Analyzing driver eye movements to investigate the impact of distraction on driving behavior

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Abstract

Distracted driving has been underlined as a critical safety issue globally that negatively affects drivers' performance. This study explores the impact of distraction imposed by mobile phones to write/read text messages on driver behavior. As a part of the i-DREAMS project, this study utilizes a car driving simulator experimental design in Germany to examine driving performance under various conditions. Besides, eye-tracking glasses are used to study drivers' eye movement behavior further. The analysis of thirty participants' eye movement data reveals a significant change in drivers' gaze patterns during the distraction drives with significantly higher gaze points towards the i-DREAMS intervention display (the utilized advanced driver assistance systems in this study). Furthermore, the overall statistical analysis of driving performance measures suggests a higher deviation of lateral positioning and longitudinal acceleration rates during the distraction drives.

Keywords: Driving simulator; Distraction; Eye-tracking; Driver behavior; Advanced driver assistance systems

1. Introduction

Driving distractions has been emphasized as a growing concern for traffic safety that can negatively impact the performance of drivers on the road [1]. Driver distraction refers to the driver's temporary shift of attention from the task required for safe driving to the secondary task(s) not related to driving [1] and can engage drivers in different ways –depending on the type of secondary task. Texting while driving, as a form of mobile phone distraction, refers to the task of writing/reading a text message, writing/reading an Email, browsing social media, etc. Texting while driving can engage drivers: (I) visually by taking the driver's eyes off the road to the device screen, (II) auditorily through the notification sound that diverts the driver's attention away from the driving task, (III) physically by removing hand(s) from the steering wheel to reach/use the mobile phone, and (IV) cognitively by engaging the driver' focus and attention in reading/writing task while driving. According to the World Health Organization, drivers using mobile phones are nearly four times more likely to be involved in a crash than non-distracted drivers [1]. In addition, using a mobile phone while driving leads to higher reaction times, poor lane keeping, unsafe distance from the leading vehicle, fewer glances ahead, and thus a high risk of being involved in safety-critical events compared with non-distracted driving conditions [1-2].

1.1. Distraction in driving simulator studies

Driving simulator studies have proven successful in understanding driver performance, given the level of control offered by high-fidelity simulators [3]. Various simulation experiments have been conducted to test safety-critical events and examine driver behavior under such driving conditions. For instance, Yannis et al. [4] evaluated the impact of texting on the behavior of young drivers under various conditions (e.g., different road types and weather conditions). The experimental study showed a delayed reaction to safety-critical events and, thus, a higher crash risk among distracted drivers. Another simulator experiment compared the driving performance of distracted (i.e., engaged in text messaging task) and non-distracted drivers [5]. The results revealed that distraction significantly affected driver behavior, such as lane maintenance, speed maintenance, and attention shifts. Finally, Dumitru et al. [6] investigated the impact of in-vehicle smartphone-based advanced driver assistance systems (ADAS) on the drivers' behavior when engaged in social networking applications. Different scenarios were designed to explore driving performance with and without distraction factors and with and without warnings. The statistical analysis indicated that the ADAS application reduced driving violations by roughly 43% compared to the cases with no warning. In general, earlier research suggests exploring further specific countermeasures that reduce mobile phone distraction and thus improve safety, including driver monitoring systems.

1.2. Distraction studies using eye movement data

Eye-tracking instruments are frequently utilized to research drivers' eye movement behavior and the effect of distraction on driving performance. In addition, eye movements and gaze data can provide insight into drivers' cognitive processes and, thus, a more comprehensive understanding of their behavioral patterns. For example, Hashash et al. [7] utilized eye movement data to study the impact of texting and social media browsing on driver behavior in various risky traffic situations. The experimental study revealed that driver engagement in texting or browsing social media deteriorated driving performance, while both tasks showed similar attention allocation patterns. Another study assessed the impacts of distracted driving under different simulated circumstances [8]. The study demonstrated a decline in driver's gaze ratio on the road during the visual-manual load tasks and an increase during the overloaded cognitive task compared to the normal driving condition.

