Impact of mobile phone use and music on driver behaviour and safety by the use of a driving simulator

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Abstract

This study attempts to investigate and compare the impact of mobile phone use and listening to music on driver behavior and the probability of being involved in an accident. An experimental process on a driving simulator was carried out, in which all the participants drove in a mountainous road with and without mobile phone (handheld mode) and music. Lognormal regression models were developed for driver speed and it appeared that mobile phone use leads to a statistically significant decrease in speed, while music tends to increase it. Moreover, a 'difficult' conversation at the mobile phone leads to an increase in reaction time at unexpected events, and mobile phone use in general leads to an increase in the distance of the vehicle from the central axis of the road. Through a binary logistic regression analysis it appeared that the 'difficult' conversation at the mobile phone may bring about a significant increase in the accident probability, in case of an unexpected event activated by the experiment coordinator. Finally, regarding the use of mobile phone with a 'difficult' conversation, as a general conclusion it was noted that the lower speed and the increase of the distance from the central axis of the road cannot compensate for the much greater risk for an accident, in case of an unexpected event, due to increased reaction time.

Introduction

The analysis of the degree to which distraction factors may affect the behavior and safety of drivers, has received increasing attention in the international literature. Driver inattention or distraction has been associated with an important proportion of road accidents, ranging from 10-15% (McEvoy et.al, 2005; Wang et.al, 1996) to 25% (Stutts et.al, 2005).

A plethora of studies investigated the impact of mobile phone use on the driver performance while a few have dealt with the influence of music. The majority of the studies, whether they included an experiment in an actual or in a simulated environment, indicate in general that, mobile phone use and music while driving lead to a change in the driver's behavior, and that the use of mobile phone is related with negative effects on the driver's safety.

Mobile phone use

An earlier simulator study (Rakauskas et.al, 2004) showed that, as a result of engaging in a mobile phone conversation while driving, participants reduced significantly their average speed, whereas the presence of different difficulties of conversation did not influence mean speed or speed variability. In addition to this, neither steering variability nor mean lateral speed were found to be influenced by the presence of any difficulty level of cell phone conversation. Tornos and Bolling (2006), in another simulated study that included a variety of driving environments and mobile phone usage conditions, inferred that cell phone conversation reduced driving speed at any environment for handheld mode, while for the handsfree mode, speed was reduced only in a rural environment of 90 km/h speed limit and in an urban complex environment.

Alm H. and Nilsson L. (1993) carried out another simulator experiment, aiming to detect the changes in driver behavior as a function of a hands-free mobile phone use in combination with the curvature of the driving tasks. Regarding the effects on the speed, it was concluded that speed appeared lower in drivers that used the mobile phone contrary to those who drove without distraction. However, it was noted that the speed difference between the two groups of drivers was rather large and statistically significant only under the circumstance of driving in the easy route, which was straight, unlike the hard route that was very curvy and resulted in the imposition of a rather high workload on the drivers. Furthermore, it was observed that the difference in the lateral position was larger for the hard driving condition than the easy condition.

Rosenbloom (2006) also examined the impact of using a hands-free mobile phone while driving on vehicle speed and headways, and found that drivers who performed short phone calls reduced their speed while talking on the mobile phone, in contrast with other drivers who engaged in lengthy conversations and increased their speed.

Through another simulator study (Strayer et.al, 2006), a performance comparison was made between cell phone drivers, either on hand-held or hands-free mode, and drivers who were legally intoxicated from ethanol. As for the speed profiles, intoxicated drivers reduced speed more than cell phone drivers, but in both of those categories speed appeared lower than the average speed of participants in the single-task driving.

Concerning the effect of different driver's distractions on speed, through another simulator experiment that included involving in a cell phone conversation or reacting with an in-car passenger, it was demonstrated that when approaching a hazard point of the road, drivers with no distraction and drivers with in-car passengers reduced their speed whereas the average speeds of cell phone drivers decreased only slightly or not at all (Charlton, 2009).

Several of the studies aforementioned have also dealt with the impact of cell phone conversation on reaction time. The simulated study of Tornos and Bolling (2006) resulted in the observation that reaction time was increased in all driving environments, due to cell phone conversation, regardless of the phone usage conditions (hands-free or handheld mode). On the contrary, Alm H. and Nilsson L. (1993) who included in their survey the factor of the curvature of the road came to the conclusion that the hands-free usage of cell phone did not bring about a significant influence on their reaction time in contrast to the curvature. Furthermore, through the comparison of cell-phone conversing and intoxicated driving (Strayer et.al, 2006), it was pointed out that drivers reacted slower to a stimulus when using the mobile phone, compared to the situation of non distracted driving, whereas it seemed that participants reacted the same way to a stimulus whether they were driving under the influence of alcohol or sober. Finally, a recent study that included a simulated braking task (Bellinger et. al, 2009), showed that participants reaction time increased statistically significantly in the presence of the cellular telephone conversation compare to when it was absent.

