First exploration of the effect of road and traffic environment on distracted driving through a driving simulator study

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Abstract

The objective of this research is the investigation of the effect of road and traffic environment parameters on different types of distracted driving. For this purpose, a driving simulator experiment was carried out at the simulator of the National Technical University of Athens, in which participants were asked to drive under different road and traffic conditions (urban and rural area), and under different types of distraction (conversation with passenger, mobile phone). The data collected from the driving simulator experiment include both longitudinal control measures (mean speed, headways), lateral control measures (lateral position) and the reaction time of the driver at unexpected incidents. The results suggest that participants either talking on the mobile phone or with a passenger drive at lower speed and with increased headway compared to driving without any distraction source, especially in rural areas with low traffic. Furthermore, conversation with passenger indicates higher variability in vehicle lateral position and increased reaction times at unexpected incidents.

Keywords: Safety, simulator experiment, driver distraction, driving behaviour.

Résumé

L'objectif de cette recherche est l'étude de l'effet des paramètres de l'environnement routier et la circulation sur la distraction a la conduite. Une etude de simulateur de conduite a été réalisée au simulateur de l'Université nationale technique d'Athènes, où les participants devaient conduire sous différentes conditions d'environnement routier et du trafic (zone urbaine et rurale, trafic faible ou élevé), et sous différents types de distraction (téléphone portable, conversation avec passager). Les données recueillies à partir du simulateur de conduite comprennent à la fois des mesures de contrôle longitudinal (vitesse moyenne, espaces inter-véhiculaires), des mesures de contrôle latéral (variabilité de la position latérale) et le temps de réaction du conducteur à des incidents inattendus. Les résultats montrent que les participants parlant au téléphone mobile ou conversant avec un passager roulent à des vitesses inférieures et avec des espaces inter-véhiculaires augmentés, comparé a la conduite sans aucune source de distraction, en particulier dans les zones rurales à faible trafic. Par ailleurs, la conversation avec le passager indique une variabilité plus élevée dans le positionnement latéral du véhicule et une augmentation du temps de réaction à des incidents inattendus.

Keywords: sécurité routiere, etude simulateur, distraction du conducteur, comportement du conducteur.

1. Background and Objectives

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, as examining distraction causes and impacts in a controlled environment helps provide insights into situations that are difficult to measure in e.g. a naturalistic driving study.

Driver distraction factors can be subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle). The in-vehicle sources of distraction include the use of mobile phone (either for conversing or for texting), conversation with passengers, smoking, eating or drinking, listening to music and in-vehicle assistance systems (e.g. navigation systems) (Johnson et al., 2004; Stutts et al. 2005; Neyens & Boyle 2008), and their effects are largely examined by means of simulator experiments (Horberry et al. 2006; Bellinger et al. 2008). For the purpose of this research, an extensive literature review was carried out, presenting driving simulator studies on driver distraction, with emphasis on the effects of mobile phone use and conversation with passengers.

A range of studies have shown that the use of mobile 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 talking on the mobile phone. Using a driving simulator, Strayer et al. (2003) found that talking 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 mobile 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 mobile 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 mobile phone conversation. Bryas et al. (2009) investigated whether making a conversation asynchronous (using an answer phone instead of a mobile 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.

Several studies attempt to compare the effect of mobile 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.

Drews et al. (2008), examined how conversing with passengers in a vehicle differs from conversing on a mobile phone while driving by comparing how well drivers were able to deal with the demands of driving when conversing on a mobile phone, conversing with a passenger, and when driving without any distraction. The results show that the number of driving errors was highest in the mobile 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 Maciej et al. (2011) the conversational patterns of 33 drivers and passengers in different in-car settings were compared to a hands-free mobile phone and to a hands-free mobile 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, it was shown that, compared to a conversation partner on the mobile 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 mobile 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 mobile 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.

Within this context, the objective of this paper is to investigate the effect of road and traffic environment parameters on distracted driving due to mobile phone or passenger conversation, by means of a driving simulator experiment. Within this experiment, 17 drivers were asked to drive under different road and traffic conditions, and under different types of distraction (mobile phone, conversation with passenger). The driving performance measures examined include both longitudinal control measures (mean speed, headways), lateral control measures (variability in lateral position) and the reaction time at unexpected incidents.

