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Assessment of Driving Simulator Studies on Driver Distraction

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ABSTRACT

The objective of this research is the critical assessment of the strengths and limitations of driving simulator studies on driver distraction. For this purpose more than 40 scientific papers have been examined with respect to the design of driving simulator experiments on the effects of various sources of driver distraction (in-vehicle or external). More specifically, for each experiment reviewed, several basic characteristics have been recorded and analysed such as the sample characteristics (size, sex, age distribution), the experiment design (number of trials, duration and type of driving tasks, simulated road and traffic environment), as well as the distraction source examined (cell phone, conversation, visual, music, driver assistance systems, etc.). Through this analysis it was found that the majority of studies are based on small samples, between 30-40 participants, in most cases not representative of the general population (e.g. mostly young or middle aged). The most common distraction sources examined are visual distraction and cell phone use. The simulated road environment of most experiments was rural, whereas ambient traffic is not explicitly simulated. The number and duration of trials vary considerably. Driver distraction is measured in terms of its impact to driver attention (hands-off the wheel, eyes-off the road), driver behaviour (vehicle speed, headway, lateral position, driver reaction time) and driver accident risk. The analysis suggests that the design and implementation of such experiments is still inconsistent and often does not conform to experimental design principles.

Keywords: driver distraction, driving simulator, road safety.

INTRODUCTION

Driver distraction is estimated to be an important cause of vehicle accidents. Although driver distraction can be considered as part of everyday driving, the penetration of various new technologies inside the vehicle, and the expected increase of use of such appliances in the next years, makes the investigation of their influence on the behaviour of drivers and on road safety very essential. Within this context, driving simulators have become a widely used tool for examining the impact of driver distraction, individual driver differences and roadway design, as examining distraction causes and impacts in a controlled environment helps provide insights into situations that are difficult to measure in a naturalistic driving study.

The objective of this research is to present a review and assessment of driving simulator studies on driver distraction. For this purpose more than 40 scientific papers and reports have been examined with respect to the design of driving simulator experiments on driver distraction with focus on studies published in international peer-reviewed Journals and Conference Proceedings. More specifically, for each experiment reviewed, several pieces of information have been recorded such as the sample characteristics (size, sex, age distribution), the experiment design (number of sessions / trials, duration and type of driving tasks, road environment e.g. urban/rural/motorway, ambient traffic etc.), as well as the distraction source examined (cell phone, conversation, visual, music, driver assistance systems, etc.).

This paper is structured as follows: first, the definitions and types of driver distraction are presented, and the advantages and limitations of driving simulator experiments are briefly presented, in general and concerning driver distraction studies in particular. Then, an exhaustive literature review of driving simulator studies on driver distraction is carried out. From the results of the review, a comparative assessment of the existing driving simulator experiments is carried out for basic components of the experiment (sample characteristics, experiments design, driver distraction measures) and conclusions are drawn.

DEFINITIONS AND TYPES OF DRIVER DISTRACTION

There is a lack of consensus in the literature about what is meant by the terms “driver inattention” and “driver distraction”. Definitions of these two constructs, and thinking about the relationship between the two, vary enormously.

The term distraction has been defined as “a diversion of attention from driving, because the driver is temporarily focusing on an object, person, task or event not related to driving, which reduces the driver’s awareness, decision making ability and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes” (Hedlund et al., 2005).

On the other hand, very few definitions of driver inattention exist in the literature, and those that do, like driver distraction, vary in meaning. Lee et al. (2008), for example, define driver inattention as “diminished attention to activities critical for safe driving in the absence of a competing activity”. Regan et al. (2011) summarise this discussion and suggest that: “Driver Inattention” means insufficient or no attention to activities critical for safe driving and “Driver distraction” is just one form of driver inattention, with the explicit characteristic of the presence of a competing activity.

Human factors in total are the basic causes in 65-95% of road accidents (Sabey and Taylor, 1980; Salmon et al., 2011). Driver impairment or distraction factors appear to account totally for 12% of all road accident contributory factors, while in-vehicle distraction factors account for 2/3 of the total distraction factors (Department for Transport, 2008).

Driver distraction factors can be subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle). Although different studies report different specific distraction factors in each category, one of the most complete and comprehensive approaches is presented in Table 1 (Regan et al., 2005).

