included dynamic agents within the simulation such as pedestrians crossing the street and motorcyclists. The order of the sections was rotated at random between subjects to counterbalance possible learning effects. At the end of each scenario there was a freeze – where the subjects could assess the situation and their response. We experienced no cases of simulator sickness or dropping-out within our sample group.

We designed a questionnaire tailor made for investigating abstract attitudes and subjective perceptions regarding risk and control. The questions varied in response-format from those that required graded answers on a pre-determined scale to those that required elaboration. We asked the subjects to fill out the first set of questions regarding self-assessment before they entered the simulation scenarios, so as to capture their perception prior to engagement with ADAS. Then during the scenarios we asked questions specific to situation awareness and usability during the freezes. After the simulator part, we again asked our subjects to fill in questionnaires and participate in semi-structured subjective interviews, where they had another opportunity to provide rich data on their perceptions of risk and control and their subsequent acceptance or need for ADAS. Apart from Automatic Breaking Systems, none of the subjects were familiar with the advanced assistances systems that we were testing. The interview part of the experiment was divided into two main stages, namely pre-simulation and post-simulation. In the first stage, we interviewed the subjects in depth regarding their self-assessment of personal driving skills as well as identifications with driving styles. We further questioned them regarding their attitudes towards risk-taking and control within the context of automation. In the post-simulator stage, we interviewed the subjects in relation to their perceived performance in the various situations; their awareness of risk, as well as their acceptance of perceived assistance in those same situations. Their interview feedback was recorded both on audio and video. One major limitation
of the experiment was its reliance on simulator tests alone and no trials on test-tracks or real roads, especially given the objective of the study being to examine perceptions of ‘risk’. However given the ethical constraints of placing subjects in situations of high criticality, the simulator option emerged as the only feasible one for the moment. As these systems are developed further and introduced in the market, one can carry out field trials, in real traffic conditions.

3 Theoretical framework

Within the broader Human-Computer-Interaction community it has become tacitly accepted knowledge that people cannot articulate what they are doing (a notion sometimes used as a justification for observational studies and sometimes used to avoid talking to users at all). Activity theory within this context has something interesting to tell us about the value of interview data. We have used this framework to critically analyse the complex and rich information we’ve gathered from users about their perceptions and motivations for using ADAS. The fundamental concept of the Activity approach was formulated by Lev Vygotsky [4], who spoke of artefact-mediated and object (motivation)-oriented action. At the apex of this model (see fig.3) lies the mediating tools (instruments) which are situated between the group undertaking the activity (subject) and their desired goals and motivations (object). While the constraints and access points (rules) determine the interactions between the subject group and the stakeholders (community), the hierarchies of power and expertise within an organization (division of labour) mediate between the stakeholder communities and the overarching objectives and outcomes of the activity. It is important to note that an activity system is never static. Tasks are reassigned and re-evaluated, rules are bent and reinterpreted. There is constant movement between the nodes of the activity system. What initially appears as an object may soon be transformed into an outcome, subsequently turned into an instrument, and perhaps later into a rule [5].

![Activity Model Diagram](image)

Fig.3. The activity model (Engeström 1987, p.78)

“Tools” mediate the relationship between subject and object, while the relationship between subject and community is mediated by "rules" and the
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relationship between object and community is mediated by the "division of labour". What is of specific relevance to our study here is the way this model enables us to examine the mediatory role played by ADAS and the influence this has on driver behaviour.

4 Analysis

The environment that we refer to here concerns the physical features of the road (weather, geometry, signs and signals), the driver's own speed and direction, and the paths and speeds of other road users. As subject here we refer to the individual driver, while the instruments in question would be the ADAS and IVIS functions available within the experimental car. Our explicit goal here, or the object, would be to reduce accidents and injury on the road, thereby making the overall environment safer by endowing the subject with more informed decision-making powers. In Fig. 4 below we see this represented within the framework of the activity model.

