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Abstract

Driving simulator studies are popular means to investigate driving behavior in a controlled environment and test safety-critical events that would otherwise not be possible to test in naturalistic driving conditions. While several factors are known to affect driving performance, driving distraction has been emphasized as a safety-critical issue across the globe. In this context, this study aims to explore the impact of distraction resulting from mobile phone use to write and read text messages on driver behavior. As a part of the greater i-DREAMS project, this study uses a car driving simulator experimental design in Germany to test driver performance under a variety of conditions. Wearable eye-tracker glasses are used to investigate the attention allocation and eye movement patterns of drivers. This research focuses on driver response to different risky events on the road (i.e., pedestrian collision, tailgating) and the impact of distraction on driving performance. A set of eye movement and driving performance measures of 58 participants are analyzed. The results reveal a significant change of drivers' gaze patterns during the distraction drives with significantly higher gaze points towards the i-DREAMS intervention display. The overall statistical analysis on driving performance measures suggests nearly a similar impact on driver behavior during distraction drives, with a higher deviation of lateral positioning despite the risk level of the events on the road and lower longitudinal acceleration rates for pedestrian collisions and non-critical events during distracted driving.

Keywords: Driving simulator; Distraction; Eye-tracking; Driving behavior; Advanced Driver Assistance Systems

1. Introduction

While several factors are known to affect driving performance, driving distraction has been emphasized as a critical safety issue across the globe, with the World Health Organization stating distracted driving as a key problem contributing to tens of millions of injuries on roadways each year [1]. In 2016, nine percent of fatal traffic crashes were distraction-related, highlighting the negative role of distracted driving on traffic safety [2]. Driver distraction occurs due to the temporary shifting of attention from the task required for safe driving to the secondary task(s) not related to driving [1], and depending on the type of secondary task, it can engage drivers visually, auditorily, physically, and cognitively. Different in-vehicle or external sources can lead to driver distraction, such as conversing with passengers, eating/drinking, daydreaming, and reaching for an object. However, with the rapid growth of smart technologies, such as smart mobile phones, smartwatches, and advanced navigation systems, drivers are exposed to a high number of in-vehicle distraction sources. Texting while driving is a form of mobile phone distraction that refers to the task of writing/reading a text message, writing/reading an email, browsing social media or a website, etc. Texting while driving can engage drivers in many ways, including 1) visually by taking the driver's eyes off the road to read/write a text message, 2) auditorily through notification sounds that diverts the driver's attention away from the driving task, 3) physically by removing hand(s) from the steering wheel to reach the mobile phone and read/write a text message, and 4) cognitively by engaging the driver' focus and attention in reading/writing tasks while driving. According to relevant literature, drivers who used their mobile phones to read/write text messages had a delay in response to stimuli on the road, reduction in speed, poor lane keeping, and fewer glances ahead to compare with non-distracted drivers [3-5]. Basacik et al. [5] show that the use of the mobile phone can increase the reaction time by approximately 30% and reduce the driver's ability to maintain a safe distance from the lead vehicle. As a result, texting while driving is associated with a high risk of being involved in safety-critical events [6]. Some studies estimated two to nine times higher crash risk for drivers engaged in mobile phone-related distraction than non-distracted ones [6-8]. In one observational study from 2012, the average daytime cell phone use while driving was found to be seven percent [9], and since then, cell phone use has increased globally [10]. In the United States in 2018 alone, 2841 fatalities were associated with distraction [11]. The results from the Second Strategic Highway Research Program Naturalistic Driving Study (SHRP2) showed that hand-based mobile phone distractions increased the crash risk, with odds ratios indicating that texting while driving increased crash risk by roughly 6.1 [12-13].