Table 1: Driver distraction sources by category (in-vehicle / external)

In-vehicle	**External**
Passengers	Traffic control
Communication	Other vehicle
Cell phone talking and texting	Seeking location / destination
Entertainment systems	Pedestrian / cyclist
Vehicle systems	Accident / incident
Eating / drinking	Police / Ambulance / Fire brigade
Smoking	Landscape / architecture
Animal / insect in the vehicle	Animal
Coughing / sneezing	Advertising signs
Stress	Road signs and markings
Daydreaming	Sun / other vehicle lights

Several studies have examined the effect of external distraction sources that may attract the driver’s attention during the driving task. The results suggest that, although these sources do attract the driver's attention (e.g., in terms of eye glances towards the source of distraction), neither the drivers’ behaviour (e.g., in terms of speeding), nor safety are significantly affected (Horberry and Edquist, 2009).

On the other hand, significant factors impacting driving performance and safety have been associated with in-vehicle sources of distraction, on which particular emphasis was put in the recent years. These include the use of a mobile phone or a navigation / recreation system, discussing with another passenger, smoking, eating or drinking etc. (Strayer et al., 2003; Johnson et al., 2004; Lesch and Hancock, 2004; Neyens and Boyle 2008; Bellinger et al. 2008; Yannis et al., 2010), and have been found to potentially influence both driver behaviour (e.g. in terms of driver speed, lateral position and headways) and road safety (i.e. in terms of reaction times and accident probability).

ADVANTAGES AND LIMITATIONS OF SIMULATORS

Driver distraction research often makes use of driving simulators, as they allow for the examination of a range of driving performance measures in a controlled, relatively realistic and safe driving environment. Driving simulators, however, vary substantially in their characteristics, and this can affect their realism and the validity of the results obtained.

More specifically, driving simulators have a number of advantages over on-road studies. First they provide a safe environment for the examination of distraction issues using multiple-vehicle scenarios, where the driver can negotiate very demanding roadway situations while engaging in secondary tasks. Second, greater experimental control can be applied in driving simulators compared with on-road studies, as they allow for the type and difficulty of driving tasks to be precisely specified and any potentially confounding variables, such as weather, to be eliminated or controlled for. Third, the cost of modifying the cockpit of a simulator to allow for the evaluation of new in-vehicle systems may be significantly less than modifying an actual vehicle. Finally, a large range of test conditions (e.g., night and day , different weather conditions, or road environments) can be implemented in the simulator with relative ease, and these conditions can include hazardous or risky driving situations that would be too difficult or dangerous to generate under real driving conditions, especially when distraction tasks are involved.

The use of driving simulators as research tools does, however, have a number of disadvantages, overall and for distracted driving research in particular. First, data collected from a driving simulator generally include the effects of learning to use the simulator and may also include the effects of being directly monitored by the experimenter. Second, driving simulators, particularly high-fidelity simulators, can be very expensive to install. Simulator discomfort / sickness is another problem encountered with simulators and is particularly pronounced in distracted driving experiments, because of the secondary task or tasks involved.

Despite these limitations, driving simulators are an increasingly popular tool for measuring and analyzing driver distraction, and numerous studies have been conducted, particularly in the last decade. In the next section, a detailed review these driving simulator experiments is presented, in which the experiments are grouped in terms of the distraction factor investigated: cell phone, conversation with passengers, music, radio, in vehicle information systems, eating, drinking, smoking, alcohol, visual distraction, cognitive distraction, advertising signs etc.

REVIEW OF DRIVING SIMULATOR EXPERIMENTS

Review of simulator studies on in-vehicle distraction sources

<u>Cell phone</u>

A range of studies have shown that the use of cell phones has adverse consequences on driver's behaviour and the probability of being involved in an accident. Haigney et al. (2000) examined the effects on driving performance of engaging in a mobile phone task using hand-held and hands-free mobile phones. Thirty participants completed four simulated drives while completing a grammatical reasoning task designed to simulate a mobile phone conversation. The results revealed that mean speed and the standard deviation of acceleration decreased while participants were conversing on the mobile phone.

Using a driving simulator, Strayer et al. (2003) found that conversing on a hands-free mobile phone while driving led to an increase in following distance from a lead vehicle and this increase was particularly pronounced under high traffic density conditions. Rakauskas et al. (2004) used a driving simulator to determine the effect of easy and difficult cell phone conversations on driving performance, and found that cell phone use caused participants to have higher variation in accelerator pedal position, drive more slowly with more variation in speed, and report a higher level of workload regardless of conversation difficulty level. Furthermore, Kass et al. (2007) examined the impact of cell phone conversation on situation awareness and performance of novice and experienced drivers. The performance of 25 novice drivers and 26 professional drivers was measured by the number of driving infractions committed such as speeding, collisions, pedestrians struck, stop signs missed, and centerline and road edge crossings. The results indicated that novice drivers committed more driving infractions and were less situationally aware than their experienced counterparts during the cell phone conversation. Bryas et al. (2009) investigated whether making a conversation asynchronous (using an answer phone instead of a cell phone) reduces the negative impact of phone calls, as the communication in this occasion is under the driver's control, allowing allows him/her to pace the interaction better. The results showed better scores for correct responses to stimuli for answer phone communications than for phone communications, although response times were higher in both communication conditions than in the driving alone condition.