![ADAS Activity model](image)

Fig.4. ADAS Activity model

The outcome of the activity however is determined by the interactions between the various nodes. And given the subjective nature of risk it is not surprising that the final outcome of the activity could take form either in line with the desired object of activity or in tangent to it. For instance the perceived level of risk will be relatively low if the driver is confident about having the necessary coping skills, and higher in the case of those who doubt their abilities. This was precisely what was reported by one of our subjects during his self-assessment exercise:

"I consider myself a risk taker, however it is very important for me to be in control. Being in control for me means being aware of what is happening around me, to be at a speed that I can master and in general be in charge of the situation."

Thus our subject was implying that risk taking was acceptable, in so far as the some of the variables were under his control. Taking this a step further, it is logical to argue that individuals differ not only in the accident risk they are willing to accept but also in their ability to perceive accident risk and in their decision-making and executive skills in the face of risk. In other words, people differ in both willingness (i.e. acceptance) and ability (skill). Perceptual skill includes the
ability to correctly assess one’s level of decision-making and vehicle-handling skill. This is important, because it implies that persons with limited decision-making or vehicle-handling skills are at no greater accident risk, provided they realize their limitations and act accordingly.

However as situation awareness varies amongst drivers, so does their subject evaluation of the posed risk. Burger et al. [6], have found that those with a high desire for control exhibited a greater illusion of control (perceived control over chance events). In terms of Risk Compensation, this could mean the allowance of additional risk accepted in line with increased perceptions of control. This is what we referred to earlier as the tangential outcome that the activity could take, where the subject (driver) interacts with his/her environment via certain tools (in this case ADAS) that result in his/her adapted behavior compromising safety.

The theory of risk compensation suggests that safety measures which reduce risk to levels below the setting of the “risk thermostat” will be countered by behaviour which reasserts the levels with which people were originally content. If the propensity, or willingness, to take risks is the principal determinant of the accident rate then this rate can only be reduced by measures that reduce the propensity.

The primary functionality of ADAS, as is understood at present, is to facilitate the task performance of drivers by providing real-time advice, instruction and warnings. This type of systems is usually also described by the term “co-driver systems” or “driver support systems”. Driver support systems may operate in advisory, semi-automatic or automatic mode [7], all of which may have different consequences for the driving task, and with that on traffic safety. Although the articulated object or goal of a driver support system is to have a positive effect on traffic safety, unintended effects have been shown on driver behaviour, indicative of negative effects on traffic safety [8]. Firstly, the provision of information potentially leads to a situation where the driver's attention is diverted from traffic. Secondly, taking over (part of) the driving task by a co-driver system may well produce behavioural adaptation. This behavioural adaptation, or compensation as it is called in a wider field, must be taken into account when investigating the conditions for introduction of ADAS [9]. When interviewed post simulation, one of our subjects outlined for us this very feature of compensation.

“When a system adds something that I don’t have, for instance in the case of fog, or night-time if a system takes control, due to my inability to see well in poor conditions, I can accept that.”

Would this mean that when normally the driver would drive cautiously in such impaired conditions, he would now compensate and thus pay less attention to his immediate environment due to the new options afforded to him via such tools? The critical issue here is one of dependency on a technical artefact that could potentially lead to overlooking crucial variables and affecting the stakeholders in an adverse way. For instance there is now substantial evidence that the effect of risk compensation has been to shift part of the burden of risk from people in vehicles to vulnerable road users outside vehicles, leaving the total number killed in road accidents that could be attributed to seat belt legislation little changed [10].
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Real life situations always involve an intertwined and connected web of activities, which can be distinguished according to their objects. Participation in connected activities having very different objects can cause tensions and distortions, as is seen in this case to be risk compensation. For instance the intention or motivation of the ADAS designer would be to enable the driver to better cope with impaired conditions such as fog, low visibility etc. However the motivations underpinning the driver’s behaviour might be centered around reducing mental load, and hence once the driver assumes that the ADAS will automatically take over certain functions, he might alter or adjust his level of risk acceptance thereby not achieving the intended object of enhanced safety. Interestingly though perhaps not surprisingly the tolerance for errors in such systems emerged as very low, as was articulated by our subjects:

“As long as the automation was doing something that had not occurred to me before, I’d be glad that it was there. I am more grateful of automation of course in critical conditions. But if it made a mistake even once, I would not use it, as its very important that the car responds in a way that I want it to. A high level of accuracy is imperative.”