2. Methodology and data

2.1. Overview of the experiment

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. 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.

Within this research, a large driving simulator experiment is carried out, common for two research projects: the DISTRACT and the DriverBrain research project.

- The DISTRACT research project, entitled "Analysis of causes and impacts of driver distraction", concerns endogenous and exogenous causes of driver inattention and distraction (http://www.nrso.ntua.gr/distract).
- The DriverBrain research project, entitled "Analysis of the performance of drivers with cerebral diseases", concerning drivers with Alzheimer's disease, Parkinson's disease, Cerebrovascular disease - both in their MCI (pre-dementia) stages, but also in their mild dementia stages (http://www.nrso.ntua.gr/driverbrain).

For the purposes of these two research projects, a common driving simulator experiment was designed by an interdisciplinary research team of transportation engineers, neurologists and psychologists

The experiment includes three types of assessment:

- Medical / neurological assessment:
  The first assessment concerns the administration of a full clinical medical, ophthalmological and neurological evaluation, in order to well document the presence of a disorder and its characteristics.
- Neuropsychological assessment:
  The second assessment concerns the administration of a series of neuropsychological tests and psychological-behavioural questionnaires to the participants.
- Driving at the simulator:
  The third assessment concerns the driving behaviour by means of programming of a set of driving tasks into a driving simulator for different driving scenarios.

2.2. Sampling scheme

The sample of participants comprises two distinct groups:

- One "impaired" group of participants with a some pathological condition (e.g. neurological disease), explicitly selected by the neurology / neuropsychology research teams.
- One "control" group of participants with no known pathological condition.

A sample of 300 participants is to be examined in approximately 2 years time. Currently the experiment is at an early stage and 17 healthy participants (10 females and 7 males) aged 25-75 years old (M=57,3) have completed the driving trials. Impaired participants are not considered in this research. It is therefore noted that the preliminary findings of this work are based on a small sample of drivers, and therefore need to be considered with some caution.

2.3. Driving at the simulator

The design of the distracted driving scenarios is a central component of the experiment and includes driving in different road and traffic conditions, such as in a rural, urban area with high and low traffic volume. More specifically, this assessment includes an urban driving session with up to six trials and a rural driving session with up to six trials. These trials aim to assess driving performance under typical conditions, with or without external distraction sources. The driving simulator experiment takes place at the Department of Transportation Planning and Engineering of the National Technical University of Athens, where the Foerst Driving Simulator FPF is located. It is a quarter-cab simulator with a motion base.

The driving simulator experiment begins with a practice drive (5-10 minutes), until the participant fully familiarizes with the simulation environment. Afterwards, the participant drives the two sessions (~20 minutes each). Each session corresponds to a different road environment:

- A rural route that is 2.1 km long, single carriageway and the lane width is 3m, with zero gradient and mild horizontal curves.
- An urban route that is 1,7km long, at its bigger part dual carriageway, separated by guardrails, and the lane width is 3.5m. Moreover, narrow sidewalks, commercial uses and parking are available at the roadsides.

Fig. 1. Rural route

Fig. 2. Urban route

Within each road / area type, two traffic scenarios and three distraction conditions are examined in a full factorial within-subject design. The distraction conditions examined concern undistracted driving, driving while conversing with a passenger and driving while conversing on a mobile phone.

The traffic scenarios are:

- QL: Moderate traffic conditions – with ambient vehicles' arrivals drawn from a Gamma distribution with mean m=12 sec, and variance σ^2=6 sec, corresponding to an average traffic volume Q=300 vehicles/hour.
- QH: High traffic conditions – with ambient vehicles' arrivals drawn from a Gamma distribution with mean m=6 sec, and variance σ^2=3 sec, corresponding to an average traffic volume of Q=600 vehicles/hour.