1.1. Distraction in Driving Simulator Studies

Driving simulator studies have proven to be successful in the evaluation and understanding of driver performance given the level of control offered by high fidelity simulators [14]. Yannis et al. [15] examined the impact of texting on young drivers' behavior through a simulation experiment. A set of text messages was sent to the participants during the drives in rural and urban areas and under various weather conditions (i.e., good, rainy, and night). Results indicated that texting while driving can lead to a delayed reaction to hazardous events, and thus, a higher crash risk. McKeever et al. [16] tested the driver performance while texting by considering a baseline loop condition (with no distraction) and a task-engaged loop (with distraction) in a driving simulator. Their investigation demonstrated that text messaging had a significant effect on driver behavior, such as lane maintenance, speed maintenance, and shifts of attention. Thapa et al. [17] compared the impact of phone conversation and text messaging on driver performance at different levels of complexity. The results revealed a significant decrease in both longitudinal and lateral control of the vehicle for texting and driving events, while the mobile phone conversation had no substantial impact on the driving task. Another experimental study using a driving simulator investigated the influence of driver's engagement in social media applications [18]. Three scenarios were designed for the experiment for driving with and without distraction factors and with and without advance driver assistance systems (ADAS) warnings. The statistical analysis showed that the application of ADAS helped in reducing driving infractions by approximately 43% compared to the situation in which there were no warnings. Oviedo-Trespalacios et al. [19] explored the relationship between self-regulatory secondary task performance and driving, in which participants were allowed to use their mobile phone for text messaging or browsing social media whenever they felt appropriate. Results showed that the extent of engagement in the secondary task affected both longitudinal and lateral control of vehicles. In contrast with hands-free interactions, drivers with longer visual-manual interactions selected higher driving speeds. This is likely connected to the theory of risk homeostasis, suggesting all people adjust their behavior in response to their desired level of perceived risk [20]. Drivers are unaware of the real risk that occurs when texting and driving, due to their inability to perceive risk accurately in driving conditions [21]. Overall, previous research shows that there is a need to investigate further specific countermeasures that decrease driver distraction due to cell phone use to increase safety, including driver monitoring systems.

1.2. Distraction Studies using Eye Movement Data

Eye-tracking devices have been used frequently to measure drivers' eye movements and visual attention and investigate the effect of distraction on driving performance [22-23]. Eye movements and gaze data can provide insight into drivers' cognitive processes and intended actions, and thus, a more thorough understanding of their behavioral patterns. Hashash et al. [24] examined the effects of texting and social media browsing while driving on driver behavior and attention allocation by using eye movement data. A variety of risky traffic situations were simulated during the experiment, e.g., a pedestrian crossing the road in front of the driver, sudden braking of a leading vehicle. The analysis of different driving performance (e.g., speed, reaction time) and eye-tracking measures (e.g., number and duration of fixations, gaze position) revealed that both texting and browsing social media impair the performance of drivers, but texting while driving is more detrimental to the driving task. Concerning attention allocation, texting, and browsing social media were found to cause very similar outcomes. Kim and Yang [25] evaluated the effects of driver distraction under different simulated environment conditions (e.g., normal driving, visual-manual load, and cognitive overload). The study showed there was a reduction of drivers' gaze ratio on the road during the visual-manual load tasks compared to normal driving. In contrast, the driver's gaze on the road increased during the overloaded cognitive task than during normal driving conditions. Desmet and Diependaele [26] explored the effects of hands-free phone conversations while driving on driver visual attention in a field trial. The findings suggested that during hands-free phoning, the gaze behavior is impacted to a lesser degree by the driving task; drivers seemed to fixate less on traffic-related information. Similar results were found by Nabatilan et al. [27] during a simulation experiment in which the visual behavior of the drivers was assessed by using eye-tracking systems, driving error, and a subjective workload assessment tool. The driving performance of inexperienced and experienced drivers was evaluated through simple and complex driving tasks performed with and without a mobile phone-related distraction. Another study investigated the glance behavior of drivers in relation to roadside advertising signs [28]. The duration, frequency, and angle of driver glance were analyzed to understand how the sign placement in the visual field can affect driver behavior. Participants showed significantly higher glances towards the moveable signs compared with passive signs.

While previous studies aimed to understand the impact of distraction and used eye-tracking data to investigate distraction, there is limited research studying the impact of interventions on driving performance. As a part of the greater i-DREAMS project, this study uses a car driving simulator experimental design in Germany to test driving performance under a variety of conditions. Driving behavior was investigated in this paper by observing drivers' eye movements during the distraction, and comparing them with scenarios without distraction, and also in critical events, with and without interventions.

