Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria

Impact of mobile phone use on driving performance: findings from a simulator study

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Abstract

Mobile phone use while driving is one of the most common driver distractions and one of the main causes of traffic accidents. This research aims to investigate the impact of mobile phone use on drivers' behaviour in urban and rural road networks. A driving simulator experiment with 50 participants was carried out, who drove under different types of mobile phone distraction (no distraction, handheld conversation, handsfree conversation, speaker mode conversation). Within the framework of the statistical analysis, discrete choice models were designed to investigate the influence of mobile phone use, as well as other relevant parameters, on driving behaviour considering maximum driving speed, reaction time and standard deviation of lateral position. Based on the findings of the present research, mobile phone conversation is significantly affecting driving performance causing lower drivers' maximum speeds and higher reaction times and standard deviations of the lateral position.

Keywords: driver distraction; driver behaviour; driving simulator; reaction time; maximum speed; lateral position; discrete choice models

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1. Introduction

Although traffic casualties, mainly seriously injured and killed, have been reduced significantly over the past years, further reduction is required to reach the goals set by the EU and the national strategies. Driver distraction plays a dominant role in road accidents where the driver is at fault, and may arise from sources inside or outside of the vehicle (Lesch & Hancock, 2004; Horberry et al., 2006; Neyens & Boyle, 2008). One such source is mobile phone use while driving, which results in both physical and cognitive distraction, and has been found to increase accident probability by three or four times (McEvoy et al., 2005; Choudhary and Velaga, 2017).

Several studies, mainly through simulator experiments and naturalistic studies explore the effect of mobile phone use on driver behaviour. Driver behaviour can be represented through a number of indicators relevant to longitudinal control such as driving speed, acceleration/deceleration and vehicle headways, lateral control such as position in lane, reaction time, driver errors, and so on. Driver speeds have been found to decrease with the use of mobile phone while driving. Maximum speed, mean speed and speed deviation are among the explored indicators. Drivers adopt lower speeds when using a mobile phone, probably also as a result of a risk compensation mechanism (Alm and Nilsson, 1994; Törnros and Bolling, 2005; Törnros and Bolling, 2006; Metz et al, 2015; Choudhary and Velaga, 2017). Speed deviation on the other hand exhibits higher values, mainly due to driver distraction. Following distance has also been found to increase with the use of a mobile phone (Collet et al, 2010; Saifuzzaman et al., 2015; Papadakaki et al., 2016). Caird et al. (2008), on the other hand, did not find a significant effect of mobile phone use on following distance.

Driver performance has also been found to be impaired considering reaction time; drivers exhibit higher reaction times with mobile phone use (Alm and Nilsson, 1994; Consiglio et al., 2003; Caird et al., 2008; Al-Darrab et al., 2009; Collet et al., 2010). Beede and Kass (2006) found that drivers committed more traffic violations and had more attention lapses (most of those concerning peripheral tasks) but at the same time their reaction time to events occurring directly in the line of sight was found to be lower when having a conversation on the mobile phone while driving.

Lateral position has also been found to be affected by mobile phone use. The effect is usually measured through lateral position deviation, which exhibits higher values for mobile phone use (Alm and Nilsson, 1994; Papadakaki et al., 2016). Törnros and Bolling (2005) on the other hand found reduced deviation of the lateral position with mobile phone use, while Caird et al. (2008) and Collet et al. (2010) found no effect on lateral position deviation.

The effect of mobile phone on driving performance, as determined from the aforementioned studies, exhibits contradictory results. This may be partly due to the different methodologies, scenario, sample or distraction characteristics studied in each case. The objective of the present study is to analyse the effect of mobile phone use while driving, considering different mobile phone use modes (handheld, handsfree and speaker mode) and at the same time different environments (urban vs rural road networks) on specific elements of the driving behaviour, employing discrete choice models. The experimental procedure is described in the next section, while the conducted analysis and its results are presented in Section 3. The main findings are discussed in Section 4.