A main issue that has lately been a matter of research in a worldwide level is the effect of mobile phone use on the probability of being involved in a car accident. Lam (2002) investigated the association between various types of distractions, inside and outside the vehicle, and the increased risk of car crash injury among drivers of different ages. In general, significant associations were observed between distractions inside the vehicle and an increased risk of car crash injury across all age groups. More specifically, concerning the distractive factor of mobile phone use, it was noted that the age group of drivers of 25-29 years old had the highest frequency of phone use-related crash injuries. In addition to this, the results of a simulator study (Charlton, 2009), dealing among the rest with the effect of the hands free use of mobile phone while driving, suggested that drivers who used the mobile phone recorded the highest accident rates.

Music

There are four types of driver distraction: visual, auditory, physical, and cognitive. Auditory distraction occurs when the driver momentarily or continually focuses their attention on sounds or auditory signals rather than on the road environment (Direct Line, 2002). Surveys suggest that unaccompanied driving is the most popular and frequently reported setting for listening to music (Brodsky, 2002). Drivers listen to music because they find it enjoyable, relaxing and entertaining, or because it prevents boredom (Dibben and Williamson, 2007).

It has been observed that listening to music while driving can have both negative and positive effects on driving performance and safety. Beneficial effects of music listening while driving include the improvement of the driver’s reaction time (Spinney, 1997) as well as the maintenance of his alertness (Stevens and Minton, 2001; Turner et.al, 1996). On the other hand, it has been found that the more demanding the auditory task, the greater the effect on driving performance (Spence and Ho, 2008). Another study (Henry, 2006) also appears to support the hypothesis that music as a stimulus while driving is distracting as it was observed that music listening caused more errors on a simulated driving task than did a no-music condition.

Another simulator survey (Pêcher et.al, 2009) aimed to detect the effect of different types of emotions emerging during music listening in a driving task, on the driver’s behavior. The music excerpts used in the experiment were distinguished in three categories, happy, sad and neutral. Happy music was associated with an important decrease of mean speed which slightly decreased for sad music, whereas no differences were pointed out for the situation of driving with neutral music. Furthermore, the distance of the vehicle from the middle of the road was found larger in case of driving with music that caused pleasant emotions to drivers, while it was observed to decrease when driving with sad and neutral music. Concerning the influence on the driver’s safety, it was noted that drivers had an easier lateral control of the vehicle when listening to sad or neutral music, contrary to the situation of driving with happy music where lateral control was significantly deteriorated. Finally, through an earlier simulator experiment (Bellinger et.al, 2009), the effect of music on driver's reaction time was investigated and it was observed that reaction time was not influenced by the presence of music.

Within this framework, the present study aims to investigate whether and in what ways the use of mobile phone and listening to music influence the driver's behaviour and safety. The driving behaviour and safety measures used concern speed, lateral position (i.e. the distance of the vehicle from the central axis of the road), reaction time at unexpected incidents, and the related probability of being involved in an accident. The present study focuses on further investigating the effects of listening to music on driving, a topic on which existing research is inconclusive, and on explicitly comparing mobile phone use, in different levels of difficulty of conversation, with listening to music.

The study was carried out through an experimental process on a driving simulator and the data were collected from the simulator's measurements as well as from a questionnaire. The data collected was then analysed by means of appropriate statistical modelling techniques.

Method

Experiment Participants

Forty eight young adults, 29 men and 19 women, between the ages of 19 and 29 years old, voluntarily participated in the simulator experiment. All of the participants were licensed drivers, owned a mobile phone device that used during the experiment and were in their majority, students of the National Technical University of Athens.

Apparatus

The apparatus of the experiment consisted of the Driving Simulator FPF of the Department of Transportation Planning and Engineering of the National Technical University of Athens. It is a medium-fidelity, quarter-cab simulator with a motion base.

Experiment Design

At first, participants were asked to fill in a questionnaire so as to appraise their personal attribute in general and their usual driving behavior and background, focusing on the characteristics related to mobile phone use and music listening while driving (e.g. frequency of mobile phone use and music listening, mobile phone mode preferred while driving – bluetooth, hands-free, on speaker or handheld, cognition or not of a potential risk implicated in engaging in any of these two activities while driving, etc.). After being given a short description of the experiment and instructions, as for transferring as much as possible their actual driving behavior to the simulation experiment, participants had to familiarise themselves with the simulator through a trial session before the main drive test.

The music stimulus was presented via an mp3 device with two stereo speakers positioned on the right and on the left of the central LCD 40” screen of the simulator, facing the subject. For the purposes of this experiment it was decided to maintain a constant music volume and tempo and instrumental background for all participants, regardless of their preferences, that were indicated and comprehended in the research through the questionnaire. Therefore, the music volume was adjusted high to 75 dBA and the song used was “Sleep Now in the Fire” by Rage Against The Machine, a rap metal genre song of fast tempo (127 BPM).

At the main driving test task, all participants had to drive in the same road with mountainous characteristics (several slopes, curves, background mountains, etc.), continuously, with and without mobile phone and music. More specifically, the drives took place on a two-way road that included one bridge and one tunnel, without a median or barriers and there was ambient traffic on both road directions.