While previous studies understood the impact of distraction, limited research explores the impact of interventions on driving performance. As a part of the i-DREAMS project, this study employs the car driving simulator experimental design in Germany to test driver performance under various conditions. In this paper, driving behavior is investigated by monitoring the eye movements of distracted drivers and comparing them with non-distracted driving conditions, but also in critical events, with and without interventions.

2. Methodology

An experimental design was developed to investigate the impact of distraction on driver performance. For this reason, a series of critical events (i.e., tailgating, and pedestrian collision) were used to design three driving sessions (each ~15min) for the simulator trials [9]:

- **Monitoring Scenario**: The first session includes a monitoring drive with no intervention.
- **Intervention Scenario**: The second session includes an intervention drive with fixed timing warning.

- **Distraction Scenario**: The third session includes an intervention drive with interventions based on task completion capability.

A short practice drive (~5min) was designed to help participants become familiar with the driving simulator environment and its operational aspects.

2.1. Design of risk scenarios

The driving scenarios embedded six critical events (CEs) for tailgating and pedestrian collisions. The tailgating behavior was explored through a low-speed lead vehicle in front of the driver that imposes the events, and the pedestrian collisions were investigated by triggering three critical events between a pedestrian and the driver. In addition, eight text messages at two complexity levels (i.e., simple, and complex) were sent to the participants during the distraction scenario: six text messages before the critical events and two when there was no event [9]. 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.

2.2. Driving simulator experiments

The experiments were conducted in Germany at the chair of Transportation Systems Engineering of the Technical University of Munich, using a customized driving simulator developed by DriveSimSolutions (DSS). The simulator uses fully customizable STISIM Drive 3 software that allows the creation of custom scenarios and data collection at every simulation update frame. Tobii Pro Glasses 2 were used to gather participants' gaze data during the driving sessions. Tobii Pro Glasses 2 captures all the details of the surrounding environment by offering a full-HD scene camera with a large field of view. In addition, the i-DREAMS safety-oriented intervention systems were activated during the intervention and distraction scenarios. These included real-time and in-vehicle warnings (i.e., audio, visual) in safety-critical situations for lane departure, headway, forward collision, pedestrian collision, and mobile phone distraction warnings.

Sixty participants from different age groups (18-75 years old) were recruited to complete the driving simulator experiment. Besides, questionnaires were used to collect information regarding driver demographics, driving experience, and participants' perspectives on driving assistance technologies. The entire experiment took approximately two hours, and participants were remunerated with a 25 EUR voucher upon completion. This paper analyzes the complete data of thirty participants collected during the first data collection stage.

3. Analysis and Results

3.1. Eye movement data

The Analyzer module of Tobii Pro Lab software was used to analyze the eye movement data during all distraction events (i.e., where drivers received text messages) and extract the desired measures. Initially, a time of interest (TOI) was defined for logging each distraction event. Then, various areas of interest (AOI) were created to identify where participants looked during distraction events and specify different region boundaries. AOI varied with session drives and were constantly adjusted to produce more accurate results. After analysis, various eye movement measures were extracted using different metrics and based on the pre-processed data generated by the Pro Lab Gaze filter's functions. Two measures of eye movement, obtained after applying fixation metrics, were selected for analysis:

- **The Average Fixation Duration** which records the elapsed time between the first and the last gaze points in the sequence of gaze points.
- **The Number of Fixations** that occurred during the TOI and within the targeted AOI.

3.2. Driving simulator data

The outputs of driving data are generated at the completion of the simulation runs. In this research, a set of parameters was scrutinized during the logged TOI in all scenarios (i.e., monitoring, intervention, and distraction scenarios) to investigate the impact of distraction on driving performance. The selected parameters were:

- **The Lateral Positioning** that measures the vehicle's position with respect to the lane center.
- **The Longitudinal Acceleration Rate** which is defined as the rate of velocity change in the direction of the vehicle's longitudinal axis [10].

- **The Lateral Acceleration Rate** which is defined as the velocity change in the direction of the vehicle's lateral axis [10].

