Mobile Phone Use, Speed and Accident Probability of Young Drivers

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Abstract
In this paper, the interrelation between handheld mobile phone use, driver speed and accident probability is investigated. A driving simulator experiment was carried out, in which young participants drove in different driving scenarios: urban and interurban areas, good or rainy weather, with or without the occurrence of unexpected incidents. Log-normal linear regression methods were used to analyze the influence of mobile phone use and other parameters on the mean speed of drivers. Binary logistic regression models were used to analyze the influence of mobile phone, change in speed and other parameters on accident probability. The results suggest that mobile phone use leads to statistically significant overall decrease of the mean speed. However, some drivers increased their speed during the mobile phone conversation, a case which has received little attention in the literature. Mobile phone use leads to significant increase of accident probability, indicating that the speed reduction when using a mobile phone is not sufficient to counterbalance the overall increased risk, especially when an unexpected incident occurs. The odds of accident occurrence at an unexpected incident while using a mobile phone and driving were found to be almost 5 times higher compared to not using a mobile phone. Young drivers did not present a significantly different mean speed in rainy conditions; however, they had higher odds of accident occurrence in rainy conditions. It was indicated that a combination of increase in speed, use of mobile phone and adverse weather conditions makes accident avoidance in case of an unexpected incident very difficult.

Keywords - mobile phone; driving simulator; speed; accident probability; young drivers.

1. Background and objectives

Driver distraction is observed when a driver's attention is, voluntarily or involuntarily, diverted away from the driving task by an event or object, to the extent that the driver is no longer able to perform the driving task adequately or safely [34]. More specifically, driver distraction involves a secondary task, distracting driver attention from the primary driving task [12, 39] and may include four distinct elements: visual, acoustic, motor and mental distraction [32], which are often difficult to isolate.

Existing research has revealed that approximately 30% of drivers that were involved in a road accident reported some source of distraction before the accident occurred [25]. The penetration of various new technologies inside the vehicle (mobile telephones, navigation systems, sound system, other systems of assistance of driving etc.), but also the expected increase of use of such technologies in the next years, makes the further analysis of their influence on the attention of drivers, on traffic behaviour and on road safety very important [27].

During the last decades, a large number of studies were carried out aiming to investigate the impact of mobile phone use on driving performance, either in natural or in simulated driving environment, or on the basis of self-reported data. Several studies identified significant effects of hand-held or hands-free mobile phone on various driving performance measures. Haigney et al. [16] found that mean speed and the standard deviation of acceleration decreased while participants were conversing on the mobile phone. Yannis et al. [45] carried out a field survey, where young drivers' behaviour was recorded while they were actually driving inside a University

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campus, and found that mobile phone use was associated with reduced speed and increased vehicle headways, both in interrupted and uninterrupted traffic flow conditions. Alm and Nilson [1] investigated the effects of mobile phone use on drivers' reaction time, lane position, speed, and mental workload. The strongest effects were identified when drivers were engaged in a relatively easy driving task, where findings showed that mobile phone use had a negative effect on reaction time and led to a considerable reduction of speed. Rakauskas et al. [31] used a driving simulator to determine the effect of easy and difficult cell phone conversations on driving performance, and found that cell phone use caused participants to have higher variation in accelerator pedal position, drive more slowly with more variation in speed, and report a higher level of workload regardless of conversation difficulty level.

In other related studies, hand-held and hands-free modes are compared with other types of in-vehicle impairment or distraction. Burns et al. [5] studied the impairment caused from hands-free and hand-held phone use in relation to the decline in driving performance caused by alcohol. It was found that driver reaction was 30% slower when using a mobile phone while driving, compared to driving with BAC levels of 80mg/100ml, and by 50% slower compared to non-impaired driving. Rosenbloom [36] 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. Another simulator study compared two phone modes (i.e. hand-held vs. hands-free) in various environments [44], and found that speed was reduced while using the mobile phone in all driving environments for hand-held mode, but only in two different environments for hands-free mode, namely in a rural environment and in a complex urban environment. On the other hand, the results in Burns et al. [5] showed a clear trend of significantly poorer driving performance (in terms of speed control and response time) when using a hand-held phone, whereas hands-free phone conversation was better than hand-held. Hancock et al. [17] conducted a simulator experiment, in which drivers had to answer their mobile phone while at the same time they had to make an important stopping decision. The results showed significantly slower reaction times to a stop-light in the presence of the mobile phone distraction task, leading to increased violations of the stop-light.