During the route, participants drove in the conditions of: no distraction, conversing in the mobile phone, listening to music; the conditions were presented in a counterbalanced way along the route. Two phone calls that required different level of mental effort took place and the participants had to answer their mobile when it rang, only by hand, and they all had to engage in the conversation initiated by the researcher, without regard to their everyday driving habits. The questions posed to the drivers during the two conversations were the same for everyone. At the “difficult” call, the driver was asked to find the answer to a mathematical function while at the “easy” call, he was asked to provide instructions for how one can access a known point of the city of Athens from another.

The phone calls were made in specific kilometric points of the route by one of the researchers who was observing the experiment through a connected camera, located in a different room. The surveyor responsible for the calls also filled in a form, in which she marked the time that the phone calls took place and their duration, whether the answers given by the participants during the mobile phone conversations were correct or incorrect and whether each driver had a hard time answering the questions of the calls or not. It is noted that the presence of difficulty in answering the questions was considered irrelevant to the validity of the answer given by the driver and was defined as the existence of a significant delay in responding.

During the drive test, another surveyor located inside the simulator room inducing unexpected incidents to occur at fixed kilometric points, one in every consecutive driving condition of distractions (easy call - difficult call - music) and no distractions. The unexpected incidents concerned the sudden presence of an animal on the roadway at a fixed distance from the vehicle (estimated at real-time in relation to the vehicle’s speed).

Collected data

All the data and variables to be analysed were accumulated by the simulator software (i.e. variables related to the characteristics of the stimulator drive), the questionnaire (i.e. variables related to the driving behavior and background of each driver), and the forms with the observations of the surveyors.

Regarding the participants driving experience, 42% held a driving licence from 1 to 4 years and 58% from 5 to 9 years. As for their perception concerning the risk of mobile phone use while driving, only 8% of the drivers stated that they do not consider engaging in a mobile phone conversation to be dangerous, 15% consider it to be very dangerous while the rest of them think that a medium risk is implicated in this behavior. Furthermore, it was observed that 65% responded correctly when were asked to give the directions aforesaid during the “easy” call, while only 38% gave the correct answer to the mathematical function of the “difficult” call. The self-reported frequency of mobile phone use while driving among these participants was notably high, as 79% of participants reported using their mobile phone while driving more frequently than once a day; moreover, 71% of participants use a handheld phone. As for the music, only 6% reported that prefer a really low music volume when driving, 19% a high volume and 75% a medium volume. In addition to this, 19% of the drivers characterized the music stimulus of the experiment as uninteresting, 30% as annoying and 51% as very nice.

Models Development

Mean speed, mean reaction time and mean distance from the axis of the road were analysed and modelled through lognormal linear regression, as the logarithm of speed was found to conform to a normal distribution. On the other hand, driver safety was investigated by modelling accident probability by means of binary logistic regression. It is noted that standard longitudinal and lateral control measures were opted for in this research as dependent variables of the analysis, while driver workload measures are not examined, given that these are mostly subjective (Caird and Horrey, 2011). Overall, eight models were developed: for mean speed (4), for reaction time (1), for mean distance from the axis (2) and for accident probability (1).

Each independent variable was initially tested alone through univariate analysis and kept in the final model provided that the corresponding parameter estimate was significant at approximately 90% significance level, by means of t- tests (for the lognormal linear regression analysis) or Wald- tests (for the binary logistic regression analysis). After that, correlation tests were carried out on the statistically significant variables of the univariate analysis so as to detect the correlated variables. In case two or more variables were correlated, the variable of the final model was selected on the basis of its statistical significance and its relevance to the objectives of the analysis. Thus, the sets of explanatory variables to be included in the multivariate models were identified. All the variables and their values that were collected and examined during this research, either from the simulator experiment or from the questionnaire, are presented in Appendix I.

In every analysis, in order to achieve a comparative assessment of variable effects within and across the models, the variables' elasticities were calculated, so as to estimate dimensionless relative effects. In linear regression models, elasticities are defined as the percentage change in the dependent variable yi resulting from a 1% change in the explanatory variable xik, or from a transition of one category of the discrete explanatory variable xik to another (Washington et.al, 2003). The theory of pseudo-elasticity can be applied in discrete variables in a logistic regression analysis

(Shankar and Mannering, 1996; Chang and Mannering, 1999). In this case, pseudo-elasticities reflect the change in the estimated probability resulting from the transition to one discrete value of a variable to another, and can be estimated for binary variables (Ulfarsson and Mannering, 2004).

Finally, the quality of each model was determined by means of the R2 coefficient for the lognormal regression models and by means of the likelihood ratio test (LRT) for the binary logistic regression models.

Modelling driver’s mean speed

Four different log-normal linear regression models were developed for drivers' mean speed: one for each type of distraction (i.e. “easy” call, “difficult” call, music) and one separate model with a combination of the three distraction factors, so as to compare their effects on driver’s behavior. At this point it is noted that the three distraction factors were examined separately during the experimental process.

The statistically significant explanatory variables of the final models include road design characteristics, driving behavior characteristics, as well as personal driver characteristics. In detail, the final explanatory variables were: vertical alignment and horizontal alignment (road design characteristics), mean distance from the right border, motor revolutions per minute, mean time to collision and mean time to line crossing (driving behavior characteristics), gender, self-reported frequency of mobile phone use, risk perception, weekly milage, trouble answering the phone call questions (personal driver characteristics). The three distraction factors were included in the models as explanatory variables. The significant parameter estimates, their t-test values and their elasticities in the final models are summarized in Table 1.