2. Methodology

An experimental design was developed to investigate the impact of distraction on driver performance through a series of critical events (i.e., tailgating, and pedestrian collision). The selected critical events were used to design three driving sessions (each ∼15 minutes) for the simulator trials. The first session (the monitoring scenario) included a monitoring drive with no intervention, the second session (the intervention scenario) included an intervention drive with fixed timing warnings, and the third session (the distraction scenario) included an intervention drive with interventions based on task completion capability. For the third session, the modified conditions varied the intervention thresholds [29]. A short practice drive (∼5 minutes) was designed to help participants become familiar with the driving simulator environment and its operational aspects. The following sub-sections present the driving simulator experiments and risk scenarios for the case study of the German experiments within the i-DREAMS project.

2.1. Driving Simulator Experiments

The experiments were conducted in Germany at the chair of Transportation Systems Engineering at the Technical University of Munich (TUM), using a customized driving simulator developed by DriveSimSolutions (DSS). The driving simulator is based on a Peugeot 206 and uses many authentic parts, such as a complete dashboard, adjustable driver seat, steering wheel, and instrument cluster with functional speed and tach gauges. Visuals are provided through three 49" 4K monitors providing a 135° field of view. Driver controls include pedals (throttle, brake, and clutch), gear shifter (6 speed + reverse or sequential) and authentic controls for turn indicator, low beam, high beam, and horn. The driving simulator has a dimension $(W \times L)$ of $260cm \times 200cm$. The simulator uses a fully customizable STISIM Drive 3 software, allowing for the creation of custom scenarios and data collection at every simulation frame. The sampling frequency of the driving simulator is 60 Hz.

Participants' gaze data during all three sessions are collected by Tobii Pro Glasses 2. Tobii Pro Glasses 2 are equipped with two cameras for each eye that uses Tobii's 3D eye model, ensuring automatic slippage compensation and making it possible to run eye-tracking studies in dynamic environments. Pro Glasses 2 capture all the details of the surrounding environment by offering a full-HD scene camera with a large field of view. The eye-tracker has a 100 Hz sampling frequency that leads to generating 100 samples per second. The Analyzer module of Tobii Pro Lab is used to analyze the recorded gaze data and export this in different formats for further analysis.

The safety-oriented intervention systems developed within the i-DREAMS project were activated during the intervention and distraction scenarios. In addition to the headway, pedestrian, forward collision, and lane departure warnings were triggered in case of unsafe driving maneuvers by drivers. Drivers received audible and visual warnings via the clock display of the car replaced with the i-DREAMS display. During the distraction scenario, a visual mobile phone distraction warning was triggered when drivers received a text message. Table 1 summarized multiple sources of data collection used during the simulator runs.

A total of 60 participants from different age groups (18-75 years old) were recruited to complete the driving simulator experiment, as well as pre- and post-experiment questionnaires. Questionnaires were designed to collect information regarding driver demographics, driving experience, and participants' perspectives on driving assistance technologies. A section was allocated in the questionnaires to evaluate participants' attitudes with respect to different in- and out- of vehicle distraction types. The entire experiment took approximately two hours including driving the practice scenario, monitoring scenario, intervention scenario, distraction scenario, filling out the questionnaires, and session breaks. To minimize the risk of simulation sickness, participants got a 10-minute break between the sessions and were constantly screened during the trials by a moderator. The entire data collection process was fully anonymized by assigning a 30-digit ID to each participant. The participants were remunerated with a 25 EUR voucher at the end of the experiment.

Table 1: Data collection sources utilized in the simulator experiments in Germany. Source: [30]

Data Source	Purpose
Mobileye	Forward Collision Warning (FCW), Lane Departure Warning (LDW), Pedestrian Collision Warning (PCW), etc.
PulseOn wearable	Cardiovascular data such as interbeat interval.
CardioGateway	i-DREAMS real-time interventions such as headway warning.
Questionnaires (one entry questionnaire & two exit questionnaires)	To assess driver background factors, technology acceptance and feedback based on the usage of the i-DREAMS real-time intervention system.
Simulator log files	Measurement of driving performance variables.
Tobii Pro Glasses 2	Eye movement data of participants.