Furthermore, many researchers [14, 19, 23, 11, 24, 46, 30, 13] analysed the effects of mobile phone use on driver behaviour by means of meta-analyses and literature reviews. Caird et al. [8] focus on a detailed meta-analysis of the effects of the different tasks involved in mobile phone use (e.g. handheld, hands-free, talking, listening, dialing, typing, searching etc.) per driving performance measure and per research method, and report a mean increase in reaction time of 0.25 seconds to all types of phone-related tasks while driving, estimated on the basis of meta-analysis.

Only a few studies analyzed the effect of mobile phone use directly on road safety. In McEvoy et al. [25], all participants had been involved in road accidents necessitating hospital attendance. It was found that mobile phone use up to 10 minutes before a crash was associated with four times higher likelihood of accident occurrence. Similar results were obtained by Redelmeier and Tibshirani [33], who found that using a mobile phone was associated with accident risk that was about four times higher compared to the risk of the same drivers when not using a mobile phone. Lam [22] reported that the road accident injury risk of young drivers using a mobile phone was estimated to be almost 2.5 times higher compared to not being distracted by a mobile phone.

Moreover, only a few studies have examined the effects of mobile phone use on young drivers' behaviour in particular. Young drivers are known to be a particularly high risk group in terms of road safety, and the penetration and use of mobile phone while driving among younger age groups is notably higher [43, 47]. Antonopoulos et al. [2] analysed the self-reported risky driving habits and previous accident involvement of university students from Italy and Greece, and found that the frequent use of mobile phone while driving was associated with about 50% increased probability of accident involvement.

Strayer and Drews [40] found that both younger and older drivers were impaired by mobile phone conversations and reduced their speed. On the other hand, Horberry et al. [18] examined the distracted driving performance of different age groups and found that older age groups reduced their speed more while distracted by a mobile phone conversation than younger age groups, allowing themselves a larger safety margin. Furthermore, Kass et al. [20] examined the impact of cell phone conversation on situation awareness and performance of novice and experienced drivers, in terms of the number of driving infractions committed such as speeding, collisions, pedestrians struck, stop signs missed, and centerline and road edge crossings. The results indicated that novice drivers committed more driving infractions and were less situationally aware than their experienced counterparts during the cell phone conversation. Schlehofer et al. [38] explored psychological predictors of cell phone use while driving for college students and mobile phone use was found to reduce their performance on a simulation task. Reimer et al. [35] examined the impact of distractions on young adult drivers with attention deficit hyperactivity disorder (ADHD) resulting that drivers with ADHD had more difficulty on the telephone task, yet did not show an increased decrement in driving performance greater than control participants.

Summarizing the findings from the above studies, mobile phone use while driving may significantly affect various measures driver's behaviour and safety, however, the interrelation between the change of speed and accident probability while using a mobile phone has not been explicitly examined. Moreover, the particular case of the effect of mobile phone use on driver's performance during an unexpected incident, and the resulting probability that this incident turns into a road accident, have not been extensively addressed. In a few recent researches, reaction time to incidents is used as a proxy of safe driving performance during a mobile phone conversation, both in simulator studies [5, 21], and in naturalistic driving studies [29, 10].

Within this context, the present research aims to investigate the interrelation between mobile phone use while driving, speed and accident probability by means of a driving simulator experiment on a group of young drivers. In particular, the research aims to analyse the effect of mobile phone use in combination with the effects of the road and traffic environment (urban, interurban), weather conditions (good weather, rain), driver characteristics (gender, annual mileage, driving habits) and incident occurrence.

This research focuses on young drivers, a particularly high risk group, whose distracted driving behaviour and accident risk while distracted have not been adequately examined in the literature. First, the effect of mobile phone use on young driver's speed is modelled, and subsequently the related accident probability is modelled in relation to both mobile phone use and the change in driver's speed. It is noted that in the present research mobile phone use involves answering a handheld phone, talking and listening, whereas dialing or typing is not examined.

2. Methods and data

2.1. Equipment

A simulator experiment was designed and carried out for the objectives of the present research (for details the reader is referred to [37]). The NTUA driving simulator is a dynamic quarter-cab simulator of the Foerst Company. The simulator consists of 3 LCD wide screens 40’’ (full HD: 1920x1080pixels), a driving position and support motion base. The dimensions at a full development are 230x180cm, while the base width is 78cm and the total field of view is 170 degrees. Although the driving conditions in the simulator cannot be absolutely similar with those that drivers may actually experience on the road [7], the relative influence of the various parameters on driver's behaviour and safety are not expected to be significantly affected by the use of a simulator. In fact, the NTUA simulator was recently validated against an on-road experiment and relative validity was satisfactory [26].