Regarding mobile phone use, it was observed that engaging in a conversation, whether of a “difficult” or an “easy” mental workload, leads to a statistically significant decrease of mean speed, revealing perhaps, apart from the physical distraction of the handheld mode, an attempt of drivers to counter-balance the increased mental workload resulting from the conversations (Yannis et.al, 2011).

Regarding music listening while driving, it was found that the presence of the musical stimuli of the experiment leads to an increase of mean speed, both for men and women. That reveals that drivers possibly got “carried away” by the music stimulus rhythm and tempo, regardless of their general music or volume preferences during driving, or their personal opinion on the specific song.

Regarding the comparison of the three examined distraction factors, drivers appeared to drive at the higher speed when listening to music and at the lower speed when engaging in a difficult conversation on the mobile phone (Papathanasiou and Postantzi, 2011).

Furthermore, through the sensitivity analysis it was found that drivers who stated to consider talking on the mobile phone while driving as a high risk behavior (risk perception variable), drive at lower speeds than the others, even when driving non-distracted. In addition to this, sensitivity analysis showed that, at the “easy” call, the mean speed of a mobile phone conversing driver, who does not consider mobile phone use to be very dangerous, is practically equal to a non-conversing driver who, on the other hand, thinks that this behavior is very dangerous. On the contrary, mean speeds of those two risk-perception types of drivers differ more for the “difficult” call distraction task. Moreover, the results suggested that when the driver has difficulty to cope with the mental workload of the conversation, he reduces his speed, given that the difficulty of each driver in answering the questions was defined as a significantly observed delay in responding.

TABLE 1 Parameter estimates, t-test and elasticity values of the mean speed models

Explanatory variables	Difficult call			Music			Easy call			Combination of distraction factors		
	β_i	t-test value	Elasticity e_i	β_i	t-test value	Elasticity e_i	β_i	t-test value	Elasticity e_i	β_i	t-test value	Elasticity e_i
Continuous variables												
Motor revolutions per minute	5,09E-05	13,842	0,097	4,97E-05	12,189	0,092	3,59E-05	9,883	0,068	7,11E-05	17,222	0,135
Mean distance from the right border	-	-	-	-0,025	-4,255	-0,024	-1,70E-02	-3,142	-0,016	-0,013	-2,235	-0,013
Mean time to collision	6,40E-06	4,955	0,032	7,77E-06	4,964	0,039	7,64E-06	5,963	0,038	-	-	-
Mean time to line crossing	-	-	-	-	-	-	-	-	-	-3,20E-05	-8,712	-0,007
Descrete variables												
Difficult call	-0,010	-1,808	-0,002	-	-	-	-	-	-	-0,027	-3,491	-0,004
Music	-	-	-	0,036	4,406	0,004	-	-	-	0,040	4,130	0,003
Easy call	-	-	-	-	-	-	-0,018	-2,970	-0,003	-0,022	-2,626	-0,002
Tangent road section	0,138	25,615	0,032	0,169	24,959	0,037	0,149	25,729	0,038	-	-	-
Uphill road section	-0,059	-10,776	-0,012	-0,052	-6,695	-0,008	-0,062	-9,654	-0,014	-	-	-
Gender	-0,027	-5,101	-0,007	-0,040	-6,871	-0,010	-0,033	-5,980	-0,008	-0,031	-4,925	-0,008
Weekly milage above the average	0,017	3,403	0,004	-	-	-	-	-	-	-	-	-
Mobile phone use while driving more than once a day	-	-	-	-	-	-	-0,020	-3,702	-0,004	-	-	-
Driver considers talking on the mobile phone as a high risk activity	-0,045	-6,176	-0,004	-	-	-	-0,023	-2,942	-0,002	-	-	-
Trouble answering the easy phone call question	-	-	-	-	-	-	-0,020	-3,595	-0,004	-0,028	-4,274	-0,006
R^2	0,581			0,617			0,621			0,234		

The other explanatory variables that were found to significantly affect drivers’ speed can be analysed as follows: mean motor revolution reflects drivers’ speeding behavior, given that increased motor revolutions correspond to more acceleration time and thus to even increased speeds. Speed was observed decreased when driving closer to the central axis of the road, a fact that in this specific type of road (two-way road without median) may be explained by a potential perception of an increased risk by the driver and his effort to achieve a safer vehicular control. Drivers implicitly note higher speeds when an obstacle is far away and lower as they approach it. Mean speed is higher at straight line road sections and lower at uphill road sections. Additionally, speed is associated with the weekly mileage and the self-reported frequency of mobile phone use while driving: it is increased for those who claim to drive a lot per week and decreased for the drivers who use the mobile phone many times a day, probably as a result of their experience in counter-balancing the increased physical and mental effort. It was finally noted that, distracted or not, men drive at higher speeds than women.

