Modelling stochastic gaze distribution for multi-agent traffic simulation – Impact of driver characteristics and situational traffic circumstances on the driver's gaze behaviour

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Abstract: The prospective safety impact assessment with multi-agent traffic simulation is an important approach for evaluating traffic safety effects of advanced driving assistance systems (ADAS) and automated driving systems, especially at their early development stage. The main challenge in the virtual simulation approach is that it requires a detailed and valid representation of interactive processes between driver, system and environment in traffic. Current driver models lack the consideration of driver individuality and often do not cover the entire chain of cognitive processes from information acquisition to action implementation. This led to the development of the Stochastic Cognitive Model (SCM) in order to consider adequately the individual characteristics as well as the cognitive and physical capabilities and weaknesses of the human driver. Most of the relevant information from the environment is retrieved by the driver's visual sense channel. Based on these pieces of information the driver forms an understanding of the current situation and makes decisions about his future behavior. Hence, modelling the driver's gaze behaviour, and thus visual perception of the traffic environment and relevant stimuli for action and decision making, is crucial and one of the most challenging issues for driver modelling. This paper focusses on a variety of factors that can have an impact on the driver's gaze behaviour. In detail, the impact of driver characteristics, driver states and situational traffic circumstances is investigated. Therefore, two experimental studies in real traffic and in a driving simulator were conducted. A significant impact of driver characteristics and driver states on the driver's gaze behaviour was observed in a driving simulator study with a with representative German driver sample under controlled conditions concerning traffic flow and surrounding. Differences in gaze behaviour, depending on various situational circumstances, in detail, when being faced with specific traffic scenarios, were investigated in a realistic driving study on a German motorway. Results of both studies are merged and reported and finally, the relevance of considering these factors for modelling cognitive driver behaviour is discussed.

Keywords: Driver Behaviour Modelling, Safety Impact Assessment, Multi-agent Traffic Simulation, Gaze Behaviour, Driver Characteristics, Anticipation.

1. INTRODUCTION

Various automobile manufacturers are intensively working on the development of ADAS and automated driving functions to make driving more comfortable, and more importantly, to maintain or even enhance the traffic safety. Prior to the launch of new automated driving functions, automobile manufacturers have to make sure that their systems are safe in use and that they have a positive impact on traffic safety, which means that they reduce the amount of accidents as well as mitigate the consequences of inevitable crashes. Plus, it must be tested, if the driving function is causing new critical situations or even lead to new accidents. Generating a positive delta in traffic safety between traffic without and traffic with the investigated system is the premise for the release of the new driving function. Especially in early development stages as well as during the complete development process of ADAS, it is not always possible to run tests in real traffic, e.g. on the public motorway. Additionally, in relation to the amount of safe traffic and the happening of only slightly critical situations, the number of accidents in real traffic is too low to run valid analyses of the effectiveness of ADAS based on the reconstruction of single cases from real traffic data solely. Therefore, additional methods are used for prospective safety impact assessment of ADAS, e.g. virtual simulation (see Kompaß et al., 2015; Eckstein et al., 2013). By means of multi-agent traffic simulation, it is possible to run a high number of virtual driving tests that can be repeated under identical testing conditions with and without active safety functions (Wachenfeld & Winner, 2015). Thereby, generic traffic can be observed as well as specific driving scenarios, which are

relevant for automated driving. For multi-agent traffic simulation, system, environment and driver behaviour must be modelled properly to generate highly realistic virtual traffic, which is indispensable to get reliable data and valid results. Modelling driver behaviour is one of the most challenging tasks, which requires a lot of research and psychological understanding of human characteristics, capabilities, limitations and the underlying cognitive processes, such as information acquisition, information processing, reasoning, anticipation or decision making (see Helmer et al., 2015; Wang et al., 2017). Drivers use their senses for perceiving their environment in traffic properly, e.g. other traffic participants, traffic lights or other salient stimuli in the surrounding. Thereby, the driver's visual perception is the most important sensory channel when leading a vehicle through traffic (see Crundall et al., 2003; Schlag et al., 2009). For a comprehensive acquisition of relevant information in the current traffic situation, the traffic environment must be globally scanned and perceived thoroughly. On that basis, the driver forms an understanding of the current situation and makes decisions about his future behavior. Hence, for the representation of information acquisition and information processing within a virtual traffic agent, modelling the driver's gaze behaviour is crucial and one of the most challenging issues in the development of an applicable driver behaviour model. Beyond the individual differences between drivers due to their different physiological and psychological prerequisites, the driver's gaze behaviour can also be affected by personal intentions or external stimuli. Without conscious intention, drivers shift their attention to salient stimuli when they appear, such as spotlights or pedestrians appearing from the roadside and crossing the street (bottom-up process). On the other hand, when drivers intend to follow a certain action, e.g. changing lanes, they would consciously look for relevant information around the vehicle, e.g. checking side mirrors (top-down process). Areas, which are relevant for the driving task and deliver the driver important information for guidance of the vehicle, are called Areas of Interest (AOI). In Figure 1 those AOIs, which have been considered for the present analyses, are marked in red (left mirror, front left, rear mirror, front/vanishing point, front right, right mirror).

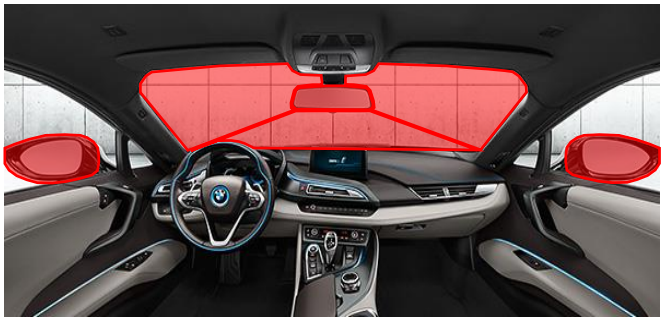

Fig.1. Areas of interest (AOIs), which were considered in Study I.