2. Data Collection

2.1 Driving Simulator experiment

For the needs of the study a driving simulator experiment was designed, using the FOERST Driving Simulator FPF (Figure 1). The experiment consisted of 6 different driving scenarios, with each scenario being about 3.5 kilometers long where 2 kilometers were driven while having a conversation on the mobile phone and rest were driven with no distraction (baseline scenario - Base). The conversation involved simple questions on the participants' personal interests and activities, the news etc. Three different ways of using the mobile phone were investigated: handheld (HH), handsfree (with wired headphones) (HF) and speaker mode (Sp), with all participants using all three of them. Participants were only receiving the calls, in order to minimise the sources of distraction to those caused by the conversation itself.

Out of the six drives three were in a rural road environment and three in an urban one. The rural road was an undivided two-lane road (overtaking was not permitted) and with low curvature horizontal curves. The main part of the urban scenario consisted of divided four-lane roads, while traffic controlled junctions, a roundabout and a priority junction were also present. Both in the rural and urban scenarios moderate traffic conditions were simulated.

To measure drivers' reaction time, a "STOP" sign appeared at the windscreen at different points along the route, and drivers were instructed to make a sudden stop upon its appearance. "STOP" signs appeared twice in each scenario both during the baseline and distraction scenarios.

The simulation procedure involved a short introduction on the simulator and the experiment, and a 5 minute familiarization drive. Participants were instructed to drive as they normally do, and they were informed that their performance would not be assessed. Following the simulator experiment, participants were asked to fill-in a questionnaire with information considering general driving and mobile phone use habits and preferences, as well as socioeconomic characteristics. Although driving conditions in the virtual environment cannot be identical to those perceived by the driver in the real world, the relative influence of the various parameters on driver's behaviour is not anticipated to be significantly affected by the use of the simulator.

Fig. 1 FOERST Driving Simulator

2.2 Sample characteristics

50 adults, 32 men and 18 women, between the ages of 20 to 60 years old (mean value 31 years old) participated in the simulator experiment. All of the participants held a driver's license and owned a mobile phone device which they used during the experiment. Participants' socioeconomic characteristics are presented in Table 1.

Table 1. Participant socioeconomic characteristics

	Categories	Number		Categories	Number
Gender	Male	32	Driving experience	1-4	18
	Female	18		5-9	14
Age group	18-24	24		10-14	3
	25-34	9		> 14	15
	35-44	10	Education	Secondary school	2
	45-54	6		High school	25
	>55	1		Bachelor's	14

Income	< 400	11		Master's	7
	400-700	13		Doctoral	2
	700-1000	8	Familiarisation with the mobile phone	Not at all	0
	>1000	18		Slightly	0
Mobile phone use while driving	Yes	38		Moderately	7
				Very	18
	No	12		Extremely	25

The questionnaire included several questions on elements of mobile phone use while driving, in order to explore possible correlations with driving behaviour. Figure 2 presents the distribution of the degree at which the driver feels safe when having a conversation on the mobile phone while driving. Drivers feel safer when having a mobile phone conversation while driving in urban areas, compared to rural areas. At the same time, drivers use their mobile phone driving more in urban areas (Figure 3).