2.2. Design of Risk Scenarios

The driving scenarios were developed using a total of six safety-critical events (CEs) for tailgating and pedestrian collision. Pedestrian collisions were investigated by triggering three critical events between a pedestrian and the driver:

- **CE 1:** A pedestrian crosses the road illegally (the traffic signal does not permit crossing) when the driver is approaching the intersection on the green phase.
- **CE 2:** At a mid-block crossing, a pedestrian initially obstructed from the driver's view by a bus commences crossing the road while the driver is approaching.
- **CE 3:** A pedestrian crosses the road at an uncontrolled intersection while the driver is approaching.

The tailgating behavior is explored through a low-speed lead vehicle in front of the driver that imposes the events:
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- **CE 1:** A car is driving at a low speed in front of the driver, while the available gap in the opposite traffic is not long enough for an overtaking maneuver.
- **CE 2:** A car overtakes the driver and suddenly merges into the lane in front of it with the result that the driver needs to adjust the driving speed.
- **CE 3:** A car enters the highway in front of the driver, with the result that the leading car needs to make a harsh brake.

Figure 1 shows examples of safety-critical pedestrian collision and tailgating events in the simulated driving environment.

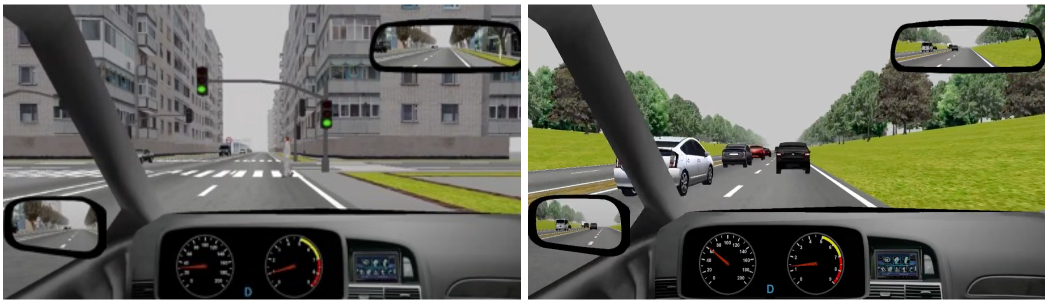

Figure 1: Screenshots of CE 1 - pedestrian collision (left) and CE 2 - tailgating (right) in the simulated driving environment.

To investigate distraction, eight text messages at two levels of complexity (simple and complex) were sent by the moderator to the participants during the distraction scenario (Tab. 2). Six text messages were triggered before the critical events, and two text messages were triggered, when there was no event. Before the trial, participants were trained to only reply to the text messages, which are in the form of a question. The text messages could be sent or received both in German and English. An iPhone 7 mobile phone was provided for participants to use for text messaging during the trial, and all text messages were sent through the WhatsApp application. Before the start of the third session, participants were able to familiarize themselves with the mobile phone, WhatsApp application, and the text message notification sound. A message appeared in the scenario generation window, at the distance at which the distraction should have been triggered. This helped moderators apply the distraction at the same time/distance interval for all participants. To avoid learning effects, three driving scenarios (scenarios A, B, and C) were created with different orders of critical events. A Balanced Latin square method was applied to equally distribute the scenarios between the participants. The Latin square ran through five times for 60 participants.

Table 2: Distraction design of session 3 (distracted driving). Source: [29]

Distraction	**Event**	**Complexity level**	**Content of the text message**	**Length (character)**
Reading text message (TM)	CE 1 - Pedestrian collision	simple	“Thank you for participating in the experiment”	45
Reading & replying to TM	CE 2 - Tailgating	complex	“Can you name two cities you want to visit?”	question:42 answer: max. 25
Reading TM	No event (NE)	simple	Your dentist appointment is scheduled for 30/04/2021 at 14:15”	62
Reading & replying to TM	CE 3 - Tailgating	simple	“Where is your hometown?”	question:24 answer: max. 15
Reading a TM	CE 2 - Pedestrian collisions	simple	“Nice to see you at the café yesterday”	37
Reading a TM	CE 3 - Pedestrian collisions	simple	“50% off on online orders! Today only!”	34
Reading & replying to TM	No event (NE)	complex	“What are two things that you enjoy doing the most?”	question:45 answer: max. 25
Reading & replying to TM	CE 1 - Tailgating	complex	“27+30=?”	question:7 answer: max. 2

3. Analysis and Results

A total of 60 participants participated in this experiment in two stages. A data cleaning strategy was performed to choose the completed data of participants for all scenarios. Two participants, with an incomplete recording of the driving simulator and eye-tracking data, are removed from the data analysis. In this research, data of 58 participants are selected for analysis.