Shinar et al.(2005) found that 96 min of dual-task simulator-based practice, distributed over 5 days, was sufficient to eliminate driving impairment from cell phone use in a group of considerably more experienced drivers. Notably, dual-task learning was primarily observed on the mean and standard deviations of lane position, steering angle, and speed. Additionally, learning was greatest when driving was coupled with a math task rather than naturalistic conversation. From these results, Shinar et al. (2005) concluded that previous driving research had likely overestimated real-world impairment by forcing the driving pace, using unnatural conversation surrogates, and failing to repeat the driving condition.

Schlehofer et al. (2011) explored psychological predictors of cell phone use while driving for 69 college students who firstly completed a survey and predicted their driving performance both with and without a simultaneous phone conversation and finally drove on a driving simulator. Cell phone use was found to reduce their performance on the simulation task. Reimer et al. (2010) examined the impact of distractions on young adult drivers with attention deficit hyperactivity disorder (ADHD) resulting that drivers with ADHD had more difficulty on the telephone task, yet did not show an increased decrement in driving performance greater than control participants. In contrast, participants with ADHD showed a larger decline in driving performance than controls during a secondary task in a low demand setting.

<u>Conversation with passengers</u>

Several studies attempt to compare the effect of cell phone use and passenger conversation through driving simulator experiments. In Laberge et al. (2004), eighty participants were randomly assigned to one of three conditions: driving alone, driving with a passenger, and driving with a cellular phone and results indicate that lane and speed maintenance were influenced by increased driving demands. Furthermore, response times to a pedestrian incursion increased when the driver was driving and talking compared with those detected when the driver was not talking at all.

Drew et al. (2008), examined how conversing with passengers in a vehicle differs from conversing on a cell phone while driving by comparing how well drivers were able to deal with the demands of driving when conversing on a cell phone, conversing with a passenger, and when driving without any distraction. The results show that the number of driving errors was highest in the cell phone condition; in passenger conversations more references were made to traffic, and the production rate of the driver and the complexity of speech of both interlocutors dropped in response to an increase in the demand of the traffic.

In a within-subject design (Maciej et al., 2011) the conversational patterns of 33 drivers and passengers in different in-car settings were compared to a hands-free cell phone and to a hands-free cell phone with additional visual information either about the driving situation or the driver.

Participants were instructed to have a naturalistic small-talk with a friend and the results of the drivers' speaking behavior showed a reduction of speaking while driving. Moreover, compared to a conversation partner on the cell phone, a passenger in the car varies his speaking rhythm by speaking more often but shorter.

Charlton (2009) compared the driving performance and conversational patterns of drivers speaking with in-car passengers, hands-free cell phones, and remote passengers who could see the driver's current driving situation (via a window into a driving simulator). The results proofed that driving performance suffered during cell phone and remote passenger conversations as compared with in-car passenger conversations and no-conversation controls in terms of their approach speeds, reaction times, and avoidance of road and traffic hazards.

In the Driving Simulator of the University of Calgary 40 young drivers encountered motorcycles and pedestrians while making left turns drivers either drove alone or conversed with an attractive confederate passenger. Measures of looked-but-failed-to-see errors, hazard detection and social factors were analyzed. Higher rates of LBFTS errors and hazard detection occurred while conversing than while driving alone (White and Caird, 2010). Furthermore, Yannis et al. (2011) investigated the effect of different types of conversation on road safety in rural roads. The results suggest that 'simple' and 'complex' conversations are associated with decreased speeds while 'complex' conversations were systematically associated with increased distance from the central axis of the lane, significantly increased reaction times at unexpected incidents and increased accident risk.

Music, radio

Compared devices such as mobile phones, relatively few studies have investigated the effects of interacting with portable music players on driving performance (Reed-Jones et al., 2008; Hughes et al., 2008).