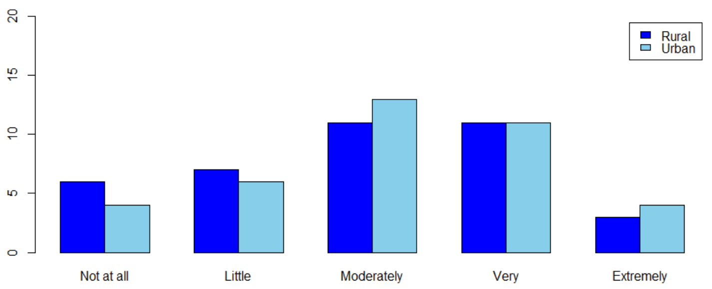

Fig. 2 Distribution of drivers' feeling safe

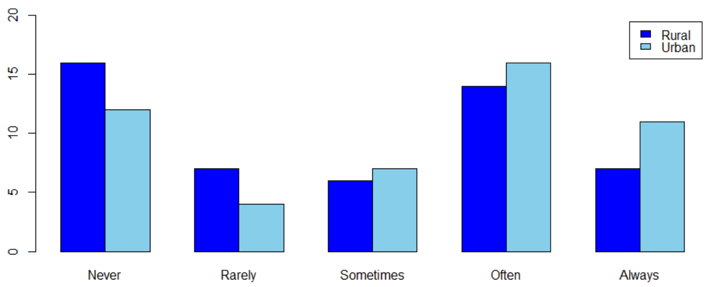

Fig.3 Frequency of mobile phone use when driving

Studies indicate that using the mobile phone while driving affects driving behaviour. Figure 4 shows how drivers perceive that their driving behaviour changes when having a conversation on the mobile phone while driving. This however, might differ from their actual and hence recorded driving behaviour. 17 drivers noted that they drive more carefully and 16 drivers that they reduce their speed. At the same time 3 drivers claim that they don't change their driving behaviour during the phone call. It is also worth noting that only 2% of the sample knows the legislation concerning mobile phone use while driving. The remaining 98% have partial knowledge or complete ignorance.

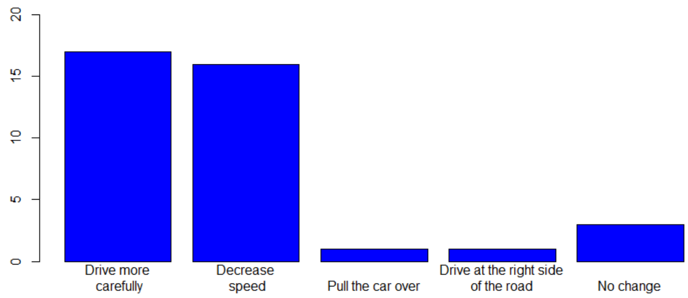

Fig. 4 Distribution of driving behaviour's change due to mobile phone use

3. Analysis

3.1 Methodology

Analysis of variance (ANOVA) was performed to compare mean speed, maximum speed, reaction time and standard deviation of lateral position between baseline and distracted driving, which were set to be the initially investigated driving behaviour indicators. Statistically significant differences were accepted at the 5% level of probability ($p < 0.05$) or greater. Results indicated that mobile phone conversation significantly affects all examined variables except for the mean speed. The parameters that were found to be affected by mobile phone use were further analysed, using discrete choice analysis.

Discrete choice models consider the choice from a set of mutually exclusive and collectively exhaustive alternatives. The selected alternative exhibits the highest utility among those available at the time a choice is made (Ben-Akiva & Lerman, 1985). Within the framework of this study the mutually exclusive alternatives are the different categories of the indicators representing driving behaviour. Considering the fact that a wide range of indicator values represents "normal" driving behaviour, three discrete categories can be defined: low, normal and high. For discrete choice analysis this can be represented as:

- Low, if $y < k_1$
- Normal, if $k_1 < y < k_2$
- High, if $y > k_2$

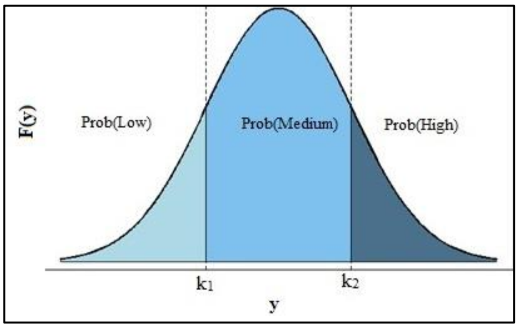

Fig. 5 Probability distribution

Thus according to Figure 5, the probability of a driver's maximum speed to be low is equal to the probability of y being less than k_1.