3.1. Analysis of Eye Movement Data

The eye movement data are recorded using Tobii Pro Glasses 2 eye-tracker and the Analyzer module of the Tobii Pro Lab software was used to extract the desired parameters. In this study, the eye movement data were analyzed during all distraction events, i.e., critical events of tailgating, pedestrian collision, and non-critical events, where drivers received text messages. Initially, a time of interest (TOI) with a one-second offset before and after the event was defined for logging each distraction event. The logged events are matched in scenarios with different order of events using the participant simulator data and the distance that distractions were triggered. Then, areas of interest (AOI) were created for the road ahead, steering wheel area (car speedometer), i-DREAMS display, and mobile phone screen to identify where participants are looking at during the critical events and in the distraction scenario (Fig. 2). The AOI changes to the road ahead and steering wheel area for monitoring scenario, and the road ahead, steering wheel area, and i-DREAMS display for intervention scenario. Pedestrians are tracked in all scenarios with an additional AOI. All AOI are constantly adjusted during the drive to produce more accurate results, and the overlapping of areas are manually corrected through either deactivating or altering the area size. The time lag between the start of the eye-tracker recording and the driving simulator scenarios is included in the analysis. It is worth noting that there was no need for data synchronization since the aggregated eye movement measures are extracted for the purpose of this research.

A variety of eye movement measures are extracted using different metrics and based on the pre-processed data generated by the Pro Lab Gaze filter functions. One significant metric is fixation time, defined as the time periods during which the eyes are relatively still with the central foveal vision in place. During the fixation time, the cognitive system can process detailed information on objects being looked at. In Tobii Pro Lab, fixation is a sequence of raw gaze points with an estimated velocity below the threshold set in the I-VT (Velocity-Threshold Identification) gaze filter and for any eye movement below 100 degrees/sec [31]. Two measures of eye movement, obtained after applying fixation metrics, are selected for analysis. The first measure is the average fixation duration which records the elapsed time between the first and the last gaze points in the sequence of gaze points. The second measure is the number of fixations that occurred during the selected time intervals (TOI) and within the targeted AOI.

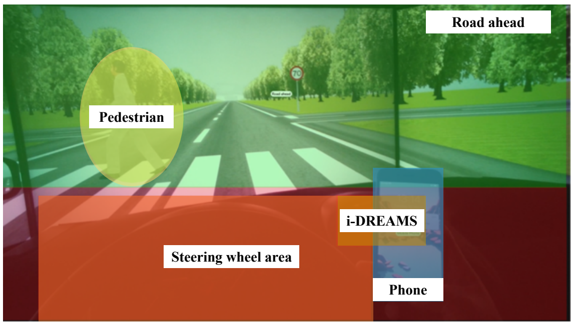

Figure 2: An example of the AOI created for intervention scenarios.

3.2. Driving Simulator Data

The outputs of driving data are generated at the completion of the simulation runs with several parameters pre-set to be saved into the BSAV data files generated in STISIM. The name of the generated files is specified in the "output data file" field in the main window of STISIM Drive and stored in the specified sub-directory in the STISIM Drive configuration. As shown in Table 1, multiple sources of data collection are used during the simulator runs. In this research, a set of parameters is scrutinized during the logged TOI in all scenarios (i.e., monitoring, intervention, and distraction scenarios) to investigate the impact of distraction on driving performance. This includes lateral positioning and longitudinal and lateral acceleration rates. The position of the vehicle with respect to the lane center is measured through the variable lateral position. The variables of longitudinal and lateral acceleration are defined as the rate of velocity change in the direction of the vehicle's longitudinal and lateral axis, respectively [30].