In a related driving simulator experiment, 27 participants completed drives under each of three conditions: without audio materials, with audio materials from a movie, and with audio materials from radio. Performance was measured in terms of lateral control, speed control, and response to hazards and participants provided self-reports of distraction and driving impairment. Audio materials appeared to have minimal effects on driving, perhaps because listening while driving is fairly well practiced and easily modulated, and does not involve speech production (Hatfield and Chamberlain, 2008).

Chisholm et al. (2008) examined the effects of repeated iPod interactions on driver performance to determine if performance decrements decreased with practice. Measures of hazard response, vehicle control, eye movements, and secondary task performance were analyzed and resulted on increases in perception response time and more collisions while drivers were performing the difficult iPod tasks.

Moreover, in Garay-Vega et al. (2010), 17 participants between the ages of 18 and 30 years old were asked to use three different music retrieval systems while driving in order to record measures of secondary task performance, eye behavior, vehicle control, and workload. When compared with the touch interface, the voice interfaces reduced the total time drivers spent with their eyes off the forward roadway.

Another study on the effects of using a portable music player on simulated driving performance resulted that performing music search tasks while driving increased the amount of time that drivers spent with their eyes off the roadway and decreased their ability to maintain a constant lane position and time headway from a lead vehicle (Young et al., 2012).

In this framework, an experimental process on a driving simulator was carried out, in which 48 participants between 19 and 29 years old, drove in a road with mountainous characteristics with and without mobile phone (handheld mode) and music. Lognormal regression models were developed for driver speed and it appears that mobile phone use leads to a statistically significant decrease in speed, while music tends to increase speed (Yannis et al., 2011).

In Vehicle Information Systems

The safety evaluation of in-vehicle information systems (IVIS) is less advanced, with new products being continuously marketed. It has been argued (Carsten and Brookhuis, 2005) that the safety evaluation of products such as IVIS require analysis.

Jamson and Merat, (2005) examined the systematic relationship between primary and secondary task complexity for a specific task modality in a particular driving environment. The results show that the participants seemed incapable of fully prioritising the primary driving task over either the visual or cognitive secondary tasks as an increase in IVIS demand was associated with a reduction in driving performance: drivers showed reduced anticipation of braking requirements and shorter time-to-collision.

Moreover, Horbery et al. (2006) presented the findings of a simulator study that examined the effects of operating the vehicle entertainment system and conducting a simulated hands-free mobile phone conversation upon driving performance for drivers in three age groups. The conclusions of the research are that both in-vehicle tasks impaired several aspects of driving performance, with the entertainment system distracter having the greatest negative impact on performance, and that these findings were relatively stable across different driver age groups and different environmental complexities.

In order to assess whether real-time feedback on a driver’s state can influence the driver’s interaction with in-vehicle information systems, Domnez et al. (2006), tested 16 young and 12 middle-aged drivers real-time feedback, that alerts drivers based on their off-road eye glances,

and concluded that distraction was observed as problematic for both age groups with delayed responses to a lead vehicle-braking event as indicated by delayed accelerator releases. The findings of Reyes and Lee, (2008), who examined the effects of cognitive load on driving performance for interactions with an in-vehicle information system that varied in duration from 1 to 4 min., suggest that two mechanisms might account for the distraction-related performance decrements in this study: competition for processing resources and interference due to activation of competing goals.
Finally, Benedetto et al. (2011), examined the effects of in-vehicle information systems (IVIS) usage on eye blinks in a simulated Lane Change Test (LCT) and results suggest that blink duration, with respect to blink rate, is a more sensitive and reliable indicator of driver visual workload.

Eating, drinking, smoking, alcohol

Rakauskas et al. (2008) performed a simulator study which aimed to analyse the combined effects of distraction induced by in-vehicle tasks and alcohol on longitudinal and lateral vehicle control. Their results showed the most pronounced effects of alcohol on lateral control when drivers were distracted by a demanding in vehicle task. It is evident that it would not be feasible to investigate such an issue under on-road conditions without creating danger for participants and/or other parties involved.
In another research regarding alcohol, Harrison et al. (2011) examined the interactive impairing effects of alcohol intoxication and driver distraction on simulated driving performance in 40 young adult drivers using a divided attention task as a distracter activity. As hypothesized, divided attention had no impairing effect on driving performance in sober drivers. However, under alcohol, divided attention exacerbated the impairing effects of alcohol on driving precision.
Young et al. (2008) investigated the impact of eating and drinking while driving. At designated points on the drive, which coincided with instructions to eat or drink, a critical incident was simulated by programming a pedestrian to walk in front of the car. The evidence suggests that the physical demands of eating and drinking while driving can increase the risk of an accident.
In the same framework, Yannis et al. (2011), analysed the effects eating and smoking on driver behaviour and on road safety in rural roads by asking participants to consume a light snack and smoke a cigarette at given points along the selected road. Results suggest that eating and smoking are associated with decreased speeds.