Drivers differ in driving style (dynamic vs. calm, offensive vs. defensive), personality (e.g. sensation seeking, risk proneness, anxiety) and demographical factors (e.g. age, gender), which can have an impact on driving and gaze behaviour. Additionally, other factors, such as fatigue or stress, as well as visibility conditions or the current traffic scenario, can cause changes in gaze distribution while driving. In previous studies, correlations between driver behaviour and driver characteristics as well as personality could be observed (see Deffenbacher et al., 2003; Matthews et al., 1998; Mesken et al., 2007; Stephens & Groeger, 2009; Dahlen, 2006). Data from a recent driving simulator study from Witt et al. (2018) have shown that age, sensation seeking and anxiety predicted proneness to speeding and driving with low distance to proceeding vehicles. In another study from Witt et al. (2017), correlations between fatigue, stress and width of the useful field of view (UFOV) could be proven. When observing and statistically describing a test person's gaze behaviour, one can use several parameters. In the present studies, the three relevant parameters depicted in Table 1 were selected and will be reported in the following sections.

Table 1. Relevant gaze behaviour parameters

Parameters	**Unit**	**Description**
Mean glance duration	Sec	The average glance duration in the direction of an Area of Interest (AOI) in the selected time interval.
Parameters	**Unit**	**Description**
Attention ratio	%	Percentage of glances at an AOI in the selected time interval.
GLP (Glance location probability)	%	Probability that the test person will gaze at an AOI during a particular time interval.

This paper focusses on the factors mentioned above, which can have an impact on the driver's gaze behaviour, in detail on the duration and the transition of gaze. In two independent studies the impact of these factors were investigated by comparing the test persons' gaze behaviour under different states or different traffic and environmental conditions. In the first study we used a dynamic driving simulator for investigating inter- and intraindividual differences in gaze behaviour, depending on driver characteristics, driver personality and driver state (fatigue, stress). In a second study, we made up a realistic driving study design and observed how drivers behave on the motorway with focus on the analysis of the drivers' gaze behaviour in relevant traffic scenarios, e.g. approaching of two slow driving vehicles on the right lane.

The following section gives an overview of the current knowledge about gaze behaviour while driving. Subsequently, the SCM (Stochastic Cognitive Model), a cognitive driver behaviour model, and its subcomponents will be briefly described to clarify the context of the present research (see Wang et al., 2017; Mai, 2017). Finally, empirical data collection and analysis will be described and results will be presented and discussed.

2. THE STOCHASTIC COGNITIVE MODEL

For running traffic simulations valid models are needed for all three relevant components: the environment, the vehicle (and the system) and the driver. Modelling driver behaviour is one

of the most challenging tasks that necessitates a valid and reliable data basis in terms of observable driving behaviour as well as the understanding of human cognitive processes. One of the key factors of human cognition is the visual perception of the environment and relevant information and stimuli in the surrounding traffic (see Crundall et al., 2003; Schlag et al., 2009). The way, in which drivers perceive and interpret their environment, including the actions of other drivers, can vary considerably. In the following section the submodules of the stochastic cognitive driver model (SCM), which considers a variety of cognitive processes, including perception and information processing, is presented. The SCM is a cognitive driver behaviour model for motorway traffic and is being developed since 2015. The functional concept of the SCM is based on human cognitive processes with focus on stochastic process modelling. In comparison to other driver models (e.g. COSMODRIVE by Delorme, 2001; ACME by Krajzewicz et al., 2002; SSDRIVE by Cacciabue et al., 2010) the SCM contains all levels of human (cognitive) behaviour (information acquisition, information processing, decision making and acting) and is based on a stochastic instead of deterministic parameters. Moreover, a further feature of the SCM is to consider the impact of driver individuality on driver behaviour as well as changes in driver behaviour due to different states of arousal (e.g. stress) or alertness (e.g. fatigue). The SCM consists of different sub-modules to represent the behaviour of different drivers (see Figure 2).

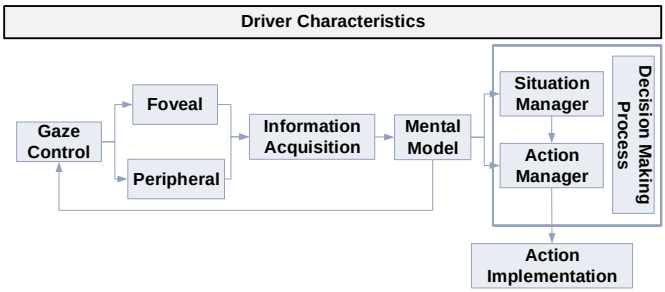

Fig.2. Sub-modules of the SCM.

Information Acquisition. This sub-module is responsible for the driver's internal representation of the environment and the current situation. Particular focus is on the visual perception, which considers the peripheral and foveal field of view of the driver as well as gaze control with stochastic principles, which ensures that the model receives only information about surrounding objects from the region the agent is looking at. For filling this sub-module with valid data, driving simulator studies were conducted that will be described in the following sections.

Mental Model. This sub-module is responsible for the recognition of situation patterns. Current information of the information acquisition sub-module as well as information from working memory with information from previous time steps is processed. All gathered information is aggregated to describe the microscopic traffic properties and extract features of the environment that are needed in the next module. The impact, changes in gaze behaviour have on the processes in this sub-module, will be discussed in section 5.

Decision Making Process. Driver's decision making process is mainly located in the sub-modules *Situation Manager* and *Action Manager*. In these sub-modules, the current situation is assessed according to the information derived from information processing in the Mental Model. Based on the outcome of information processing, a decision is made about the next driver action. For the action selection, also stochastic variations are considered. This sub-module divides the chosen action based on an action pattern catalogue into primary (acceleration, deceleration, steering and normal driving) and secondary driving actions (e.g. light activation, intention signals by activating indicators, etc.).