3.3. Statistical Analysis Results

As previously stated, a set of eye movement and driving performance measures are selected for analysis. Before performing statistical testing, a Shapiro-Wilk test of normality was applied to all variables to determine if the distribution of data comes from a normally distributed population. If the Shapiro-Wilk test fails to reject the null hypothesis, meaning that data is normally distributed, a one-way repeated measures analysis of variance (ANOVA) is performed for the statistical test. One-way repeated measures ANOVA evaluates whether the population means of three levels (monitoring, intervention, and distraction scenarios) of a within-subjects variable are equal. If the relationships are proved statistically significant (p-value ≤ 0.05), a further Post Hoc test of Tukey multiple pair-wise comparisons is applied to determine which means amongst the set of means differ from the rest. When the ANOVA test proves statistically insignificant relationships (p-value > 0.05) between the groups, the Tukey test is no longer performed. If the Shapiro-Wilk test rejects the null hypothesis of normal distribution, the ANOVA test is no longer applicable, and instead, a Kruskal-Wallis test is applied. In the Kruskal-Wallis test, the significance level of the p-value is similar to levels in the ANOVA test. Following the rejection of the Kruskal–Wallis test, a Post Hoc analysis of the Dunn test is used to determine which groups differ from other groups.

Table 3 summarizes the analysis of the measures utilized to evaluate the eye movement behavior of drivers during three scenarios (monitoring, intervention, and distraction). As previously stated, the focus of this research is on distracted driving, and thus, driving behavior are examined during the period of triggering mobile phone distraction and compared with the similar TOI during monitoring and intervention scenarios. Eye movement data extracted through the Analyzer module of Tobii Pro Lab software is aggregated for all participants and the mean values of fixation duration and fixation count are used for each distraction event. A similar approach is taken for simulator data analysis. The eye movement and driving performance data are analyzed for critical events and non-critical events, separately. The statistical significance of driving performance measures in three scenarios are shown in Table 4.

Table 3: Statistical test results of the differences in mean of drivers' eye movement measures.

Measure	AOI	TOI	Scenario		z-value	p-value
Fixation Duration (Average)	Road Ahead	CEs	Monitoring	Intervention	1.167	0.242
				Distraction	-2.452	**0.021***
			Intervention	Distraction	-3.620	**0.000***
	i-DREAMS Display	CEs	Monitoring	Intervention	-	-
				Distraction	-	-
			Intervention	Distraction	-1.645	**0.000***
	Dashboard Area	CEs	Monitoring	Intervention	-0.088	0.929
				Distraction	-3.728	**0.000***
			Intervention	Distraction	-3.640	**0.000***
Fixation Count	Road Ahead	CEs	Monitoring	Intervention	-2.879	**0.000***
				Distraction	-11.68	**0.000***
			Intervention	Distraction	-8.806	**0.000***
	i-DREAMS Display	CEs	Monitoring	Intervention	-	-
				Distraction	-	-
			Intervention	Distraction	3.322	**0.000***
	Dashboard Area	CEs	Monitoring	Intervention	-1.996	**0.045***
				Distraction	-7.944	**0.000***
			Intervention	Distraction	-5.948	**0.000***
Fixation Duration (Average)	Road Ahead	NEs				0.108
	i-DREAMS Display	NEs	Monitoring	Intervention	-	-
				Distraction	-	-
			Intervention	Distraction	0.455	0.649
	Dashboard Area	NEs	Monitoring	Intervention	-1.522	0.127
				Distraction	-3.781	**0.000***
			Intervention	Distraction	-2.259	**0.035***
Fixation Count	Road Ahead	NEs	Monitoring	Intervention	-5.144	**0.000***
				Distraction	-7.491	**0.000***
			Intervention	Distraction	-2.347	**0.018***
	i-DREAMS Display	NEs	Monitoring	Intervention	-	-
				Distraction	-	-
			Intervention	Distraction	3.441	**0.000***
	Dashboard Area	NEs	Monitoring	Intervention	-1.821	0.068
				Distraction	-4.043	**0.000***
			Intervention	Distraction	-2.222	**0.039***

*P-value level of significance ≤0.05

Table 4: Statistical test results of the differences in mean of metrics to evaluate driving performance.