Overall, both “difficult” and “easy” conversations on the mobile phone bring a statistically significant decrease in drivers’ speed while the presence of music leads to statistically significant speed increase. Lower speeds are generally associated with positive road safety outcomes (e.g. fewer road accidents and fatalities) (Yannis et.al, 2011) while higher with negative. In the next sections, additional driver behavior parameters are analyzed, namely the distance from the central axis of the road and reaction time, in order to achieve a spherical examination of the distracted driver behavior.

Modelling reaction time

Out of the three distraction factors examined, only the “difficult” call was found to have a significant effect on drivers’ reaction time in case of an unexpected event. Music and “easy” call were not found to have any significant effect. The significant parameter estimates, their t-values and elasticities in the final models are summarized in Table 2.

TABLE 2 Parameter estimates, t-test and elasticities of the reaction time model

Explanatory Variables	β_i	t-test value	Elasticity e_i
Continuous variables			
% use of brake	-0,002	-2,000	-0,109
Wheel revolution to the right	3,87E-04	1,776	
Descrete variables			
Difficult call	0,114	3,710	0,135
Gender	-0,044	-1,798	
Tangent road section	0,129	4,101	1,996
Trouble answering the difficult phone call question	0,071	2,581	
R^2	0,149		

The “difficult” cell phone conversation was found to cause a statistically significant increase of drivers’ reaction time. It appears that when the driver engages in such a complex conversation that requires a relatively advanced mental workload (i.e. mathematical function), he might become distracted, do not identify an obstacle immediately and thus react with delay to a potential collision. Furthermore, it was observed that drivers who had difficulty in responding to the question of the cell phone conversation, despite the decrease of their mean speed, appeared to react slower than the other drivers.

Moreover, wheel revolution (in this case to the right) corresponds to delayed reaction time; wheel revolution is strongly related with curvature on the road and an already distracted driver might react slower to an unexpected event when trying simultaneously to deal with horizontal curves and possibly lower-visibility. Straight road line also appears to have a negative effect on reaction time, as it is widely believed hat long straight lines provoke monotonous driving tasks and result in a situation where the driver becomes distracted in his thoughts (absent-minded).

As regards the other explanatory significant variables of driver's reaction time, they can be analysed as follows: drivers using the speed control pedal longer (Acc) may be more cautious than the others who use it to accelerate and decelerate abruptly. The second group might be characterized to some point by a more aggressive driving behavior, therefore by a more increased reaction time. The variable of gender had also an effect on reaction time, indicating that women react more rapidly than men to an unexpected incident.

Modelling the vehicle's distance from the central axis of the road

Both "difficult" and "easy" calls were found to statistically significantly affect drivers' mean distance from the central axis of the road. Music on the other hand was not found to influence the distance from the central axis of the road. The significant parameter estimates, their t-values and elasticities in the final models are summarized in Table 3.

The results suggest that a "difficult" or an "easy" conversation at the mobile phone leads drivers towards driving closer to the right border of the road, which may be explained by the fact that, being aware of the risks involved during that type of multitasking, in such a type of undivided road as this, they attempt in this way to reduce the perceived risk of a collision with a vehicle from the opposing direction, a behavior that has been previously explained (Bairamis and Sklias, 2010).

Moreover, it was observed that, drivers who stated to use a bluetooth device for their phone calls during driving in their everyday lives, drove closer to the right border of the road during the experimental driving task, in which they were asked to use the phone by hand. That can be possibly explained by the extra difficulty involved in the physical distraction of the handheld mode, a task with which they are not familiarized. A similar impact on the distance from the axis of the road is also observed by the difficulty of the driver in responding to the questions of the conversation (for the "easy" call model); when having a hard time engaging in a conversation the driver pulls away from the central axis to compensate for the upraised risk of a head-on collision. The gender variable was also found significant; women unlike men, perhaps being more reserved while driving, seem to keep longer distance from the axis of the road.

On the other hand, two additional variables of the driver's characteristics are associated with driving closer to the central axis of the road, behavior which in the current experimental two lane road of no median can be characterized as dangerous. Drivers with weekly mileage above the average and drivers who stated to have been implicated, at some point in the past, in a mobile phone use-related traffic accident, drive closer to the axis of the two-lane road; the first group possibly feel more confident due to their experience and the second could be easily connected with a high-risk driving profile, given their accident related background.

TABLE 3 Parameter estimates, t-test and elasticities of the distance from the central axis of the road models

Explanatory variables	Difficult call			Easy call		
	β_i	t-test value	Elasticity e_i	β_i	t-test value	Elasticity e_i
Continuous variables						
Headway	-4,70E-06	-5,519	-0,158	-	-	-
Wheel revolution to the left	-0,002	-13,679	-0,104	-	-	-
Wheel revolution to the right	-	-	-	0,001	10,194	0,056
Mean time to line crossing	-3,80E-05	-9,438	-0,080	-3,50E-05	-8,894	-0,042
Descrete variables						
Difficult call	0,013	1,949	0,015	-	-	-
Easy call	-	-	-	0,015	2,157	0,014
Uphill road section	-	-	-	-0,052	-8,628	-0,080
Closed curves	-0,032	-4,007	-0,023	-	-	-
Gender	0,017	2,767	0,025	0,018	2,904	0,026
Driver is accustomed to use a bluetooth device	0,050	3,599	0,008	0,051	3,430	0,007
Previous involvement in a mobile phone related accident	-0,079	-5,247	-0,016	-0,047	-3,114	-0,009
Trouble answering the easy phone call question	-	-	-	0,016	2,546	0,020
Weekly milage above the average	-0,016	-2,664	-0,025	-0,016	-2,642	-0,024
R^2	0,244			0,201		