Action Implementation. Finally, the information of the previous sub-modules is used in order to change pedal positions – accelerator as well as braking pedal – and steering wheel angle that result in the longitudinal and lateral acceleration of the vehicle. By this, the movement of the vehicle for the next time step can be implemented.

Driver Characteristics. An additional sub-module containing driver characteristics and driver states, such as fatigue and stress, describes intraindividual and interindividual driver differences and their impact on driver behaviour. In a one-way stochastic process, traffic agents are provided with a set of individual driver characteristics that shift, widen or narrow baseline distributions of stochastic parameters in all sub-modules of the SCM. By this, a broad spectrum of individually different drivers can be modelled and virtual traffic simulation can be run as realistic as possible.

In the following section two studies will be reported, which were carried out to collect gaze behaviour data while driving under different traffic conditions, with different driver preconditions and driver states in general traffic as well as gaze behaviour differences in different driving scenarios.

3. STUDY I

The driving simulator study focused on the observation of differences in drivers' gaze behaviour due to different driver characteristics, mental states and under different time of day conditions. Method, measurement apparatus as well as the investigated sample will be described and results will be reported.

3.1 Participants

101 participants (45 female, 56 male) between 19 and 75 years old (Mean = 45.0 years, SD = 16.5 years) took part in the study. They were preselected aiming at a balanced distribution of driver age, fitting four groups (18-35 years; 36-50 years; 51-65 years; >65 years) and an almost equal representation of gender. The participants received research credit for their attendance. Due to dropouts caused by motion sickness, the sample size was reduced to 78 drivers. No systematic variables, which could have been responsible for the high dropout quote, can be clearly identified. Neither personal factors, such as age or gender, nor general propensity to travel or seasickness provided indication for a higher probability for the onset of motion sickness.

3.2 Design and Measurements

Participants drove a 140km long virtual motorway distance without using any driving assistance systems. Testing included standardized questionnaires prior to and after the test drive. A dynamic driving simulator was used, consisting of a hexapod, in which a full vehicle of a BMW 5 Series with standard interior design was installed. Drivers were given a 360° view of the traffic surroundings, including side mirrors and rear view. For testing, a within-subject design was chosen to consider inter- and intraindividual differences within the two groups. Participants were split into two independent sub-samples, which drove under different daytime conditions (day and night) and with different traffic density. Also, drivers in the daytime sub-sample were stressed twice by the investigator in the second half of the test drive. There was no social interaction between the driver and the investigator during the first half of the test drive.

3.3 Experimental Measures

By using standardized psychological questionnaires, demographic information was gathered as well as the individual manifestations of driving related personality traits, e.g. sensation seeking and risk proneness. For an objective measurement of stress and fatigue, an ECG (Electrocardiography) was recorded during the entire test drive. Heartrate (beats per minute, BPM) and heart rate variability (Root Mean Square Successive Differences, RMSSD) were analysed and served as control factors for the manipulation of driver state (fatigue, stress). Also, we asked the drivers before, in the middle and after the test drive to rate their level of fatigue on a standardized scale. Therefore we used the 13-point fatigue scale from Muhrer & Vollrath (2010). Drivers were asked three times how tired they were feeling in the current moment and, at first, rated their subjective fatigue semantically ("awake", "a little bit", "medium", "strong", "very strong") and then refined their rating with a tendency, if there was one ("-", "0", "+"). For the psychological interview prior to the test drive, following standardized questionnaires and measurement instruments were used:

Brief Sensation Seeking Scale (BSSS). The BSSS is a short version of the Sensation Seeking Scale (SSS-V), which was constructed by Zuckerman, Eysenck & Eysenck and in its original version contains 40 items in a forced-choice format (Zuckerman et al., 1978). It is a self-report measure for sensation seeking, which is a dispositional risk factor for self-endangering behaviour, e.g. for unsafe driving (Hoyle et al., 2002). The BSSS consists of eight items with responses indicated on a five-level Likert scale ("strongly disagree", "disagree", "neither disagree nor agree", "agree", and "strongly agree"). Each of the four primary dimensions of sensation seeking (experience seeking, boredom susceptibility, thrill and adventure seeking, disinhibition) is represented by two items. Internal consistency for the eight items is satisfying with Cronbach's alpha = .76 (Hoyle et al., 2002).

The short scale Risk Proneness-1 (R-1) and self-reported patience. The short scale R-1 (Beierlein et al., 2014) measures the self-reported risk proneness of a person with a single item asking for self-consideration of someone's tendency to take risks ("How do you see yourself - how willing are you in general to take risks?"). Main test quality criteria of the R-1 are fulfilled. Retest-reliability of the R-1 is $r = .74$ ($p < .001$), construct validity is $r = .57$ ($p < .001$) (Beierlein et al., 2014). Based on the wording of the short scale R-1, a single item measurement of self-reported patience was added to the driver survey ("How do you see yourself - how patient are you in general?").

State-Trait-Anxiety-Inventory (STAI) – Short version. The State-Trait-Anxiety-Inventory is a questionnaire for measuring anxiety as an anxious tendency as well as anxiety due to situational circumstances. The 10-item German short version of the STAI-S with responses on an eight-level Likert scale ranging from "not at all" to "absolutely" was used (Grimm, 2007). The German short version bases on the original version from Spielberger et al. (1970). Percentage of approval was calculated as test score for situational tendency for anxiety.