Review of simulator studies on external distraction sources

Visual and cognitive distraction

Visual distraction and cognitive distraction can be described as “eye-off-road” and “mind-off-road”, respectively (Victor, 2005; Noy et al., 2004). Both of them can undermine drivers’ performance. Visual distraction occurs when rivers look away from the roadway, while Cognitive distraction affects driving by disrupting the allocation of visual attention to the driving scene and the processing of attended information.
Liang and Lee, (2010), Kaber et al. (2012) and Muhrer and Vollrath, (2011) compared driving without distraction to visual distraction, cognitive distraction, and combined visual and cognitive

distraction and the results show that the visual and combined distraction both impaired vehicle control and hazard detection and resulted in frequent, long off-road glances.
Regarding visual distraction, in a recent research (Metz et al., 2011), 40 participants were asked either to solve an externally paced, highly demanding visual task or a self paced menu system task. Results indicate that collisions go together with an inadequate distribution of attention during distraction. The results are interpreted regarding the attentional processes involved in driving with visual secondary tasks. Within this framework, Fofanova et al. (2011) examined the effect of age on driving performance as well as the compensation strategies of older drivers under visual distraction. The results show that older participants' overall driving performance (mean deviation from an ideal path) was worse in all conditions as compared to the younger ones and that with regard to lane change reaction time both age groups were influenced by visual distraction in a comparable manner.
Furthermore, Terry et al. (2007), assessed the ability of drivers to detect the deceleration of a preceding vehicle in a simulated vehicle-following task while the size of the preceding vehicles (car, van, or truck) and following speeds (50, 70, or 100 km/h) were systematically varied. Interestingly, increases in vehicle size had the effect of decreasing drivers' braking latencies and drivers engaged in the secondary task were significantly closer to the lead vehicle when they began braking, regardless of the size of the leading vehicle.
Regarding cognitive distraction, Chan and Signal, (2012), in another driving simulator study, provided the participants three different types of emotional information: neutral words, negative emotional words, and positive emotional words. The findings suggest that driving performance is differentially affected by the valence (negative versus positive) of the emotional content. Furthermore, drivers had lower mean speeds when there were emotional words compared to neutral words, and this slowing effect lasted longer when there were positive words.

Advertising signs

According to the international literature, external driver distraction sources are a minor proportion of road accident causes. However, the particular case of advertising signs is often considered and several studies examine the effect of roadside advertising on driver attention, behaviour and safety. In most countries, specific rules exist as per the size, location and type of roadside advertisements.
Edquist et al. (2011), examined the effects of billboards on drivers, including older and inexperienced drivers who may be more vulnerable to distractions, and suggested that billboards changed drivers' patterns of visual attention, increased the amount of time needed for drivers to respond to road signs, and increased the number of errors in this driving task.
Within the same framework, twelve volunteers participated in driving simulator drive on two identical paths, one with roadside advertising signs and one without (Bendak et al., 2010). Results revealed that two driving performance indicators, drifting from lane and recklessly crossing dangerous intersections, were significantly worse in the path with advertising signs as compared with performance on the other path. The other three performance indicators (number of tailgating times, over-speeding and turning or changing lanes without signaling) were also worse in the presence of advertising signs but the difference was not statistically significant.
Another simulator study, Young et al. (2009) quantified the effects of billboards on driver attention, mental workload and performance in Urban, Motorway and Rural environments. The

results demonstrate that roadside advertising has clear adverse effects on lateral control and driver attention, in terms of mental workload.

ASSESSMENT OF DRIVING SIMULATOR EXPERIMENTS

The literature review presented in the previous sections reveals that driving simulator experiments on driver distraction have provided valuable insight into some causes and impacts of driver distraction, by various distraction sources, in-vehicle or external. However, it is also indicated that the experiments vary considerably in terms of sample characteristics, design and analysis methods. There appears to be a lack of uniformity in the way the experiments are conceived, conducted and exploited. For that purpose, the existing studies were classified with respect to a number of key components of the experiments, allowing their comparative assessment.