3.2 Performance classification

Within the framework of the statistical analysis ordered probit models with random effects were developed for each of the investigated parameters. The examined variables were classified into three categories: low, normal and high. The classification considered variable values, with approximately those in the first quartile being considered as low, and in the fourth as high. The derived classification was slightly modified where needed considering realistic values. Maximum speeds in the urban and rural area differed greatly, and hence, further analysis in the two different road environments was conducted. Parameter classification follows:

- Maximum driving speed: <60km/h, 60-80km/h, >80km/h
- Maximum driving speed (urban): <50km/h, 50-70km/h, >70km/h
- Maximum driving speed (rural): <70km/h, 70-85km/h, >85km/h
- Reaction time: <0.88sec, 0.88-1.0 sec, >1.0sec
- Standard deviation of lateral position: <0.23, 0.23-0.30, >0.30

3.3 Mobile phone use and maximum driving speed

The discrete choice model presented in Table 2 investigates the relationship between drivers' maximum speed and several explanatory variables such as the type of distraction, the road environment and drivers' habits and characteristics.

Table 2. Parameters estimates of maximum driving speed

Variables	**Estimate**	**t-value**
(Intercept)	3.245	4.746
Distraction		
Distraction (HH)	-1.034	-4.766
Distraction (Sp)	-0.372	-1.823
Road environment		
Road environment (Urban)	-2.055	-8.803
Driver's characteristics regarding mobile phone use		
Feeling safe (little)	-1.609	-2.998
Feeling safe (moderately)	-3.515	-5.776
Feeling safe (very)	-3.509	-5.366
Feeling safe (extremely)	-3.362	-4.225
Mobile phone use while travelling with underage passenger (No)	-1.157	-4.129
Familiar with the mobile phone device (very/extremely)	1.354	3.666
Driving habits		
Frequency of over speeding in urban area (rarely)	1.766	2.869
Frequency of over speeding in urban area (sometimes/often/always)	3.118	4.491
Driver's characteristics		
Age (≥ 35)	-1.018	-3.407
Gender (Female)	-0.582	-1.943
Enjoy driving (very/extremely)	0.520	1.810
mu_1	3.214	11.721
Sigma	1.694	6.150
Free parameters	390	
Degrees of freedom	17	
Initial log-likelihood	-346.593	
Final log-likelihood	-185.134	
AIC	404.269	

Model results indicate that mobile phone affects maximum driving speed. Drivers exhibit lower maximum speeds when having a conversation on the mobile phone both on the handheld and speaker mode. At the same time, increased familiarity with the mobile phone results in drivers adopting higher maximum speeds. Drivers who feel safe (little/moderately/very/extremely) when having a conversation while driving, also exhibit a reduction of their maximum speed. Last, drivers who don't use their mobile phone when travelling with underage passengers, drive at lower speeds, compared to the ones who use it.

Another contributory factor is road environment. In particular, drivers drive at lower speeds in urban areas, due to the lower speed limits and the environment's complexity (traffic lights, road signs, pedestrians etc.). It is also observed that, drivers who exceed the speed limit in urban areas (rarely/sometimes/ often/always) exhibit higher maximum speeds, compared to the ones who don't. At the same time, drivers who enjoy driving (very/ extremely) drive at higher maximum speeds. Regarding the effect of driver characteristics on maximum speed, drivers aged over 35 years old drive slower, compared to the younger drivers. Women also achieve lower maximum speeds, compared to men.

According to further analysis results concerning the maximum driving speed in urban and rural area, in rural areas both handheld and speaker mode conversation affect drivers' maximum speed, with handheld conversation exhibiting the highest affect. In urban areas, only the handheld conversation exhibits a reduction of the maximum driving speed. Handsfree and speaker mode conversation were not fount to affect maximum speed significantly.