3.4 Hypotheses

Driver characteristics and personality traits. On the basis of their driving experience, it can be assumed that older drivers will observe their environment more efficiently than younger drivers. In detail, gaze distribution of younger drivers will vary broader than that of older drivers. This includes checking mirrors and intentionally surveying neighbouring lanes. Another hypothesis that will be tested is that with increasing age the mean fixation duration will also increase, especially when checking side mirrors and rear view. Due to different physical and mental abilities concerning visual perception and information processing it is assumed that elderly drivers need more time to build up proper situation awareness and recognize situation patterns. Concerning gender, it can be expected that there will be differences in terms of visual distractibility. Women will tend to let their eyes wander across the road or roadside structures, whereas men will mainly focus the vanishing point while driving. Besides demographic driver characteristics, we will also observe correlations between specific personality traits and gaze behaviour. Drivers with higher levels of patience will tolerate lower velocities and longer following a slower vehicle than less patient drivers. Vice versa, drivers that describe themselves as more prone to taking risks will check mirrors more often due to more frequent lane changes. The same hypothesis applies to sensation seeking. Drivers with higher scores on subscales of the BSSS, especially on the boredom susceptibility scale and the experience seeking scale, will also check mirrors more often.

Driver states. We split the participants in two subgroups. One half was driving at night with traffic conditions usual for driving on a motorway at night. The other half drove during the day, also with appropriate traffic conditions. We intended to fatigue the drivers in the night time condition by combining low traffic density with unfavourable visibility conditions in

order to establish a monotonous test drive. The other half, driving during the day with good visibility conditions and high traffic density, were stressed twice in the second half of the test drive. By this, we provoked a higher stress level, so that we can compare the drivers' gaze behaviour when fatigued with the drivers' gaze behaviour when stressed as well as in a neutral driver state (neither fatigued nor stressed). In the night time test drive, the heartrate of the drivers will be lower in the second half of the test drive than in the first half when they are not yet fatigued. Drivers, who will be stressed during the second half of the test drive, will show an increase of the heartrate. It can be assumed that in both unfavourable driver states, fatigued and stressed, a narrowing of the UFOV can be observed. Also, the frequency of checking mirrors will be lower in these driver states (side mirrors and rear mirror).

3.5 Data Analysis

For the present paper, we will focus on correlations between the driver characteristics and driving parameters mentioned above by running t-tests for calculating the Pearson correlation coefficients. For analysing differences in mean values between repeated measures for stress and fatigue, t-tests for paired samples are calculated. In addition to these quantitative data analyses, the width of the UFOV will be investigated qualitatively. Therefore, heat maps of singular test persons will be compared in conjunction with the impact of fatigue and stress.

3.6 Results

In this section, results of the study as described above will be presented. Correlations between gaze behaviour, driver characteristics, personality traits and time of day are calculated. Thereby, differences in gaze distribution between individual drivers as well as intraindividual changes in gaze behaviour within drivers during the test drive with varying driver states and under different environmental conditions are considered. In this context, results of the ECG for testing on stress and fatigue will be presented.

Driver characteristics and driver personality. Correlations between three demographic driver characteristics (age, driving experience, gender) and three dependent gaze behaviour parameters (mean glance duration, attention ratio, GLP) are considered. Mainly, we will focus on mirror checking and the width of the UFOV. Driving experience was measured as total road performance over the last year. For the analysis of driver characteristics and driver personality, we only used the baseline measurement of the subsample, which drove the daylight condition ($n = 41$). No significant correlation between age and mean duration of gazes into left, right and rear mirror were found. Also, attention ratio of mirror checking was not related to age, driving experience or gender. However, the probability of gazes (GLP) into the right mirror ($r = -.382$; $p < .05$) as well as into the rear mirror ($r = -.388$; $p < .05$) correlated significantly with the driver's age. With increasing age, probability for checking mirrors regularly is decreasing. Although there was no significant correlation with GLP for the left mirror, when summarizing GLPs for all mirrors, including the left mirror, there is still a significant correlation ($r = -.349$; $p < .05$). Neither driving experience nor gender were significantly correlated with any of the three dependent gaze behaviour parameters. Concerning driver personality, we found no significant correlation between scores on the BSSS, R-1 or STAI and gaze behaviour. Also, self-reported patience did not correlate significantly with any of the gaze behaviour parameters we considered.

Stress. In the second half of the test drive, drivers were stressed by the investigator at two different time stamps, which were the same for all participants. Therefore, we adjusted parts of the TSST (Trier-Social-Stress-Test), which was developed in 1993 by Kirschbaum and colleagues. The test consists of different tasks, in which test persons are exposed to highly stressful social situations. For the present study, we took the mental arithmetic component of the TSST and adopted it in a way, so that it can be integrated into a driving simulator setting. While the test person was driving, we instructed the driver via microphone to subtract an uneven number from another odd high number (2043 – 17 – 17 – 17 - …) and to go on calculating until the investigator will stop. The test person was asked to calculate as fast and precise as possible. When errors occur, the investigator interrupted and the test person had to restart from the beginning. For increasing time pressure, a countdown was displayed in the head-up display in the windshield of the car. In case, the test person didn't solve the last arithmetic step before time was running out, the investigator interrupted and asked the test person to again start from the beginning. Gaze behaviour was analysed during the stress test and attention ratio and GLP for checking mirrors are calculated and compared with the driver's gaze behaviour in the first half of the test drive when they were not stressed. For measuring the drivers' physical reactions to stress and controlling the effect of time/performance pressure on the drivers, ECG data was analysed. Drivers showed strong physical reactions to stress and heartrates increased significantly ($t = -5.559$, $p < .000$, $df = 29$). Effect size was good (Cohen's $d = 0.72$) and therefore, it can be assumed that stress manipulation worked and results are valid (see Cohen, 1988). We ran t-tests for dependent samples and found significant differences in attention ratio for mirror checking between driving without being stressed and driving under stress condition. Acute stress had a significant impact on the attention ratio for side and rear mirrors ($t = 7.458$, $p < .000$, $df = 37$). When stressed, caused by time and performance pressure, drivers did significantly less mirror checking (Mean = 1.96 %, SD = 2.48 %) than when driving without being stressed (Mean = 6.51 %, SD = 2.87 %). Further, Cohen's effect size value (Cohen's $d = .77$) is good and suggests high practical significance. Results for GLP for mirror checking are very similar. Probability for gazing into side or rear mirrors was significantly lower when drivers were stressed (Mean = 4.05 %, SD = 4.26 %) than before they were set under pressure (Mean = 9.34 %, SD = 3.44 %). Effect size is good ($d = .71$) and suggests that stress has a significant effect on the probability for checking mirrors ($t = 6.080$, $p < .001$, $df = 37$). Heat maps were generated and clear changes in the UFOV can be seen in such a way, as that the width of the UFOV is narrowing when drivers get stressed. Figure 3 shows a heat map of a female driver (57 years old) in

the stress condition subsample before she was stressed, whereas in Figure 4 a second heat map of the same driver when set under pressure is presented.