Table 1. Within-subject design parameters of the driving simulator experiment

Distraction Sources	***Road Traffic Conditions***			
	Urban Area		*Rural Area*	
	High Traffic	*Low Traffic*	*High Traffic*	*Low Traffic*
Conversation	√	√	√	√
Mobile Phone	√	√	√	√
No Distraction	√	√	√	√

Consequently, in total, each session (urban or rural) includes six trials, i.e. six drives of the simulated route. During each trial of the experiment, 2 unexpected incidents are scheduled to occur at fixed points along the drive (but not at the exact same point in all trials, in order to minimize learning effects). More specifically, incidents in rural area concern the sudden appearance of an animal (deer or donkey) on the roadway, and incidents in urban areas concern the sudden appearance of an adult pedestrian or of a child chasing a ball on the roadway. The experiment is counterbalanced concerning the number and the order of the trials, on the basis of several combinations of the parameters of interest.

The driving performance measures examined include both longitudinal control measures and lateral control measures. More specifically:

- Longitudinal driving control measures: mean speed, speed variability (the standard deviation of speed), mean headway (in seconds), driver reaction time at unexpected incidents (in milliseconds), as well as the gear in use (from 0: idle to 6: reverse) and the motor revolutions per minute.
- Lateral driving control measures: Lateral position (vehicle distance from the central road axis in meters), lateral position variability (the standard deviation of lateral position), the mean wheel steering angle (in degrees) and the steering angle variability (the standard deviation of steering angle).

3. Results

Because it is unlikely that all potential determinants will be of equal importance to the study, and because this research is currently at an early stage and the sample is still small a selection of the critical measures is necessary. As a result of the literature review and of pilot-testing different options, the following key measures were analysed in this first stage:

- mean speed - refers to the mean speed of the driver along the route, excluding the small sections in which incidents occurred, and excluding junction areas.
- Mean headway - refers to the time distance between the front of the simulator vehicle and the front of the vehicle ahead
- standard deviation of lateral position - refers to the variability of the distance between the simulator vehicle and the right border of the road.
- reaction time - refers to the time between the first appearance of the event - “obstacle” on the road and the moment the driver starts to brake.

3.1. Mean speed

In Table 1, the mean speed of drivers (in rural and urban areas, in high and low traffic volume) is presented per distraction factor (conversation, mobile phone use, no distraction). It is observed that in rural areas drivers reduce the speed while distracted either by talking on the mobile phone or by conversing with the passenger, especially at high traffic volume (11%) while in urban areas, drivers do not change the mean speed in the different distract situations.

Table 2. Driver mean speed per area type and traffic volume – No distraction / conversation with passenger / mobile phone use

Speed	***Rural area***		***Urban area***	
	High Traffic	*Low Traffic*	*High Traffic*	*Low Traffic*
Conversation	46,44	50,66	31,55	34,46
Mobile phone	46,83	50,39	31,61	35,39
NO Distraction	47,10	56,55	32,26	34,52

3.2. Standard deviation of lateral position

In Table 3, the variability of lateral position (standard deviation of lateral position) of drivers is presented per distraction factor and it is shown that it clearly differs regarding the area type. More specifically, in rural areas there are no differences in the standard deviation of the lateral position with or without distraction, probably because the participants drive on a single narrow lane (lane width equals to 3 meters) and there are no opportunities for e.g. lane changing, overtaking etc.. On the other hand, in urban areas, distracted drivers show somewhat increased variability in lateral position, especially when driving and talking on the mobile phone, probably because there are parts of the road with two lanes per direction, and these drivers take initiatives for lane changing or overtaking. In this case, it is revealed that undistracted drivers drive more conservatively and are better able to maintain their lateral position. It may be also worth noting that increased lateral position variability is observed in urban areas at high traffic volumes in all distraction conditions.