In addition to the issue of accuracy, two other crucial points are brought forward in the above statement. The first is the co-relation between perceived criticality and the acceptance of assistance, and the second being the co-relation between what action is performed by the ADAS tool and what is perceived as ‘want’ or motivation behind the subject or driver’s action. The acceptance of ADAS was found to vary with driver control [11]; taking the driver out of the loop was considered a problem by many (potential) end-users. An international questionnaire survey carried out by Bekiaris et al, [11], indicated that the driver population was reluctant to release vehicle control, but was willing to accept it in emergency situations. We tested this on our sample group and received responses in support. We start with an elderly driver in our sample who said:

“I am accustomed to being master of my car, so I would be very upset to let go of decisions and have no control. However if I have no chance or options in really critical situations, as in case for example of a big lorry losing control behind me, I’d be happy with automation. Also when I haven’t seen a vulnerable road user such as a motorcyclist or pedestrian, I would appreciate some assistance.”

Again we see that the subject has accepted a given level of loss of control in situations where the choice is limited and a lot at stake. There is a demarcation made for acceptance in situations where there is clearly and explicitly a value added by the ADAS tool. This sentiment was further reinforced by another member of our sample who said:

“If the situation is under my control, I don’t appreciate the car trying to take a decision. It disturbs me. But when I am a prisoner of a situation, i.e. I’m out of options, then its ok by me.”

More specifically, regarding the issue of perceived criticality a study found that taking over of control in case of short headway to a lead car was less appreciated than warnings or suggestions of the appropriate action in a test of different types of Collision Avoidance Systems [12]. Although drivers expect a positive safety effect by this type of anti-collision systems and other forms of
ADAS, they have at the same time reservations against it. Handing over control to a device and the automated braking function were evaluated as negative aspects of ADAS systems [13]. In our sample this distinction was also reinforced. For instance drivers clearly indicated which automation functions they regarded as acceptable and which they were strongly against having in their cars. What we found during the course of our experiment is that drivers sought more a ‘confirmation’ of their assessment of criticality and subsequent decision-making, than an outright decision from the system. A subject from our sample neatly captured this widely held sentiment when he said:

“The efficiency of the assistance depends on how it helps you with a decision in a critical time. So as in this case, I saw the light (diode warning) before I heard the beep, it didn’t alarm me, but only confirmed for me that it was a dangerous situation and the right decision to break.”

Thus by confirming an already held belief, the function truly assisted the driver in question, rather than further expend his limited attention in a crucial moment. The timing, sequence and intensity of this intrusion was critical in assisting him, and thus not surprisingly was rated high in acceptability value, by him. While more accepting of wider implementation of automation functions, another subject specified the limitations brought by the environment:

“I do not mind if the automation takes control of the car in a motorway, but for sure not in an urban environment, there are just too many variables. If an automation does something unexpected, this can be a limitation, but again this can be solved by training drivers and through education programs.”

In a recent study by Comte et al [14], it is demonstrated that drivers are sensitive to the prevailing traffic conditions (environment) when deciding whether to use an advanced assistance system. She investigated driver personality type and the influence this had on their propensity to use such a safety system. Towards this end she employed a questionnaire [2] that allows drivers to rate the acceptability of various driver support systems. The results from this on-road study indicated that those drivers who enjoyed and engaged in speeding, or exceeding the speed limit (i.e. take risks), were less likely to use a system that would inhibit this. This is an incredibly important finding when considering the mechanisms for implementing ADAS: as those drivers who would benefit most would be less likely to use a voluntary system. In order to arrive at a better understanding of what makes drivers more accepting and adopting of ADAS systems, we asked our sample group to qualify their choices in terms of all they experienced during the experiment (automatic breaking, steering control and intelligent speed reduction). One subject responded:

“Relevance of the assistance depends on a situation. Right now as my speed was very slow, I felt in control, even though the situation was very critical. So, I would definitely not want an automated function kicking-in at this point.”