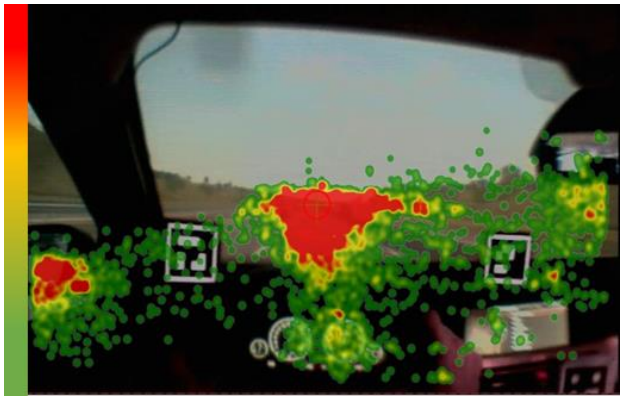

Fig. 3. Heat map of driver's UFOV in a neutral emotional driver state.

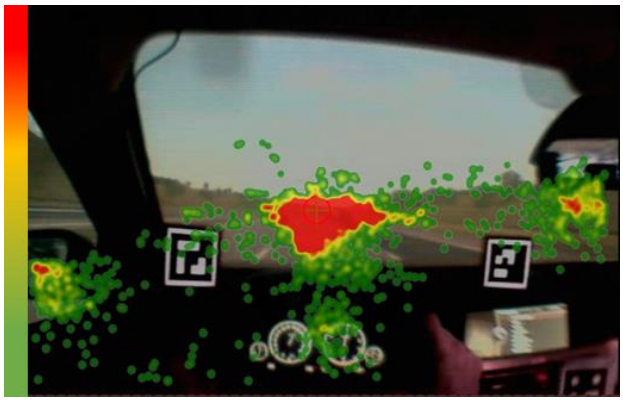

Fig. 4. Heat map of driver's UFOV when stressed.

Fatigue. For analysing the impact of fatigue on gaze behaviour, we also tried to fatigue some drivers. Therefore, the other half of the sample drove at night conditions, with monotonous traffic and low traffic density (n = 37). Before calculating t-tests for changes in gaze behaviour, results of ECG data are presented. Drivers' mean heartrate in the second half of the test drive (Mean = 79.10 bpm, SD = 9.55 bpm) was significantly lower than the mean heartrate that was measured during the first half of the test drive (Mean = 80.19 bpm, SD = 9.33 bpm) ($t = 2.385$, $p < .05$, $df = 29$). We found a medium effect size (Cohen's $d = .40$), which is not as high as the effect sizes we found in the stressed subsample but which is still acceptable. In addition, we used the 13-point fatigue scale from Muhrer & Vollrath (2010) and asked the drivers three times (before the experiment, mid-point, after the experiment) how tired they feel at the current moment. Results are consistent with data from the ECG measurement. Drivers' rates on the fatigue scale were increasing significantly during the course of the experiment. Comparing the rating before the experiment (Mean = 2.36, SD = 2.02) with the rating after the experiment (Mean = 4.64, SD = 3.49), we found a good effect size of Cohen's $d = .63$ ($t = -4.804$, $p < .05$, $df = 35$). Based on these findings, it can be assumed that drivers were truly calming down and got tired the longer they were driving under these fatiguing conditions. Fatigue had a significant impact on the drivers' gaze behaviour. Attention ratio for side mirrors was significantly lower after drivers got tired (left mirror: Mean = 1.51 %, SD = .99 %; right mirror: Mean = .24 %, SD = .26 %) than before the start of the experiment (left mirror: Mean = 2.05 %, SD = 1.22 %) (Left mirror: $t = 4.554$, $p < .001$, $df = 35$, Cohen's $d = .63$; right mirror: $t = 3.836$, $p < .05$, $df = 33$, Cohen's $d = .55$). GLP for the left mirror was lower in the second half of the experiment (Mean = 2.89 %, SD = 2.24 %) than in the first half of the experiment (Mean = 3.45 %, SD = 1.99 %). We found a significant impact of fatigue on GLP for the left mirror ($t = 3.174$, $p < .05$, $df = 35$) with a medium effect size (Cohen's $d = .47$). There were no significant differences for attention ration or GLP for right and rear mirror. The following figures (Figure 5 and 6) show the narrowing of the UFOV in the second half of the test drive when the driver got tired (female, 19 years old). Consequently, not only the width of the UFOV of stressed drivers but also the width of the UFOV of fatigued drivers is reduced drastically.

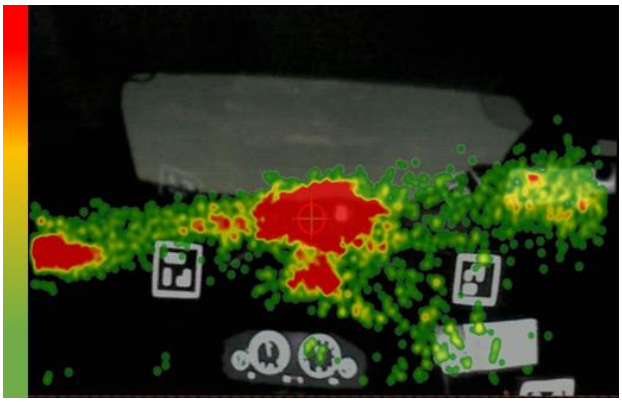

Fig. 5. Heat map of driver's UFOV in the first half of the experiment.