3.4 Mobile phone use and reaction time

The second discrete choice model presents drivers' reaction time as a function of the type of mobile phone use, the road environment and drivers' habits and characteristics. The model parameter estimates are summarised in Table 3.

Table 3. Parameters estimates of reaction time

Variables	**Estimate**	**t-value**
(Intercept)	1.229	3.197
Distraction		
Distraction (HH)	0.508	2.414
Distraction (HF)	0.512	2.432
Distraction (Sp)	0.627	2.942
Road environment		
Road environment (Urban)	0.461	3.087
Driving habits		
Frequency of mobile phone use while driving in rural area (rarely/sometimes)	-1.211	-3.190
Frequency of mobile phone use while driving in rural area (often /always)	-1.341	-3.486
Frequency of over speeding in rural area (often/always)	-0.415	-2.063
Frequency of over speeding in urban area (always)	-1.531	-3.888
Driver's characteristics		
Age (25-45)	-0.330	-1.825
Gender (Female)	1.269	5.378
Car owner (No)	1.173	3.005
Road accident in last 3years (No)	0.994	4.673
mu_1	2.183	13.927
Sigma	1.752	7.981
Free parameters	390	
Degrees of freedom	15	
Initial log-likelihood	-348.854	
Final log-likelihood	-238.036	
AIC	506.072	

Drivers exhibit poorer driving performance considering reaction time as their reaction time increases with the use of a mobile phone. Speaker mode causes the highest increase in reaction time and handheld conversation causes the lowest. This might be a result of the intrusive nature of the different modes. The highest the intrusive nature the more aware the driver is of the distraction and the more alert he/she is. Concerning use of mobile phone, drivers who use their mobile phone while driving in rural areas (rarely/sometimes/often/always) react more quickly to unexpected events compared to drivers who don't use their mobile phone.

The type of the road environment affects reaction time too. In urban areas, drivers have higher reaction times, compared to rural areas. This is probably due to the fact that urban area's complexity adds distraction to the driver and leads to higher reaction times. Moreover, drivers who exceed the speed limit in rural (often /always) and urban areas (always), also achieve lower reaction times compared to those who never exceed the speed limit.

Considering driver characteristics, drivers aged between 25 and 45 years old seem to be more alert when driving and react quicker when unexpected events occur, compared to younger drivers, while women were found to react slower, compared to men. Results also indicated that drivers who don't own a car exhibit higher reaction times, compared to the ones who own a car. Finally, accident history seems to affect driver's behaviour. Drivers who have not had a road accident in the last three years achieve worse reaction times compared to the ones who had.

3.5 Mobile phone use and standard deviation of the lateral position

The third discrete choice model presented, investigates the influence of mobile phone use and other relevant parameters on the standard deviation of lateral position of the vehicle in rural areas. Lateral position refers to the position of the vehicle on the road in the relation to the right border of the lane in which the vehicle is travelling and it is an indicator of lane-keeping ability. The model parameter estimates are summarised in Table 4.

Table 4. Parameters estimates of standard deviation of lateral position in rural area

Variables	**Estimate**	**t-value**
(Intercept)	2.170	2.777
Distraction		
Distraction (HH)	1.431	3.967
Distraction (HF)	1.356	3.815
Distraction (Sp)	1.687	4.459
Driver's characteristics regarding mobile phone use		
Feeling safe - rural area(moderately/very/extremely)	-1.200	-2.649
Driving habits		
Frequency of mobile phone conversation while driving in rural area (sometimes/often/always)	-0.593	-1.681
Driver's characteristics		
Age (≥45)	2.086	3.604
Gender (Female)	1.048	2.563
Enjoy driving (moderately/very/extremely)	-1.458	-1.713
mu_1	2.561	8.001
Sigma	2.002	5.999
Free parameters	195	
Degrees of freedom	11	
Initial log-likelihood	-185.531	
Final log-likelihood	-113.072	
AIC	248.144	