Regarding the other explanatory variables that were found to affect driver's mean distance from the axis of the road, they can be analysed as follows: Uphill road sections are related to lower speeds and thus to decreased distance from the central axis of the road; that possibly stems by a safety feeling of the driver who does not feel the need to compensate for a head-on collision in such low speeds. A similar feeling of safety due to increased headways seems to influence likewise the distance from the axis of the road; the more increased the headway the more the driver decreases his distance from the axis. Frequent and closed curves usually provoke driving closer to the axis of the road (against centrifugal force). A time to line crossing increase is also perhaps associated with driving away from the right border and approaching the axis of the road. Finally, wheel revolution to the right attributes to driving away from the axis while left wheel revolution to driving towards it.

Modelling accident probability

Accident probability was modeled as a binary response variable (accident in case of unexpected incident yes / no), by means of logistic regression, and the results are summarized in Table 4.

TABLE 4 Parameter estimates, Wald-test and (pseudo-) elasticities of the accident probability model

Explanatory variables	β_i	Wald	Elasticity e_i
Continuous variables			
Reaction time in case of an unexpected event	3,066	29,534	2,198
Mean speed	0,033	2,921	0,774
Descrete variables			
Difficult call	1,195	5,663	0,890
Driver enjoys driving	-1,063	3,342	-0,421
Driver considers talking on the mobile phone as a non risk activity	-1,465	1,930	-0,586
Likelihood Ratio = 53.762 (6 degrees of freedom)			

It was observed that driving engrossed in a difficult conversation leads to a statistically significant increase of accident probability, while no significant influence was detected in case of the “easy” call or music listening.

In reference to the other explanatory variables they can be analyzed as follows: As expected, the increase of mean speed was found associated with increased accident risk. Moreover, the important influence of reaction time on the accident probability was confirmed through this model; when the driver delays to react for the deceleration of the vehicle, the unexpected event is more likely to evolve into an accident.

Moreover, it was observed that, for those drivers who stated to enjoy driving, there is less possibility to implicate in an accident, compared to those who don’t, whether they converse or not at the mobile phone; it seems that someone who enjoys driving may be more concentrated and more experienced than someone who doesn’t like driving and therefore possibly avoids it in his everyday life. The risk perception variable was also associated with accident probability and it was found that drivers who did not consider talking in the mobile phone as a high risk activity had decreased probability to get involved in an accident; these drivers possibly engage frequently in secondary activities when driving and thus are more familiarized with such multitasking.

It is interesting to note that among discrete variables, difficult mobile phone conversation has by far the highest pseudo-elasticity with respect to accident probability, and reaction time is the continuous variable with the highest elasticity in the model.

The results of the present research regarding accident probability are summarized in the sensitivity diagram (Figure 1) which depicts the effect of a combination of explanatory variables on the response variable. Accident probability gradually increases with an increase of mean speed and is significantly higher when using the mobile phone for a complex conversation. It is also worth emphasizing that the highest increase of accident probability is observed for the mean speed of 80km/h where the difficult mobile phone conversation almost doubles the accident risk.