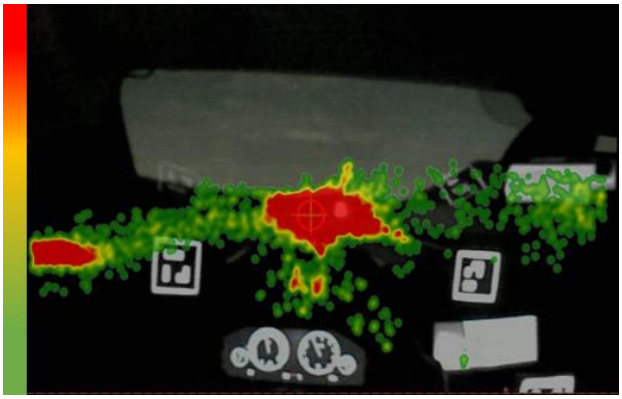

Fig. 6. Heat map of a fatigued driver's UFOV.

3.5 Discussion

We found that age has a significant impact on drivers' gaze behaviour to that extent, that younger drivers are checking mirrors more often than elderly drivers. This goes along with the prior made assumption, listed in section 3.2. One explanation for this phenomenon can be that, due to their trained capability to estimate velocities as well as distances

more properly, older drivers can extrapolate position and behaviour of approaching vehicles easier than younger, unexperienced drivers. Also, due to higher trust in their ability of keeping relevant information in working memory for a longer time period than younger drivers and using that gathered information for future actions, such as changing lanes, older drivers don't need to refresh their situation awareness repeatedly. To our knowledge, no other study has yet investigated this phenomenon and therefore, these results are highly interesting for modelling gaze behaviour and parameterising GLP and attention ratio in side and rear mirrors for rebuilding a valid mental model. Thereby, the probability for missing relevant information as well as the risk of overestimating one's abilities to extrapolate correctly may lead to driving errors or even crashes among especially elderly drivers. Concerning gender, we could observe in parts that women let their eyes wander across the road more than male drivers, whereas males focus more the vanishing point and rely on their peripheral perception. Besides relevant information across the overall road and in neighbouring lanes, women also tend to observe objects on the side of the road, which are irrelevant for the driving task more than men. There was no significant effect in relation to mirror checking but heat maps gave hints on the UFOV in front of the driver. There were no significant correlations between personality traits and gaze behaviour. The prior made assumption about correlations between sensation seeking, proneness to risk, anxiety or patience cannot be accepted.

Analysis of differences in gaze behaviour due to changing driver states brought up interesting results. Fatigued as well as stressed drivers tend to neglect checking mirrors. Especially during acute stress, there was a significant decrease of attention ratio and GLP for side and rear mirrors with a high effect size. Additionally, the width of the UFOV was drastically reduced under acute stress in comparison to the width of the UFOV under a neutral emotional state in the first half of the test drive. Both results underline the importance of emotion, especially stress due to time or pressure to perform, for perceiving relevant information from surrounding traffic. For modelling gaze behaviour in relation to driver states, this means that probability for missing relevant information and having a wrong mental representation of the environment is significantly different and must be adapted. We can assume that these findings are reliable and the correlation between stress and changes in gaze behaviour is valid due to results of the analysis of physical reactions to stress. Heartrates were significantly increasing during acute stress. The opposite was observable in the fatigued subsample. Heartrate was significantly lower during the second half of the monotonous test drive and also within this subsample mirror checking (in detail, attention ratio and GLP for the left mirror) was less frequent in the second half of the experiment than in the first half, when drivers were not yet tired. Subjective rating of fatigue goes along with these findings. This indicates that also fatigued drivers have a higher risk of missing relevant information and having a distorted mental representation of the current situation. One factor that also contributes to these findings may be that drivers change lanes less frequently and tend to stay on the right lane for a longer time period. This may be due to changing motivational factors (e.g. driving fast, enjoying the ride) or, in the stress condition, due to stress compensation strategies. It is possible that drivers tried to equalize the workload, which was needed for solving the mental arithmetic task, with the workload, which must be saved for the driving task. Some drivers may have chosen to reduce workload that was required for the driving task by driving slower and staying on one lane, whereas others used the opposite stress compensation strategy. Prior investigation showed that drivers really tend to reduce speed while being stressed, whereas fatigued drivers tend to drive faster (Witt et al., 2017). Findings of the present study go along with these results.

4. STUDY II

In the following, results from a realistic driving study, which was carried out to investigate the driver's gaze behaviour in traffic situations with variable cognitive demands, will be presented. The aim of this study was to describe differences in gaze behaviour in more complex traffic situations, which require higher cognitive processes in order to acquire a holistic understanding and awareness of the current situation. The initial investigated traffic situation patterns *Approach* and *Following* were extended to *Normal Approach*, *Salient Approach*, *Normal Following*, and *Salient Following*. The difference between a *Normal Approach* and a *Salient Approach* is set by a dynamic time headway (THW) threshold. Within *Salient Approaches* the THW between the two vehicles on the right lane in front of the EGO-driver is smaller (and thereby, more critical) than during a *Normal Approach*. The calculation rules for *Approach* and *Following* are derived from Lee's Tau-Theory (1976). For further description of the dynamic THW threshold, see Ring et al. (2017).

4.1 Participants

A sample of 24 employees at an automotive manufacturer (3 females, 21 males) between 20 and 48 years (Mean = 31.08 years, SD = 6.94 years) took part in this study. For naïve participation, it was necessary that none of the test persons was preconditioned according to the study's test procedure. Neither were the participants involved in the study's aim of analysis nor in related research topics.