All types of mobile phone use examined affect the standard deviation of vehicle's lateral position significantly. Speaker mode conversation has the highest effect on drivers' lateral position, followed by handheld conversation, whilst handsfree conversation demonstrates the lowest effect. The degree of the effect of the different modes presents an inverse pattern compared to the effect on reaction time. The reason is that keeping the lateral position of a vehicle is affected not only by the cognitive distraction (as reaction time is) but also by the physical interference, as the driver has to handle the steering wheel. Another contributory parameter is the degree at which the driver feels safe when having a conversation on the mobile phone while driving in a rural area. Drivers who feel moderately, very or extremely safe when having a conversation while driving, exhibit a reduction of the standard deviation of lateral position. Moreover, drivers who are used to having mobile phone conversations while driving (sometimes/often/always), exhibit better driving performance compared to drivers who never or rarely use their mobile phone while driving.

Drivers who enjoy driving (moderately/very/extremely), were found to achieve lower levels of the standard deviation of lateral position, compared to drivers who answered that they don't like or like driving a little. Considering driver characteristics, drivers aged over 45 years old, exhibit increased values of the standard deviation of lateral position, indicating that they find difficulties in lane keeping, compared to younger drivers.

Furthermore, male drivers perform better compared to female drivers, confirming the findings in the other two indicators.

4. Discussion

Driver behaviour is affected by the use of the mobile phone. This effect as described through the indicators of maximum speed, reaction time and deviation of the lateral position is summarised in Table 5.

Table 5. Impact of mobile phone use on driving behaviour (+: increase, -: decrease, 0: no effect)

Measure	Type of mobile phone conversation		
	Handheld	Handsfree	Speaker mode
Maximum Speed	-	0	-
Maximum Speed (Rural Area)	-	0	0
Maximum Speed (Urban Area)	-	0	0
Reaction Time	+	+	+
St. Dev. Lateral Position (Rural Area)	+	+	+

Results demonstrate that driving behaviour is affected with the use of the mobile phone. Mobile phone use affects driver's maximum speed. Handheld and speaker mode conversation result in a reduction of the maximum driving speed, which is in accordance with findings from other similar studies (Alm and Nilsson, 1994; Yannis et al., 2010; Choudhary and Velaga, 2017 and so on). This can be a consequence of driver distraction or of the risk compensation mechanism (or both). Drivers exhibit higher reaction times when using their mobile phone. All types of mobile phone use examined (HH, HF, Sp), found to affect reaction time significantly. These results are also consistent with previous works (Alm & Nilsson, 1993; Al-Darrab et al., 2009; Papantoniou et.al., 2014, and so on). A highly significant effect of mobile phone conversation on lateral position deviation in rural area is also demonstrated. Handheld, handsfree and speaker mode conversation cause higher levels of standard deviation of the lateral position. This is also noted in several previous studies (Alm & Nilsson, 1994; Young & Richard, 2012,). Mobile phone conversation while driving, considering reaction time and lateral position, does not only impair drivers' behaviour but also drivers' safety, regardless of the mobile phone mode used. This highlights the need to reflect on the existing legislation of mobile phone use while driving. Currently, in Greece for example using the mobile phone on speaker mode is allowed; results at the same time indicate that driving performance deteriorates.

At the same time, the effect of mobile phone use on driver performance was found to decrease with increased experience of using the mobile phone while driving. This should be considered in the design of relevant legislation or driving licensing schemes. It is relevant especially in countries where using the mobile phone while driving is legal.

As indicated from the questionnaire analysis, a substantial proportion of drivers (76%) use their mobile phone while driving, out of which 32% usually have a handheld conversation, 22% a handsfree conversation and only 46% use the speaker mode, which is the only legal mode (together with Bluetooth). At the same time, only 2% of the participants are aware of the legislation considering mobile phone use while driving, with the remaining 98% having partial knowledge or complete ignorance. The results of this study highlight the need for actions raising public awareness as well as for reconsideration of the Greek legislation and driver's training curricula concerning mobile phone use.

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