First, the distraction sources examined and the sample characteristics are summarized in Table 2. In almost all studies examined, distraction was induced in some way by the experimenter, often by letting the participant perform a secondary task. These tasks can correspond more or less to what drivers might do in real traffic, like use the cell phone, enter an address in the navigation system, plan a route on a map versus memorizing and adding numbers, checking for matching words or being temporarily blinded by occlusion goggles. The tasks can be visual, auditory, motor or combined, they can be simple or complicated, and they can require immediate attention or leave the driver some leeway in deciding when to attend to the task. A large number of studies concern cell phone distraction while driving, and its comparison with other distractions. Conversation with passengers and manipulation of in-vehicle information systems are often examined. For the other distraction sources, a small number of simulator studies were available.

As regards the sample characteristics, it is observed that the majority of studies are based on small samples, between 30-40 participants (average number is 38), while in the vast majority of studies examined equal numbers of male and female participants. In most cases, the sample is not representative of the age distribution of the general population; the vast majority of studies focus on young (18-25 years old) or middle aged (26-55 years old) participants, while only 17,4% of the researches examine older drivers (aged >55 years old). This is possibly due to practical recruitment issues; for instance, several studies have easily recruited university students, which are directly accessible.

Moreover, in the vast majority of the experiments (70%) participants were asked to fill in questionnaires of self-reported driving behaviour and demographic data; however, this data is not fully exploited in most studies. In more than 65% of the studies examined, participants earned benefits by taking part in the driving simulator experiment (in most cases between 15-50 €).

Concerning the design and implementation of the experiments, the results of the comparative assessment of existing experiments are presented in Table 3. Participants in almost all driving simulator experiments implemented a practice scenario, in order to get familiar with the simulator. The duration of this scenario varies enormously but in most cases exceeds 5 minutes. However, it is not reported whether specific performance measures were used to assess the driver's familiarization with the simulator before proceeding to the main experiment.

The total number of experimental trials that drivers are asked to complete is in the vast majority of studies between 2 and 6 (average is 4.5 trials). In the majority of studies, 2 trials are typically the case, one with and one without distraction, while in 10% of studies only 1 trial was scheduled, during which a distracted driving task took place at some point. The length / duration of each trial varied enormously, independently of the sample size, the number of parameters / distraction sources examined, or the total number of trials to be performed. As a consequence, there are experiments with few long trials, others with few short trials, others with many short trials, and a few with many long trials.

Table 2: Overview of driving simulator experiments: sample characteristics and types of distraction

Paper details			**Distraction Source**							**Sample Characteristics**						
	Authors	year	cell phone	conversation	visual - cognitive	music	IVIS	advertisign signs	eat, drink, alcohol	sample size	% male	25-	26-55	55+	benefits	questionnaire
1	Laberge et.al	2004	•	•						80	50%	•				•
2	Drews et.al	2008	•	•						96	25%	•	•		•	
3	Charlton	2009	•	•						112	50%	•	•	•	•	•
4	Yannis et.al	2011	•	•					•	42	48%	•				•
5	Horbery et al	2006	•		•					31	-		•	•		•
6	Reed-Jones et al	2008	•			•				32	44%	•				
7	Yannis et.al	2011	•			•				48	50%	•				•
8	Rakauskas et al	2004	•							24	50%					•
9	Kass et al	2007	•							49	49%	•	•	•		
10	Bruyas et al	2009	•							30	50%	•	•		•	•
11	Reimer et al	2010	•							60	60%	•			•	•
12	Schlehofer et al	2010	•							69	36%	•			•	•
13	White et al	2010		•						40	50%	•				•
14	Maciej et al	2011		•						33	52%	•			•	•
15	Noy et al	2004			•					24	63%	•	•		•	•
16	Donmez et al	2006			•					28	-		•	•	•	•
17	Donmez et al	2008			•					48	52%	•			•	•
18	Liang et al	2010			•					16	50%	•	•		•	
19	Fofanova et al	2011			•					20	80%			•		
20	Muhrer et al	2011			•					28	50%	•	•		•	•
21	Metz et al	2011			•					40	55%		•			
22	Chan et al	2012			•					30	-	•	•			
23	Kaber et al	2012			•					20	50%	•			•	•
24	Zhang et al	2012			•					24	50%	•	•	•		•
25	Hatfield et al	2008				•	•			27	48%		•		•	•
26	Chisholm et al	2008				•				19	53%	•			•	
27	Garay-Vega et al	2010				•				17	71%	•	•		•	•
28	Young et al	2012				•				37	46%	•	•		•	•
29	Hughes et al	2012				•				21	5%	•	•			•
30	Jamson et al	2005					•			48	-		•			
31	Donmez et al	2007					•			29	48%	•			•	•
32	Reyes et al	2008					•			12	50%		•		•	
33	Jamson et al	2010					•			18	50%		•		•	
34	Benedetto et al	2011					•			15	80%					•
35	Birrell et al	2011					•			25	56%		•			•
36	Terry et al	2008						•		78	55%	•	•	•		•
37	Young et al	2009						•		48	60%		•		•	
38	Bendak et al	2010						•		12	100%	•	•			•
39	Edquist et al	2011						•		48	63%	•	•	•	•	•
40	Rakauskas et al	2008							•	45	100%	•			•	
41	Young et al	2008							•	26	62%	•	•	•	•	
42	Harrison et al	2011							•	40	50%	•	•		•	•
	Average									**37.8**	**54%**					