3.3. Statistical analysis results

As previously stated, a set of eye movement and driving performance measures were selected for analysis. Initially, a Shapiro-Wilk normality test was applied to all variables to determine whether data distribution comes from a normally distributed population. When the Shapiro-Wilk test failed to reject the null hypothesis, a one-way repeated measures analysis of variance (ANOVA) was performed for the statical test. Next, a Post Hoc test of Tukey multiple pair-wise comparisons was applied to evaluate the ANOVA test further when needed (p-value ≤ 0.05). Finally, when the Shapiro-Wilk test rejected the null hypothesis of normal distribution, the ANOVA test was no longer applicable, and a Kruskal-Wallis test was applied instead. Following the rejection of the Kruskal–Wallis test (p-value ≤ 0.05), the Dunn's test was used for further analysis. Table 1 summarizes the analysis of the measures utilized to evaluate the eye movement behavior and driving performance during three scenarios (monitoring, intervention, and distraction), respectively.

Table 1: Statistical test results of the selected measures.

Measure	AOI	TOI	Scenario		Z-Value	P-Value
Eye Movement Measures						
Fixation Duration (Average)	Road Ahead	CEs	Monitoring	Intervention	0.239	0.810
				Distraction	-2.481	**0.019***
			Intervention	Distraction	-2.720	**0.019***
	i-DREAMS Display	CEs	Monitoring	Intervention	16.78	**0.000***
				Distraction	11.70	**0.000***
			Intervention	Distraction	5.075	**0.000***
	Dashboard Area	CEs	Monitoring	Intervention	1.004	0.315
				Distraction	-3.007	**0.000***
			Intervention	Distraction	-4.012	**0.000***
Fixation Count	Road Ahead	CEs	Monitoring	Intervention	-1.915	**0.000***
				Distraction	-8.524	**0.000***
			Intervention	Distraction	-6.608	**0.000***
	i-DREAMS Display	CEs	Monitoring	Intervention	9.418	**0.000***
				Distraction	12.32	**0.000***
			Intervention	Distraction	2.909	**0.000***
	Dashboard Area	CEs	Monitoring	Intervention	-1.784	**0.000***
				Distraction	-4.602	**0.000***
			Intervention	Distraction	-2.818	**0.000***
Driving Performance Measures						
Lateral Position (std. dev.)	–	CEs	Monitoring	Intervention	-0.549	0.582
				Distraction	2.435	**0.022***
			Intervention	Distraction	2.985	**0.008***
Longitudinal Acceleration (mean)	–	CEs	Monitoring	Intervention	-1.141	0.253
				Distraction	1.555	0.179
			Intervention	Distraction	2.696	**0.020***
Lateral Acceleration (mean)	–	CEs				0.170

*P-value level of significance ≤0.05

4. Discussion

This research investigates the impact of distraction –texting while driving– on driving performance under different driving conditions. The statistical significance in eye movement measures indicated a change in drivers' gaze patterns during the intervention and distraction scenarios. During these scenarios, drivers' gaze behavior was reduced significantly for 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 distraction 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, particularly during the distraction drives. This suggests that drivers may rely more on the intervention system while distracted. Figure 1 visualizes the drivers' gaze patterns during the critical pedestrian events and the last two sessions.

The analysis of driving performance measures shows that drivers had a significantly higher deviation of the lateral position during the distraction drive. Further, the mean value of longitudinal acceleration had a statistically significant increase during the CEs and while drivers were distracted. Finally, the mean value of the lateral acceleration measure showed no significant change during all drives.

Figure 1: Gaze density heat maps in intervention (left column) and distraction (right column) scenarios during the pedestrian CEs. The i-DREAMS display AOI is specified in the figures.

5. Conclusions

This research investigates the impact of mobile phone distraction in the presence of risky events and under different conditions, i.e., normal driving, normal driving with fixed timing interventions, and distracted driving with interventions based on task completion capability. The results suggest that driver gaze patterns significantly change while drivers are distracted, with a significant increase toward the i-DREAMS intervention display. In addition, the overall statistical analysis of driving performance measures reveals a higher deviation of lateral positioning and longitudinal acceleration rates among distracted drivers.

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