Measure	TOI	Scenario		z-value	p-value
Lateral Position (std. dev.)	CEs	Monitoring	Intervention	-0.267	0.789
			Distraction	5.273	**0.000***
		Intervention	Distraction	5.540	**0.000***
	NEs	Monitoring	Intervention	-2.930	**0.003***
			Distraction	3.306	**0.001***
		Intervention	Distraction	6.209	**0.000***
Longitudinal Acceleration (mean)	CEs				0.410
	NEs	Monitoring	Intervention	-1.228	0.219
			Distraction	-4.138	**0.000***
		Intervention	Distraction	-2.910	**0.005***
Lateral Acceleration (mean)	CEs				0.363
	NEs				0.272

*P-value level of significance ≤0.05

4. Discussion

This research investigates the impact of distraction -in the form of texting while driving- on driving performance. This incorporates different driving conditions: 1) monitoring scenario which represents the normal driving condition, 2) intervention scenario with fixed timing warnings in case of unsafe driving maneuvers, and 3) distraction scenario, with interventions based on task completion capability, where mobile phone distraction is imposed via sending a set of pre-defined text messages. The results of the evaluated eye movement and driving performance measures are discussed in the following sections.

4.1. Eye Movement Behavior

The statistical significance in the average fixation duration and fixation count indicated a change of drivers' gaze patterns during the intervention and distraction scenarios. During these scenarios, drivers' gaze behavior was reduced significantly with respect to the road ahead and dashboard area. This reduction may be associated with drivers' attentional shift from the road ahead and dashboard area to the mobile phone screen during the distracted driving and possibly to the i-DREAMS warning display during the intervention scenario. In contrast, the statistical significance of drivers' eye movement measures revealed an increase of gaze points to the i-DREAMs display. Since the i-DREAMS intervention system triggers visual and audible warnings, higher gaze points on this AOI were expected. However, during the distraction drive, fixation count measure showed a significant increase compared with the intervention drive. This suggests that drivers may have more reliance on the intervention system while distracted and check the i-DREAMS intervention system more frequent. The gaze patterns of drivers during the pedestrian critical events and in the intervention and distraction scenarios are visualized as an example in Figure 3. Regarding the NEs, the statistical significance in changes of fixation count during NEs returned a similar gaze pattern as CEs for all AOI. Although, participants had no significant changes in fixation durations on the road ahead and i-DREAMS warning display. The insignificance level of the measures in these AOI may be correlated to the lower amount of information that drivers required to process for a safe driving maneuver compared with CEs, and thus, less visual attention to the warning system.