4.2 Design and measures

The test vehicle was a BMW 5 Series (production year 2013). To observe the surrounding of the vehicle and to identify the relevant traffic situation patterns in the further data analysis, the standard short/long range front radar as well as the front camera were used. For recording the necessary data, a measuring computer, based on a technical setup of the company VECTOR, was installed. For investigating the drivers' gaze behaviour, the eye-tracking system DIKABLIS 3.0 was used. The eye-tracking system and the VECTOR-system were linked by a LAN network to ensure the synchronicity between both data frames. The test drive took place on public German motorways. Driving distance was approximately 80 km and included motorway sections on the A99, A9 and A92. Every participant drove the same route

without using any driving assistance system in order to observe driver behaviour during manual driving, solely.

4.3 Experimental Measures

For the identification of the previously described traffic situation patterns and for the calculation of the relevant kinematical and optical variables, recorded data from the test vehicle (EGO) and from the surrounding traffic participants, such as longitudinal and lateral distance to the EGO-Vehicle, absolute velocity, current lane, car width and car ID were used. Furthermore, the following AOIs were used to describe and analyse the drivers' gaze behaviour (see Figure 7).

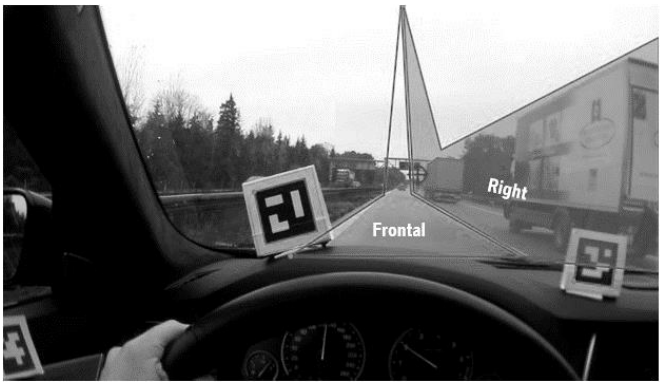

Fig. 7. Considered AOIs (*Frontal* and *Right*) for investigating gaze behaviour in the relevant situation patterns.

The right AOI represents the area, in which the actual traffic situation pattern takes place. The calculations and necessary variables for the traffic situation pattern recognition are described in detail in Ring et al. (2017). The dependent variables for analysing gaze behaviour were defined in accordance with the parameters used in the driving simulator study described above (see Table 1). By contrast with Study I, only these two AOIs (*Frontal* and *Right*) were used for the analysis. The reason for this is, that solely traffic situation patterns on the right front lane of the EGO vehicle were considered.

4.4 Scientific questions and results

In this study, the following scientific questions were targeted and considered in the further data analysis:

Scientific question 1: Is the recognition of a traffic situation pattern affecting the driver's gaze behaviour?

The Kolmogorov-Smirnov-Test was carried out for analysing the single normal-distributed gaze behaviour parameters. The results have shown a non-normal distribution of all gaze behaviour parameters from Table 1. Afterwards, the Two-Variables-Wilcoxon-Test was applied to investigate differences in the drivers' gaze behaviour in relation to different situations with high cognitive demands (*Normal Approach*, *Salient Approach*, *Normal Following*, *Salient Following*) and situations, in which only processes with low cognitive demand are necessary to recognize and understand them (*Free Drive*, *Follow Drive*). *Free Drive* describes a traffic situation, in which there is no preceding vehicle in front of the EGO-driver or is far from reach. *Follow Drive* equals a situation, in which the EGO-driver is driving behind a preceding vehicle and is thereby affected by its actions. As most of the results in Table 2 demonstrate, recognition of a traffic situation pattern has a significant impact on the driver's gaze behaviour as there is mostly an existing and significant difference between the gaze behaviour in a complex traffic situation and a cognitive less demanding situation. As all comparisons between the gaze parameters for the first group (traffic situation pattern) and the second group (low cognitive situations – Grp2) where h=1 and significance level was $p < .05$, a significant difference between this two groups in the gaze parameter could be observed (referring to the Two-Variables-Wilcoxon-Test: h = 1 means that the gaze parameter results in the complex traffic situation pattern are not from the same distribution as the gaze parameter results in the low cognitive situation). When taking a closer look at the results, it becomes obvious that (apart from the parameter *Right_Aoi_Ratio*) the gaze behaviour in a *Normal Approach* is different to the gaze behaviour in a low cognitive situation. For *Normal Follow* the results show a continuous difference between the two groups. The results of the comparison between the traffic situation pattern *Salient Approach* and the low cognitive situations is similar to the results of *Normal Approach*. Only for the pattern *Salient Follow* the difference and non-existing difference in gaze behaviour are equal. Results indicate that there is no difference in gaze behaviour concerning the parameters *Right_Aoi_Ratio* (*Free Drive* and *Follow Drive*) and *Right_Glance_Probability* for *Free Drive*.