Thus our subject qualified three things here. One, her awareness of the situation; two, her subjective evaluation of its criticality, and finally three, her decision to reject automation on grounds of her being in control. These complex and often sub-conscious calculations occur in a dynamic manner within a fraction of a second, thus not surprisingly our sample group had concerns about the ability of an ADAS to respond in similarly complex ways. This brings us to a
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very important aspect in user acceptance of assistance, namely: Trust. This is linked closely with the previously mentioned factor of accuracy or low tolerance for errors in ADAS enabled vehicles. A member of our sample group brought this to our attention when she said:

“In the case of automation, it's very important for me to know that the system will not do something opposite in reaction to what I would have done. It's very important to have this trust. So I would like a test period where the system needs to prove to me that it can make the best choice and I will need to verify this. The system will show me that it can balance pressure and speed in order to do a much better job than me in a surprising (risky) situation.”

This emerged as a common thread resonating in the responses of a majority of our sample group. The need for a match (i.e. its predictability of action) between the driver's instinctive response in a critical driving situation and the automation response was identified as a major criterion for acceptance.

In figure 5 below we see the shifting nodes of activity with the ADAS context, as represented in the subject responses we have analysed so far. To begin with the subject group can emerge as the designers of ADAS who hold certain assumptions regarding the object of their activity. This could be increased road safety as we looked at before, or simply an acceptance and user market for the systems they create. Also we see that the mediating factor has the potential to shift from the ADAS tool itself to the trust that users can invest in the system, and its predictability of response (in other words the way it matches the users intuitive response). An increased reliance on such a system could potentially lead to greater acceptance of risk and this could in turn have unintended effects on the driver and other road user stakeholder group. Finally, even if the driver group decide to relinquish decision-making control onto the system and accept the system, there is no guarantee that a direct co-relation can be drawn between the use of the system and any decline in accidents.

Fig.5. Dynamic nodes of activity
5 Conclusion

To sum, what we have covered here is a rich and complex terrain of driver risk perception, need for control, and subsequent acceptance of advanced assistance systems. Through simulator experiments, in-depth qualitative interviews, as well as situation awareness tests, we have sought to understand how in situations of varying criticality, drivers respond in terms of their acceptance of risk, as well as assistance. The uniqueness of this study lies in the depth of understanding it provides on driver motivations by adopting a qualitative methodology and the analytical tool of the activity framework. Through this lens we have seen how shifting perceptions on risk and control determine the efficacy and acceptance of ADAS systems. We have examined tangents in the activity system that result in outcomes not always matching the desired object, as in this case we saw with risk-compensation. In terms of future directions for this research, we aim at continuing our analysis efforts both in terms of driver diversity in risk-taking, as well as in terms of user acceptance of ADAS. Parallel studies that were conducted using video tools and focussing on sensation-seekers and risk takers, will be integrated with the findings of this project at a wider level.

6 References


THE EFFECT OF ISA IN RELATION TO SPEED LIMIT CREDIBILITY

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ABSTRACT: One of the most challenging areas for ITS to contribute to road safety is controlling speed behaviour. Speeding is still common practise on many roads and contributes to a significant number of crashes. An Intelligent Speed Assistance (ISA) aims to reduce speeding in a more or less intrusive manner. This is promising, however the acceptance of ISA systems is still very low. Another promising approach to reduce speeding is by improving the credibility of speed limits. A driving simulator study is conducted to investigate the effect of credibility, with or without using an open informative and warning ISA. The results show that both ISA and credibility of speed limits are effective measures to reduce speeding. Non-ISA users appear to be more sensitive for the credibility of speed limits than ISA users. With regard to the acceptance of the ISA system used in this study, the expectations were fairly positive than the experiences.

1 Introduction

1.1 Background

The faster one drives, the more likely a crash, and, in case of a crash, the more severe the injury consequences [1,2]. Excessive speed is a very common phenomenon in Europe and many non-European countries. Typically, at any time 50% of drivers are exceeding the speed limit [3] and a large safety benefit could be obtained if driving speeds were reduced. There are a number traditional and well proven measures to reduce driving speeds and to make drivers comply better with the speed limit, in particular infrastructure measures and speed enforcement. An effect is also assumed from credible speed limits, i.e. speed limits that meet the expectations of the road users, given the road features and the road surroundings. Credibility will not only have an effect in itself, but may also enhance the effects and the acceptance of other types of measures [3, 4].