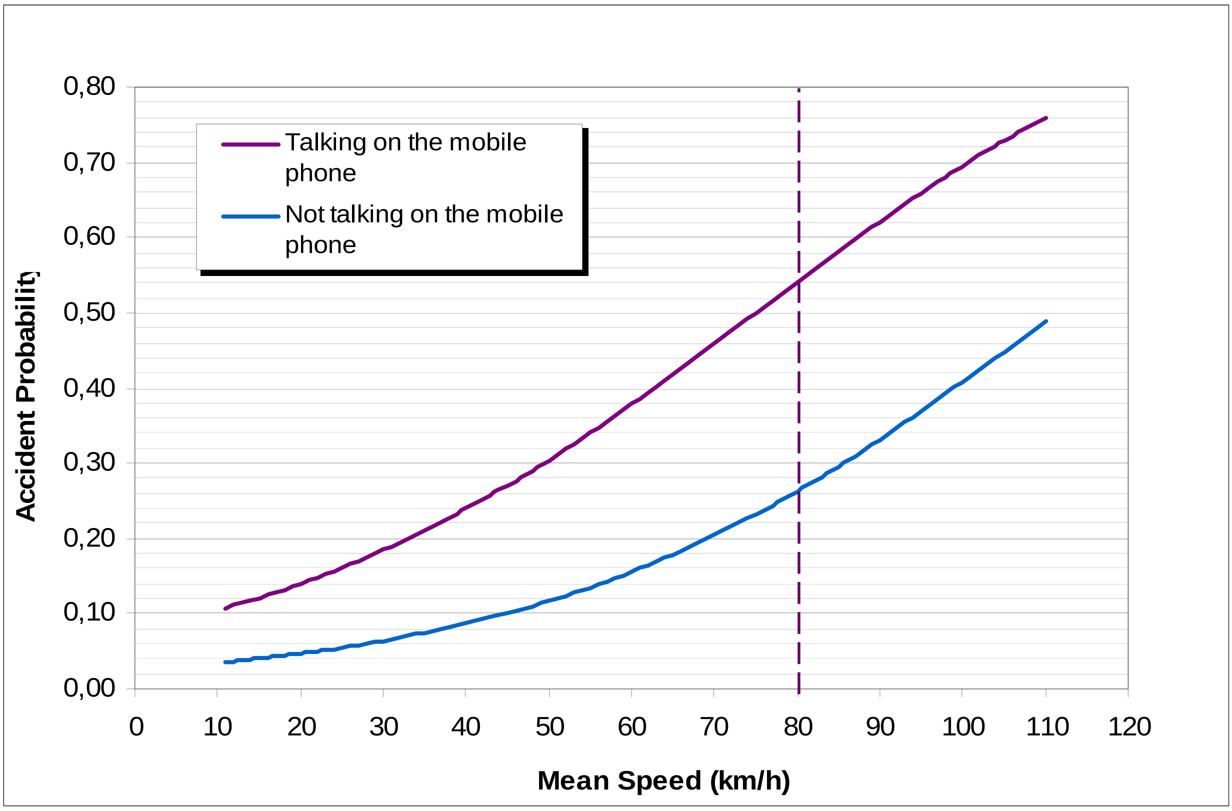

Figure 1 **Effect of engaging in a complex mobile phone conversation and mean speed on accident probability (in case of an incident)**

Conclusions

The findings of this study suggest that both “difficult” and “easy” conversations on the mobile phone bring a statistically significant decrease in drivers’ speed (possibly revealing a compensatory strategy) while the presence of music leads to statistically significant speed increase (possibly indicating that drivers are “carried away” by the music). Moreover, both “difficult” and “easy” phone conversations were systematically associated with an increase of the distance from the central axis of the road (again, a common compensatory strategy).

However, it was observed that driving while involved in a difficult conversation is also associated with significantly increased reaction times at unexpected incidents and with increased accident risk, while no significant influence was detected in case of the “easy” call or music listening. It appears that, while the above compensatory strategies seem to work in music listening (auditory distraction) and ‘easy’ mobile phone conversations (auditory and physical distraction), they are not adequate for balancing the increased risk of dual tasking in ‘difficult’ mobile phone conversation (auditory, physical and cognitive distraction).

Comparing the three examined distraction factors (“difficult” call, “easy call” music) it was observed that the greater impact on drivers’ speed emerges by engaging in a difficult mobile phone conversation while the least by engaging in an easy conversation.

It is also worth noting that drivers who stated to use a bluetooth device for their phone calls during driving in their everyday lives, drove closer to the right border of the road during the experimental driving task, where they were asked to use the phone by hand. That can be explained by the extra difficulty involved in the physical distraction of the handheld mode; therefore they drive at a longer distance from the axis of the road to minimise the risk of a head-on collision. Moreover, drivers who stated to have been implicated, at some point in the past, in a mobile phone use-related traffic accident, drive closer to the central axis of the two-lane road, a fact that could be connected with a high-risk driving profile.

This study reached the conclusion that decreasing speed and driving towards the right road border is eventually not enough to countervail the outcome of the delayed reaction time in case of unexpected incident occurrence; the combination of physical and mental workload distraction when engaging in a complex mobile phone conversation might be crucial enough to increase the accident probability. On the other hand, “easy” mobile phone conversation and music was not found to result in increased reaction times and increased accident probability, indicating that drivers may successfully compensate for these distraction factors by reducing their speed.

These results suggest the potential impacts of mobile phone and music on driver behaviour and safety. Future research should focus on the simultaneous and comparative examination of other in-vehicle distraction factors (e.g. navigation systems, eating, smoking etc.). Additionally, it would be interesting to investigate the impact of mobile phone use and music on driver behavior and safety, not only when the drivers talk on their hand-held mobile phone but also when they use a hands-free device, a bluetooth, or when they type a sms.

Results of this study should be replicated with larger groups of adults and further research is required in order to identify any differences between different age groups of drivers. Finally, it is critical to examine the impact of mobile phone and music in case the experiment takes place in real driving conditions (naturalistic driving experiments) or under different environmental or traffic road conditions.