Table 3: Overview of driving simulator experiments: experiment design and driving-related outcomes

Paper details			Experiment design															Driving-related Outcomes							
			Practice trial			Trial duration		Total Duration			Road environment				Traffic conditions										
	Authors	year	<5min	>5min	Number of trials	km	min	km	min	Counterbalancing	lanes	urban	rural	motorway	Ambient traffic	lead vehicle only	opposite traffic only	speed	lane position	reaction time	perception / situation awareness	headway	accident probability	eye glance	acceleration / deceleration
1	Laberge et.al	2004			2	4.0		8.0				•			•			•	•						
2	Drews et.al	2008		•	3		5.0		15.0	•	2		•		•			•	•						
3	Charlton	2009			1	25.3	24.0	25.3	24.0	•	2			•	•			•				•	•		
4	Yannis et.al	2011	•		3	4.0		12.0					•		•			•	•	•			•		
5	Horbery et al	2006	•		6	6.0		36.0		•	1		•					•							
6	Reed-Jones et al	2008			7		10.0		70.0	•							•	•					•		
7	Yannis et.al	2011	•		1	6.5		6.5							•			•	•	•			•		
8	Rakauskas et al	2004			6		1.7		10.0	•	2		•		•			•	•				•		
9	Kass et al	2007	•		1		11.5		11.5																
10	Bruyas et al	2009		•	4		11.0		44.0		1		•				•								
11	Reimer et al	2010		•	1	56.0		56.0				•		•	•			•			•				•
12	Schlehofer et al	2010	•		2		7.0		14.0	•			•												
13	White et al	2010			2					•	2	•	•										•		
14	Maciej et al	2011			11		18.2		200.0	•															
15	Noy et al	2004			5		12.8		64.0		2		•		•			•							
16	Donmez et al	2006			16					•	2		•												
17	Donmez et al	2008		•	4		30.0		120.0		2		•		•			•	•			•	•	•	
18	Liang et al	2010		•	8		8.0		64.0	•	2	•	•		•				•		•				
19	Fofanova et al	2011		•	4					•	3							•							
20	Muhrer et al	2011		•	2		33.0		66.0	•					•			•				•			
21	Metz et al	2011		•	8		10.6		85.0				•		•									•	
22	Chan et al	2012			4	4.6		18.4		•			•												
23	Kaber et al	2012		•	8		8.0		64.0	•	2					•									
24	Zhang et al	2012			6		25.0		150.0	•			•		•			•						•	
25	Hatfield et al	2008	•		3	6.5		19.5		•	2	•	•		•			•	•		•		•		
26	Chisholm et al	2008			6		6.0		36.0		3			•	•				•		•			•	
27	Garay-Vega et al	2010			8		4.0		32.0			•	•		•									•	
28	Young et al	2012		•	5		18.0		90.0	•	2	•						•	•						
29	Hughes et al	2012	•		6	1.1		6.6		•	2				•			•	•						
30	Jamson et al	2005		•	3	10.0	6.7	30.0	20.0	•	1				•										
31	Donmez et al	2007			4		3.8		15.0	•	2		•			•		•							•
32	Reyes et al	2008		•	6		7.5		45.0	•					•					•					•
33	Jamson et al	2010			2					•	1		•		•			•	•						
34	Benedetto et al	2011	•		6	3.5		21.0		•										•					
35	Birrell et al	2011	•		6					•	2				•			•				•			•
36	Terry et al	2008		•	2	7.5		15.0		•			•							•		•			
37	Young et al	2009	•		6		5.0		30.0	•		•	•	•					•					•	
38	Bendak et al	2010		•	2	9.3		18.6		•	3				•			•						•	
39	Edquist et al	2011			2	9.0		18.0		•	3	•	•			•			•					•	
40	Rakauskas et al	2008			2		2.0		4.0	•	4			•		•									
41	Young et al	2008			2	9.8		19.5		•	1	•			•			•	•						
42	Harrison et al	2011			1	9.5		9.5				•						•					•		
	Average				**4.5**	**10.8**	**11.7**	**20.0**	**55.4**	**71%**															