A newer, and very promising measure to reduce speeds and the number of speed-related crashes is Intelligent Speed Assistance (ISA). It has been calculated, based on the known relationship between speed and crash involvement/severity, that ISA will have a substantial effect on road safety, in particular the more intervening systems that make speeding physically impossible and that are based on dynamic speed limits [5].

While such advanced systems may be technically possible, their widespread use will need more time. Less advanced systems, based on fixed speed limits, have been tested in various countries, both in small and large field trials,
generally with positive effects on average speed [e.g. 6, 7, 8, 9]. Less intervening systems, those only informing the driver about the (fixed) speed limit in force are already on the market, e.g. Speedalert.

One of the important issues that hinder the widespread implementation of ISA is related to the public acceptance of systems. While more than half of the European drivers state that they are in favour of a system that prevents them from exceeding the speed limit [10], drivers participating in field trials had less positive ideas about ISA. However, after they had experienced the system, their opinion turned out to be more positive [6, 9].

1.2 Aim and research questions

This study aimed to investigate whether credibility affects speed choice when driving with an ISA system that informs the driver about the speed limit in force and warns if the speed limit is exceeded. As public acceptance is of major importance, the acceptance of the used ISA system was also investigated. This lead into the following research questions:

1. What is the effect of speed limit credibility on speed choice for ISA users in comparison to non-ISA users?
2. What is the difference in acceptance of the ISA system before and after the (test drive) experience?

2 Method

2.1 Design of the study

The research questions were investigated in a driving simulator study. A total of 41 subjects drove along a simulated network of mainly rural roads with speed limits of 60, 80 or 100 km/h. The study focused on speed choice at 7 road sections with a speed limit of 80 km/h, the other road sections were added to create a realistic environment.

2.2 Independent variables

In the experiment two variables were manipulated, the use of ISA and the credibility of the speed limit. The use of ISA was varied between subjects, half of the subjects were supported by an ISA system, and the other half were not. The ISA system used in this experiment was integrated in a navigation device. The ISA system provided continuous visual information about the speed limit in force and when the driver exceeded the speed limit the ISA system warned the driver visually (the speed limit indicator on the navigation device increased in size and flickered) and verbally (a female voice said: "You're exceeding the speed limit. The speed limit is .. km/h." This message was repeated every ten seconds until the speed was reduced to below the speed limit). Exceeding the speed limit was defined as 1 km/h or more over the posted limit.

The credibility of the speed limit was manipulated by varying a number of road characteristics that were identified in literature as being relevant for speed choice [e.g. 11, 12, 13], and that were possible to simulate in a driving
simulator. Road bendiness for example is considered as relevant for speed choice, but hard to simulate in a driving simulator because it increases the chance of simulator sickness. The road characteristics that were used to manipulate the credibility were road width, presence of vegetation near the road, and the type of separation between the driving directions. Each road characteristic was expected to have an effect on the intuitive speed, like a small road was assumed to reduce speed while a wide road was assumed to increase speed. Each road section had a different combination of characteristics. At some road sections all of the manipulated road characteristics were assumed to increase the intuitive speed, on the other road sections a mixture of characteristics that were assumed to increase speed and those that were assumed to decrease speed. Based on this the road sections were categorised as having a more or less credible speed limit. As literature on the subject was quite limited, the credibility of the speed limit was validated within the experiment. All subjects first drove the test route without showing any speed limit. The results showed that at the 80 km/h roads the subjects intuitively drove about 80 km/h at the road sections with credible speed limits, and that they exceeded the speed limit by more than 5% at the road sections with less credible speed limits.

2.3 Dependent variables

2.3.1 Driving speed

The main dependent variable was driving speed. To measure driving speed two variables were measured: average driving speed and speeding time. The average driving speed was computed for each road section. To avoid an effect of acceleration and deceleration near intersections, the computed averages are based on the part of the road section from 100 m after an intersection until 150 m before the next intersection. Speeding time was defined as the percentage of time on a road section that the limit was exceeded by 10% or more, thus 88 km/h or more at 80 km/h roads.