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Appendix I Variables and values available in the analysis

Dependent variables	Values	Source
Speed	mean speed (Km/h)	Simulator
RT	reaction time (sec)	Simulator
rspur	mean distance from the axis of the road (m)	Simulator
accid	accident occurrence (1:yes, 0:no)	Simulator
Explanatory variables	**Values**	
Speed	mean speed (Km/h)	Simulator
RT	reaction time (sec)	Simulator
rdist	distance of the vehicle from the beginning of the drive (m)	Simulator
rspur	track of the vehicle from the axis of the road (m)	Simulator
ralpha	direction of the vehicle compared to the road direction (degrees)	Simulator
Brk	brake pedal position in percent	Simulator
Acc	gas pedal position in percent	Simulator
Clutch	clutch pedal position in percent	Simulator
Gear	chosen gear (0 = idle, 6 = reverse)	Simulator
RPM	motor revolvation (1/min)	Simulator
Hway	headway, distance to the ahead driving vehicle (m)	Simulator
Dleft	distance to the left road board (m)	Simulator
Dright	distance to the right road board (m)	Simulator
Wheel	steering wheel position (degrees)	Simulator
Thead	time to headway, i. e. to collision with the ahead driving vehicle (sec)	Simulator
TTL	time to line crossing, time until the road border line is exceeded (sec)	Simulator
TTC	time to collision (all obstacles) (sec)	Simulator
AccLat	acceleration lateral (m/s^2)	Simulator
AccLon	acceleration longitudinal (m/s^2)	Simulator
call1	'difficult" call (1:yes, 0:no)	Simulator
call2	'easy" call (1:yes, 0:no)	Simulator
music	music (1:yes, 0:no)	Simulator
A	uphill road section (1:yes, 0:no)	Simulator
K	downhill road section (1:yes, 0:no)	Simulator
I	horizontal road section (1:yes, 0:no)	Simulator
E	tangent road section (1:yes, 0:no)	Simulator
AS	open curves (1:yes, 0:no)	Simulator
KS	closed curves (1:yes, 0:no)	Simulator
Wheel_Right	wheel revolution to the right (degrees)	Simulator
Wheel_Left	wheel revolution to the left (degrees)	Simulator
sex	person genre (1:female, 0:male)	Questionnaire
dr_exp	driving experience (0:1 to 4 years, 1: 5 to 9 years)	Questionnaire
dist_week	weekly mileage (0:under the average, 1:above the average)	Questionnaire
like	enjoy driving (1:yes, 0:no)	Questionnaire
never	never drive in rural roads (1:yes, 0:no)	Questionnaire
rarely	drive rarely in rural roads (1:yes, 0:no)	Questionnaire
often	drive often in rural roads (1:yes, 0:no)	Questionnaire
db_change	change of driving behaviour while driving in rural roads (1:yes, 0:no)	Questionnaire
ACC_mob	previous involvement in a mobile phone related accident (1:yes, 0:no)	Questionnaire
ACC_mus	previous involvement in a music related accident (1:yes, 0:no)	Questionnaire
use1	driver is accustomed to use the mobile phone hand-held (1:yes, 0:no)	Questionnaire
use2	driver is accustomed to use the mobile phone with handsfree (1:yes, 0:no)	Questionnaire
use3	driver is accustomed to use a bluetooth device (1:yes, 0:no)	Questionnaire
use4	driver is accustomed to use the mobile phone by speaker (1:yes, 0:no)	Questionnaire
use5	driver is not accustomed to use the mobile phone (1:yes, 0:no)	Questionnaire
cell_phone_freq1	mobile phone use while driving many times a day (1:yes, 0:no)	Questionnaire
cell_phone_freq2	mobile phone use while driving more than once a day (1:yes, 0:no)	Questionnaire
cell_phone_freq3	mobile phone use while driving once a day (1:yes, 0:no)	Questionnaire
cell_phone_freq4	mobile phone use while driving once a month (1:yes, 0:no)	Questionnaire
cell_phone_freq5	never use a mobile phone while driving (1:yes, 0:no)	Questionnaire
dang1	driver considers talking on the mobile phone as a non risk activity (1:yes, 0:no)	Questionnaire
dang5	driver considers talking on the mobile phone as a high risk activity (1:yes, 0:no)	Questionnaire
beh1	driver does not change driving behavior when talking on the mobile phone (1:yes, 0:no)	Questionnaire
beh2	driver stops the vehicle when talking on the mobile phone (1:yes, 0:no)	Questionnaire
beh3	driver decreases speed when talking on the mobile phone (1:yes, 0:no)	Questionnaire
beh4	driver does not talk on the mobile phone while driving (1:yes, 0:no)	Questionnaire
corr1	correct answer at the difficult phone call question (1:yes, 0:no)	Questionnaire
corr2	correct answer at the easy phone call question (1:yes, 0:no)	Questionnaire
trouble_call1	trouble answering the difficult phone call question (1:yes, 0:no)	Questionnaire
trouble_call2	trouble answering the easy phone call question (1:yes, 0:no)	Questionnaire
low	driver is accustomed to listen to low volume music while driving (1:yes, 0:no)	Questionnaire
medium	driver is accustomed to listen to medium volume music while driving (1:yes, 0:no)	Questionnaire
high	driver is accustomed to listen to high volume music while driving (1:yes, 0:no)	Questionnaire
like rock	driver likes rock music while driving (1:yes, 0:no)	Questionnaire
nice	driver likes the music excerpt (1:yes, 0:no)	Questionnaire
annoying	driver considers the music excerpt as annoying (1:yes, 0:no)	Questionnaire
uninteresting	driver considers the music excerpt as uninteresting (1:yes, 0:no)	Questionnaire
dr mus	frequency of listening to music while driving (0:often, 1:always)	Questionnaire