Another possible criticism of reviewed researches is the handling of learning effect. Learning effect can arise from repeated exposure to the same or similar driving simulator scenarios or tasks. In order to reduce the effect of this potential confound in simulation studies, repeated testing scenarios counterbalancing or randomly presenting multiple scenarios or tasks can be used. However, in 30% of studies examined no counterbalancing in the different trials was reported, indicating that learning effects may have not been treated effectively.

As regards the simulated road environment, most driving scenarios concern rural road environment, while less than 30% concern motorways. The relatively smaller proportions of urban environments may be partly attributed to the researcher’s effort to minimize simulator sickness, which is known to be more intense in more complex settings. The numbers of lanes vary from one to three, however in the majority of experiments, two lanes in each direction were observed.

Surprisingly, the effect of ambient traffic is not examined in all distracted driving experiments, as 30% of experiments are carried out at the absence of other vehicles on the simulated road network and 17% are carried out at the presence of a single leading vehicle. This is possibly due to the fact that the simulation of ambient traffic is a complex and demanding task, which, if not carried out explicitly, may be introducing a possible confounder in the experiment.

In most cases, driver distraction is measured in terms of its impact to driver attention, driver behaviour and driver accident risk. The specific measures used, however, vary significantly. It is observed that the driving-related outcomes can be ranked as follows, in terms of frequency: speed, lane position (position of vehicles, crossing the center of median lane, steering angle), accident probability, number of eye glances, headway, reaction time, overtaking, acceleration and deceleration, and hazard/risk perception and situation awareness (based on probing participants).

Summarising, the analysis suggests that the design and implementation of such experiments is still inconsistent and often does not conform to experimental design principles. It can be staid that the design of these experiments is characterized by large consensus on less critical components (e.g. practice drive, use of questionnaires), and large variability in the more critical components (e.g. number and duration of trials).

CONCLUSIONS

This paper provides a critical review of an important part of driver distraction research, focusing on the main features and results of related driving simulator studies.

In the first section of the research, the terms “driver inattention” and “driver distraction” were defined, although there is a lack of consensus in the related literature. An exhaustive literature review presented more than 40 studies with respect to the design and implementation of driving simulator experiments on driver distraction. On the basis of the comparative assessment of these studies, it is found that the majority of studies the most common distraction sources examined are cell phone use, conversation with passengers and visual distraction, as well as their comparisons.

Most experiments are based on very small samples, limited to rural road environment, with no explicit (if at all) simulation of ambient traffic. Moreover, the analysis suggests that the design and implementation of such experiments is still inconsistent and often does not conform to experimental design principles, making it is difficult to compare across studies. No pattern could be identified as regards the selection of number and duration of trials. Moreover, it is a matter of some concern that the size of the experiment is not adequately adjusted to the sample size in several studies.

The comparability of research findings is further compromised by the lack of a standardised set of individual difference measures. In the simulator experiments, driver distraction is measured in terms of its impact to driver attention (e.g. eye-glances), driver behaviour (e.g. speed, lane position, headways) and driver accident risk (e.g. reaction time, accident probability), whereas a selection – often arbitrary – of indicators is often made.

Comparability would be significantly enhanced across studies if all investigators were to report key characteristics of the sample being investigated. Common measures that would assist in comparing participant samples include: Age (mean and range), gender, race, mental status, cognitive function, visual function and physical function. Information should also be included as to where the sample was obtained. If this information was uniformly recorded across studies, researchers would be able to better explain conflicting findings with respect to standardised simulator scenarios.

Moreover, comparability and quality of results would be significantly improved if all researchers were to comply with and report basic experiment design features, such as: sample power, type of design (between- or within-subject, or mixed, full or fractional factorial design), extent of counterbalancing etc. Finally, driver-related measures should be better related to the objectives of each experiment.

In summary, simulator studies on driver distraction provide useful insights into how driver, vehicle, and roadway characteristics influence distracted driving behaviour and safety. The findings of this research highlight the need for larger scale simulator studies on driver distraction (larger and more representative samples), more standardised and rigorous experiment designs and more uniform measures of driver distraction.

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