2.3.2 Acceptance of the ISA system

The ISA users were informed about the ISA system before the test drive. They received a paper with information on the system and the type of information it would provide. Based on this information the subjects were asked about their expectations of the system. After the test drive, they were asked about their satisfaction with the ISA system based on their actual experience. The expectations and experiences were measured by presenting statements and a five-point answering scale (completely disagree, disagree, neutral, agree, completely agree). The same set of statements was used for the expectations and for the experiences, the only difference was the tense, the first set was in the present tense while the second set was in the past tense. (E.g. "It seems pleasant to me that...." versus "I found it pleasant that ....").

2.4 Analysis

The effects of ISA and the credibility of speed limits were determined by means of an analysis of variance with repeated measurements. Within these analyses the use of ISA was considered as a 'between subject factor'. The repeated
measurement concerned the speed behaviour on the different road sections with different speed limit credibility. For all analyses, a critical significance level of 5% was applied.

3 Results

The results for average driving speed and speeding time are shown in respectively Figure 1 and Figure 2. In the figures the values are shown for ISA users and non-ISA users at road sections with low and high credibility of the limits.

3.1 The effect of ISA

The main effect of ISA on driving speed was significant ($F_{1,39}=11.33; p<0.01$). ISA users drove significantly slower than non ISA users. Moreover, ISA users on average had a driving speed below the speed limit (77.5 km/h), whereas non-ISA users had an average driving speed above the speed limit (82.3 km/h).

The main effect of ISA on speeding time was also significant ($F_{1,39}=10.76; p<0.01$). ISA users exceeded the speed limit significantly less than non ISA users. ISA users, on average, did not exceed the speed limit at road sections with credible speed limits and hardly exceeded the speed limit at road sections with less credible speed limits.

3.2 The effect of credibility

The main effect of speed limit credibility on average driving speed was significant ($F_{1,39}=19.61; p<0.001$). The subjects drove significantly slower at road sections with credible speed limits than at road sections with less credible speed limits. This is the effect for the complete sample, half of the subjects with and half without ISA. As the current practise is that hardly anyone uses an ISA system, it is also interesting to look at the effect for non-ISA users only. A simple main effects analysis showed that for non-ISA users the effect of
credibility was significant ($F_{1,39}=18.38; p<0.001$). Average driving speed was lower at sections with credible limits than at sections with less credible sections. For the ISA users the effect of credibility was not significant, but there is a trend ($F_{1,39}=3.79; p<0.1$) that also ISA users drive slower at sections with credible limits.

The main effect of the credibility of speed limits on speeding time was also significant ($F_{1,39}=12.41; p<0.005$). The subjects exceeded the speed limit significantly less at road sections with credible speed limits than at road sections with less credible speed limits. Again, when looking separately at the ISA and the non-ISA users, the effect of credibility was significant for the non-user group ($F_{1,39}=17.08; p<0.001$), but there was only a trend for the ISA users ($F_{1,39}=0.66; p<0.5$).

### 3.3 The interaction between ISA and credibility

The interaction effect between ISA and credibility on average driving speed was not significant, but there is a trend ($F_{1,39}=2.92; p<0.1$) that non-ISA users were more sensitive for the credibility of speed limits than ISA users. This trend is supported by the simple main effects reported in the previous section that indicate that the effect of credibility is significant for non-ISA users and not for ISA users.

The interaction effect between ISA and credibility on speeding time was significant ($F_{1,39}=5.72; p<0.05$). Non-ISA users were more sensitive for the credibility of speed limits than ISA users.

### 3.4 Acceptance of the ISA system

The responses to the statements on the expectations of and experiences with the ISA system are presented in Figure 3. The results show that expectations of the subjects were somewhat positive and their satisfaction slightly decreased to neutral after the test. In particular the voice that warned when exceeding the speed was not appreciated. The experience did not change much of their opinion on the visual information and the visual warning, they were well accepted.
4 Conclusions and discussion

4.1 Effect of ISA

The study found a significant effect of ISA on the average driving speed and on speeding time. The ISA system in the study that both informed and warned when the speed limit was exceeded resulted in lower speeds and less time driving above the speed limit. These results confirm the findings of the large majority of studies that investigated the effect of ISA [e.g.6, 9, 14, 15, 16].