Table 2. Results of the Two-Variables-Wilcoxon-Test group comparison

Gaze Parameter	Traffic situation pattern	Grp2	h	p
right_aoi_ratio	Normal Approach	Ego Follow	1	0,0029367
right_aoi_ratio	Normal Approach	Free Drive	0	0,127919
right_glance_prob	Normal Approach	Ego Follow	1	1,977E-06
right_glance_prob	Normal Approach	Free Drive	1	5,584E-05
right_glance_duration	Normal Approach	Ego Follow	1	6,388E-12
right_glance_duration	Normal Approach	Free Drive	1	3,329E-17
right_aoi_ratio	Normal Follow	Ego Follow	1	4,331E-10
right_aoi_ratio	Normal Follow	Free Drive	1	0,000244
right_glance_prob	Normal Follow	Ego Follow	1	1,67E-17
right_glance_prob	Normal Follow	Free Drive	1	8,726E-14
right_glance_duration	Normal Follow	Ego Follow	1	8,216E-18
right_glance_duration	Normal Follow	Free Drive	1	9,791E-24
right_aoi_ratio	Salient Approach	Ego Follow	1	0,0101053
right_aoi_ratio	Salient Approach	Free Drive	0	0,2908635
right_glance_prob	Salient Approach	Ego Follow	1	9,617E-06
right_glance_prob	Salient Approach	Free Drive	1	0,0008012
right_glance_duration	Salient Approach	Ego Follow	1	3,335E-15
right_glance_duration	Salient Approach	Free Drive	1	1,424E-19
right_aoi_ratio	Salient Follow	Ego Follow	0	0,1318989
right_aoi_ratio	Salient Follow	Free Drive	0	0,5052871
right_glance_prob	Salient Follow	Ego Follow	1	0,0293621
right_glance_prob	Salient Follow	Free Drive	0	0,0586068
right_glance_duration	Salient Follow	Ego Follow	1	1,837E-05
right_glance_duration	Salient Follow	Free Drive	1	3,421E-07

Scientific question 2: How can a distribution of a driver's gaze behaviour be characterized in a relevant traffic situation pattern?

For modelling the driver's gaze behaviour, driver-specific parameters are represented by means of random variables (see Table 1). These random variables are realized by means of distribution density functions. This scientific question addresses an analysis of the distribution density functions for the relevant gaze behaviour parameters and the respective traffic situation patterns (*Normal Approach*, *Salient Approach*, *Normal Following*, and *Salient Following*). Maximum likelihood estimation (MLE) was used to approximate the continuous distribution density functions from the discrete results of the realistic driving study. To explore, if a stochastic data set is derived from a particular distribution density function, the maximum likelihood is a statistical measure to express this probability. For comparing several distribution types, the maximum likelihood for each distribution type is calculated. Subsequently, by comparing the different likelihood values of the distribution functions, the distribution with the largest likelihood value is chosen, as this distribution function represents the best fitting parameter distribution.

In accordance with the MLE for normal distribution, the lognormal distribution, the gamma distribution and the Poisson distribution are applied. Table 3 displays the results of the MLE analysis. These results show that the gaze parameter distribution can be described only by a lognormal or a gamma distribution. The parameters for every single distribution function can be taken from Table 3. Furthermore, the results of the MLE indicate that every single gaze parameter for every single traffic situation pattern characterizes a different distribution function.

Table 3. Results of the MLE method

Traffic sutuation pattern	Gaze parameter	Distribution type	Parameters
Salient Approach	Mean glance duration	Lognormal distribution	μ=-2,48, σ=1,12
Salient Approach	AOI (Attention ratio)	Gamma distribution	A=0.91, B=32.79
Salient Approach	GLP (Glance location probability)	Gamma distribution	A=2.67, B=16.72
Normal Approach	Mean glance duration	Lognormal distribution	μ=-2.24, σ=1.27
Normal Approach	AOI (Attention ratio)	Gamma distribution	A=0.94, B=33.72
Normal Approach	GLP (Glance location probability)	Gamma distribution	A=3.05, B=14.14
Salient Follow	Mean glance duration	Gamma distribution	A=1.63, B=0.08
Salient Follow	AOI (Attention ratio)	Gamma distribution	A=1.23, B=20.61
Salient Follow	GLP (Glance location probability)	Lognormal distribution	μ=39.92, σ=19.61
Normal Follow	Mean glance duration	Lognormal distribution	μ=-2,23, σ=1,14
Normal Follow	AOI (Attention ratio)	Gamma distribution	A=1.05, B=29.06
Normal Follow	GLP (Glance location probability)	Gamma distribution	A=3.23, B=13.79

To summarize the results of Study II, the following can be stated: To investigate the drivers gaze behaviour in situations with different cognitive demand, a realistic driving study with corresponding measuring systems is suitable. The investigation of the scientific question 1 has shown that there (mostly) is a difference in the driver's gaze behaviour, when drivers are faced with a high cognitive situation or a low cognitive situation. The Two-Variables-Wilcoxon-Test was used to further test this phenomenon. Scientific question 2 addresses the analysis of the distribution density functions for the relevant gaze behaviour parameters and the respective traffic situation patterns. The results of the MLE show that the parameters can be described either by a gamma or by a lognormal distribution. Furthermore, every gaze parameter has a different density function in comparison to the others. This means that gaze behaviour in different traffic situation patterns always follows a different character, which has to be considered in the further modelling of gaze behaviour for virtual traffic agents.

5. CONCLUSION

Results of both studies underline the necessity of considering divers factors for an appropriate stochastic modelling of the driver's gaze behaviour. Outcomes indicate that driver individuality as well as different driver states and changes in traffic or environmental conditions can have a significant impact on gaze duration and gaze transition probability for relevant AOIs in the surrounding of the vehicle. Especially for factors, such as driver fatigue or stress, which are often closely connected with the incurrence of accidents, data underline the importance of considering gaze behaviour and thereby information acquisition in the early stages of driver behaviour models. In particular, the narrowing of the UFOV, which was highly obvious in both driver states, indicates that not all relevant information in the surrounding traffic may be represented in the mental model of the driver. E.g. not recognizing looming vehicles or vehicles in the blind spot, can be crucial reasons for the occurrence of accidents. Feasible thoughts in the development of ADAS and automated driving functions can be earlier warnings in terms of detected fatigue or stress or shorter hands-off times while driving in a partly automated mode. Furthermore, particular situation patterns with different levels of cognitive demand for the driver to recognize the current situation pattern, have a significant impact on the driver's gaze behaviour. Additionally to this, even in solely high cognitive situation patterns, gaze behaviour is different, as depicted in different distribution density functions. Data found in the presented research studies, deliver important pieces of advice for any further work in the field of driver behaviour modelling. This applies for the refinement of the gaze control sub-module in the SCM as well as for other driver behaviour models, which are currently developed by several other stake holders and automobile manufacturers.

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