Table 3. Standard Deviation of lateral position per area type and traffic volume – No distraction / conversation with passenger / mobile phone use

Stdev Lateral Position	Rural area		Urban area	
	High Traffic	*Low Traffic*	*High Traffic*	*Low Traffic*
Conversation	0,27	0,29	1,70	1,56
Mobile phone	0,29	0,30	1,79	1,58
NO Distraction	0,26	0,34	1,52	1,45

3.3. Headway

Table 4 shows the mean headway of drivers in each trial. It is observed that in rural areas during conversation with passengers, drivers keep much larger headways from the vehicle ahead compared to trials without any distraction. This is obviously happening because of their lower speed and their conservative driving. No clear pattern can be identified concerning mobile phone use both in urban and rural area, and it appears that a larger sample is required to further analyse this question.

Table 4 Headway (s) per area type and traffic volume – No distraction / conversation with passenger / mobile phone use

Headway	Rural area		Urban area	
	High Traffic	*Low Traffic*	*High Traffic*	*Low Traffic*
Conversation	21,58	42,56	29,85	43,41
Mobile phone	11,23	41,92	32,52	36,70
NO Distraction	16,32	33,64	22,00	40,96

3.4. Reaction time

As mentioned previously, during each trial of the experiment, 2 unexpected incidents are scheduled to occur at fixed points along the drive. In Table 5, the reaction time of drivers in these unexpected incidents is presented regarding conversation with the passenger and driving without distraction. The reaction time is not analysed regarding the mobile phone use as the sample of reaction times that could be successfully measured by the simulation software was very small in this case and no conclusions can be drawn. It is observed that distracted drivers have higher reaction times in urban areas in low and high traffic as expected. Furthermore, the worst reaction time while conversing with the passenger occurs in low traffic in rural areas while without any distraction drivers achieved the best reaction time. Finally in high traffic in rural areas the reaction time with or without distraction is similar.

Table 5. Reaction time per area type and traffic volume – No distraction / conversation with passenger

Reaction time	Rural area		Urban area	
	High Traffic	*Low Traffic*	*High Traffic*	*Low Traffic*
Conversation	1,63	1,69	1,66	1,57
NO Distraction	1,65	1,37	1,53	1,46

4. Conclusions and discussion

This research is currently at an early stage and so far 17 participants have already participated in this driving simulator experiment. The preliminary results suggest that the specific methodology and design confirm the initial hypotheses and may reveal differences between driving without any distraction source, conversing with the passenger or talking on the mobile phone for several driver performance measures.

Summarizing the above results, participants driving either talking to the mobile phone or conversing with a passenger were found to drive at lower speeds compared to the trials that they were driving without any distraction source, especially in rural areas with low traffic. As would be expected, this reduced speed results under given ambient traffic conditions in increased headways. The increased headways regarding driving while conversing with the passenger and driving without any distraction source were observed in all scenarios both in urban and rural areas, in low and high traffic, while the results regarding the mobile phone need larger sample in order to be conclusive. These two measures, i.e. mean speed and mean headway, appear to be the only driving performance measures for which a comparison between driving with or without any distraction source can be carried out with the existing sample of drivers.

Drivers talking on the mobile phone as well as conversing with passengers were found to have difficulty in the variability of maintaining the vehicle position on the lane while driving in urban areas. This increased variability in lateral positioning is probably due to the additional cognitive workload of the driver who drives less carefully. Furthermore, in urban areas there are parts of the road with two lanes per direction, and these drivers may take initiatives for lane changing or overtaking which further increases the variability in lateral positioning under distracted driving conditions.

The reaction time of the drivers at unexpected incidents had differences between conversing with the passenger and driving without any distraction, while it was not analysed regarding the mobile phone as the sample is small. Drivers while conversing with the passenger found to have worse reaction times in both traffic scenarios of urban areas and in low traffic of rural areas compared to driving without any distraction, suggesting that conversing while driving has a potential negative impact on road safety and may lead to increased accident risk – this will be examined in the next stages of this research.

It is noted that the above results concern preliminary findings from the first steps of data processing; they are based on a small sample of drivers, and therefore need to be considered with some caution. It is possible that the relatively small sample size does not allow for all potential effects of distracted driving on driving performance to be identified. The representativity of the sample also needs improvement. However, the above results are quite promising and it is likely that once a larger and more representative sample is available, the analysis may be enhanced in several ways.

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