4.2 The effect of credibility

The results indicated that, overall, credible speed limits result in lower speeds and less time exceeding the speed limit than speed limits that are less credible, because they are considered to be too low. Systematic research on the effects of credible speed limits is still lacking, but these results confirm the assumptions made by many experts [e.g. 3, 4, 17, 18].

4.3 The effect of ISA related to speed limit credibility

The first main research question was whether the effect of credible speed limits was similar for ISA and non-ISA users. When looking at the time drivers speeded, this appeared not to be the case. The effect of speed limit credibility was stronger for non-ISA users than for ISA users. Looking at average speed, however, there was no significant difference between ISA users and non-ISA users, although the trend pointed in the same direction. Looking separately at the effects of credibility for ISA and non-ISA users, it appeared that this had an effect without ISA, but not with ISA drivers, both for average speed and for speeding. So, the results of this study suggest that, when driving with an informing and warning type of ISA, the credibility of speed limits does not affect
the amount of time people drive in excess of the speed limit. Regarding average speed, the results are less clear, but point in the same direction.

When interpreting this outcome, it must be born in mind that the ISA used in this study was an open one. Drivers could make their own choice about their driving speed. However, within the open category, it was a fairly intrusive system. Warnings started when the speed limit was exceeded by just 1 km/h and were repeated every 10 seconds, not only visual but also verbally. It would be well possible that speed limit credibility would affect driving speed of ISA drivers more, when the system was only informing or when the warnings were less frequent and less intrusive.

### 4.4 Acceptance of the ISA system

The second main research question was related to the acceptance of the ISA-system by the drivers. The results showed that the subjects had fairly positive expectations. However, they were somewhat disappointed after they had actually experienced it. In particular, the overall convenience of this type of ISA and of the verbal warning was judged less positive. The verbal warning was even judged negatively.

This finding is in line with another study with an informative ISA system that also concludes that there is no difference in acceptance before and after a test ride. However, most studies report that drivers become more enthusiastic about ISA, once they have experienced it in practice [6, 9, 19, 20].

One explanation of our finding may be that this particular ISA system was quite strict, with visual and verbal warnings at 1 km/h or more over the limit and repeated every 10 seconds. This could particularly explain why the drivers disliked the verbal warning system. Acceptance of the system may increase if the threshold for warnings would be higher and the warning frequency lower. Other studies also found that the less intervening systems are accepted better [5]. At the same time it is expected that, in that case, the effect of the ISA system would be smaller. Clearly, it is a matter of finding a balance between acceptance and effectiveness of the system.

Another explanation of the contradictory findings in our study may lie in the fact that our study focused on rural roads and more particularly on 80 km/h roads. It is well possible that the acceptance of ISA is different for urban roads (with 30 and 50 km/h speed limits) than for rural roads.

Our study did not make a distinction between the acceptance of ISA at road sections with a credible speed limit and sections where the speed limit was considered to be too low. Hence, based on the current study, we cannot say whether credible speed limits improve acceptance.

### 4.5 Overall conclusion

Based on the results of this study we can conclude that ISA is a promising instrument to reduce speeding and increase road safety. In line with previous research, the results of this study indicate that an (open) ISA system on its own has the potential to reduce average driving speed to below the speed limit and to decrease speeding.
Credibility of speed limits is also an important factor in speed choice and can substantially contribute to achieving lower speeds and less speeding. Still, credible speed limits cannot achieve the same result as the informative and warning ISA system of the current study.

Speed limit credibility seems to have hardly an effect if speed choice is supported by a rather strict informative and warning ISA system. It is expected, however, that speed limit credibility will be more important in case of less intruding systems that can be more easily ignored. In addition, it is likely that credible speed limits will increase acceptance of ISA systems. Future research would need to find out.

It is important to be aware of the fact that speeding behaviour is related to many different factors that are hard to realize in a driving simulator study, like time pressure, whether the driver expects to be punished for speeding, risk estimation and so on. In this study the some influencing factors, ISA and credibility, were studied. For future research it would be interesting to do a similar study on the real road in order to validate if the results are the same and it would be interesting to look and the interaction of the effects investigated in this study and other factors that effect speeding behaviour.

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