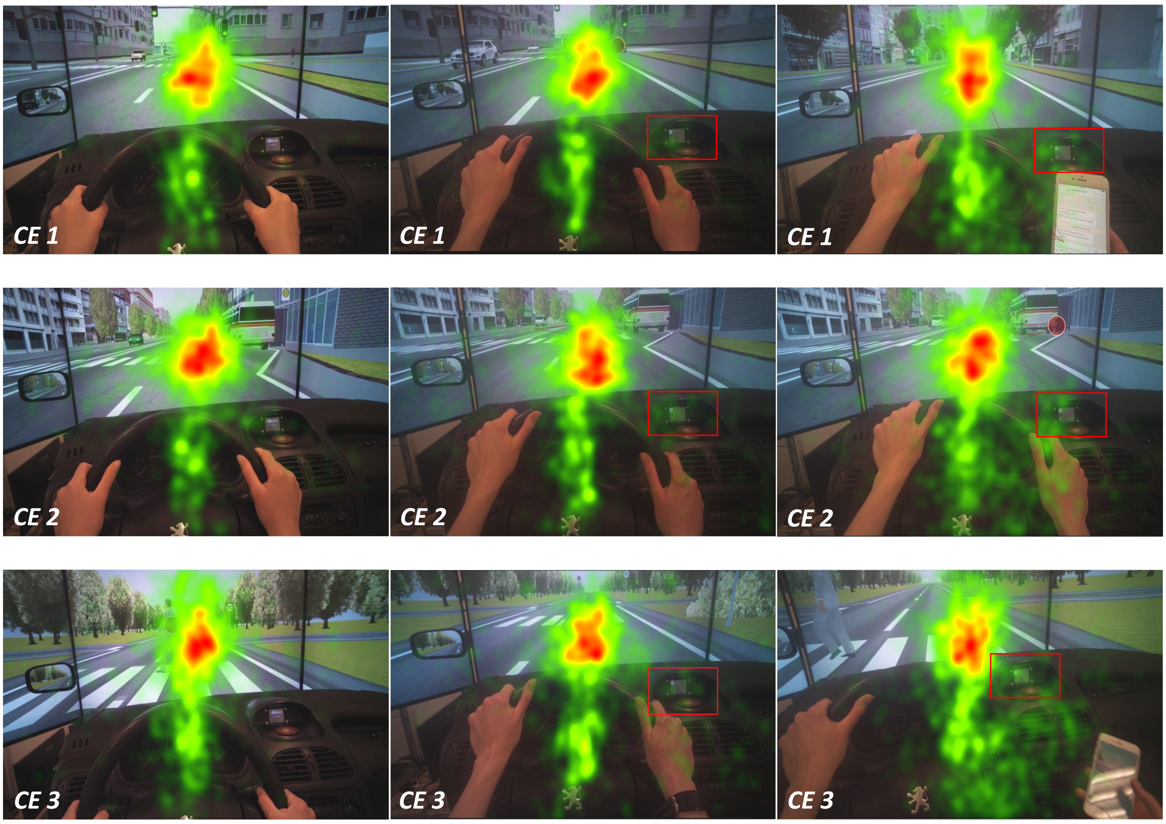

Figure 3: Gaze density heat maps in monitoring (right column figures), intervention (middle column figures) and distraction (left column figures) scenarios during the pedestrian CEs.

4.2. Driving Performance Behavior

Analyzing the driving performance measures (Tab. 4) shows that drivers had a significantly higher deviation of lateral position during the distraction drive during all critical and non-critical events. Besides, the results show that the mean value of the longitudinal acceleration significantly decreased during the NEs while drivers were distracted. Although the analysis reveals no significant statistical change in the mean value of the longitudinal acceleration during the CEs, a separate analysis is performed to scrutinize the driving performance during different events. The analysis returns the p-value of 0.026 showing the significant decrease of longitudinal acceleration during the pedestrian CEs. These results are aligned with previous findings of research on the impact of distraction on driving performance, where mobile phone distraction influenced longitudinal and lateral control of vehicles [17,19,32]. The mean value of lateral acceleration measure shows no significant change during all three scenarios. The overall statistical analysis of the measures suggests that distraction had a nearly similar impact on driving performance despite the risk level of the events on the road. Further, the analysis of driving performance measures raises the question how driving performance would compare between distraction without the i-DREAMS and distraction with the i-DREAMS intervention system, in the presence of safety critical events. However, this was not part of the current experiment, and can be considered in future works.

5. Conclusions

Driving simulator studies are widely used tools to investigate driving behavior in a controlled and safe environment, where different risky driving conditions, complex driving tasks and various traffic situations can be tested. In this research, the impact of mobile phone distraction, as a critical safety issue, is investigated. As a part of the i-DREAMS project, a car driving simulator experiment is held in Germany to evaluate driver performance under different conditions, i.e., normal driving, normal driving with fixed timing interventions, and distracted driving with interventions based on task completion capability while drivers receive text messages. Different risky events regarding pedestrian collision and tailgating maneuvers are designed to investigate the driver response under the various driving conditions. A total of 8 text messages are sent to participants during distracted driving and wearable eye-tracker glasses are used to explore the eye movement patterns of drivers. The results suggest that driver gaze patterns significantly change while drivers are distracted, with a significant increase towards the i-DREAMS intervention display. This may indicate that the i-DREAMS intervention display may be adding to the visual distraction sources available for drivers or bringing them back to the driving task. Future studies should investigate this phenomenon to understand if visual interventions offer a higher benefit than cost towards safety compared to other types of interventions (e.g., auditory-only, physical). The overall statistical analysis on driving performance measures reveals a similar impact on driver behavior, with a higher deviation of lateral positioning and lower longitudinal acceleration rates during the distracted driving. In future work, a broader range of driving performance and eye movement measures, as well as information collected through the questionnaires, will be utilized to further explore driver behavior.

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