2.2. Experiment participants

The experiment concerned the behaviour of 30 young drivers aged between 18 and 30 years, out of which 17 were males and 13 were females. All drivers held a driving licence and had a mobile phone, which they regularly used in hand-held mode (although they also reported using a hands-free or Bluetooth mode as well), and were students (80%) or graduates of the National Technical University of Athens. None of them presented any visual problems, or other medical condition (including medication) that might affect their performance at the simulator.

Before driving the simulator, the participants completed a questionnaire comprising questions related to their personal characteristics, their driving habits, especially as regards mobile phone use (e.g. frequency of using mobile phone while driving, behaviour during mobile phone use etc.), and their perception on the risk associated with the use of mobile phone while driving. Thereafter, they were asked to drive in different simulated scenarios as they would do in actual conditions. It is noted that, at the time the experiment took place (2010), mobile phone use while driving was not prohibited by law in Greece.

2.3. Experiment design and procedures

Before the experiment drive, all participants had a practice drive in a random route on the same "map" of the simulator; during this route, they got familiar with the road geometry and moderate traffic conditions of the experiment drive, but were free to choose the route (e.g. by making turns) and test the simulator vehicle (e.g. start and stop, brake and accelerate etc.), however no phone calls or unexpected events occurred during the practice drive. In most cases, the practice drive lasted approximately five to seven minutes, a time in which participants reported feeling familiar with the simulator environment and able to drive the simulator vehicle.

The selected route (Figure 1) included two interurban sections with very mild horizontal curves, separated by a mostly straight urban section, under the "moderate traffic" default scenario of the simulator, with speed limit of 100 km/h in the interurban section and 70 km/h in the urban section. This route simulates the driving through a small town during a trip along a rural road. Subsequently, participants drove the experiment route twice. Each drive, one in good weather conditions and one in rainy weather conditions, lasted approximately four minutes. During both drives, participants had to answer their handheld mobile phone every time it rang. Half of the participants were tested under good weather conditions first, and the other half was tested under rainy conditions first, in order to minimise order effects.

Figure 1 to be inserted here

The phone calls took place at fixed points along the route, specified on the basis of specific length points (i.e. the mobile phone rang at exactly the same location along the route for all drivers), and no change in road alignment, traffic signing or traffic occurred along the road sections during the phone calls. The phone calls' duration was usually 30-40 seconds. It is noted that the participants in the study were obliged to answer the mobile phone when it rang, regardless of their actual driving habits, and this may be assumed to be more demanding compared to real life situations for some of the participants [44].

A trained and experienced surveyor, located in a different room, was responsible for the calls and for the experiment progress. He filled in a form, in which he marked the time that the phone calls took place and their duration. The aim of the calls was to distract drivers, so the answers required some mental effort. Previous research has shown that the degree to which a mobile phone call affects the driver performance largely depends on the subject of discussion. For this reason, during the mobile phone conversation, the surveyor asked the drivers to provide instructions about how someone could drive from a known point of the city of Athens to another.

Moreover, during the experiment, incidents were activated at random points of the selected route, namely the sudden appearance on the road of an animal (in the interurban sections) and the unexpected opening of the left door of a parked vehicle (in the urban section).

For each driver, there were two incidents in the good weather drive and two incidents in the rainy weather drive. As the interurban road section was longer than the urban road section, the number of incidents that occurred in the interurban road section was higher overall. Incidents were not scheduled to occur at specific locations or time points, however care was taken that no other confounding factor was involved at these locations (e.g. horizontal curve, opposite traffic, traffic sign or signal, heavy goods vehicle etc.). Furthermore, incidents were not by design associated with the use of mobile phone or not, i.e. not all drivers had an incident both while talking on the mobile phone and while not talking. This option to randomly activate incident occurrence was opted for, in order to minimise carryover effects between the various tasks, e.g. learning effects, habituation or sensitization due to frequent exposure, and minimize sample power requirements that are involved in the analysis of within-subject variables. This type of incidents design is considered to be closer to real world incidents, which also occur randomly to drivers while using a mobile phone or not. It is noted, however, that with this design, since response to incidents and the related accident probability are no longer within-subject variables, they should be interpreted accordingly.

2.4. Analysis methods

The aim of the present research is to investigate the interrelation between handheld mobile phone use, young driver speeding behaviour and road accident probability with the use of driving simulator. The effects of mobile phone use are examined in combination with the traffic environment (urban / interurban), the weather conditions (good / rainy weather), driver characteristics, self-reported driving behaviour and incident occurrence while driving.

Six models were initially developed, in order to analyse the impact of mobile phone use on young drivers' behaviour and safety in terms of speed and accident probability. All the models were fitted by means of the SPSS v21 statistical software. In particular, log-normal linear regression models were developed for mean speed, as the common (i.e. base 10) logarithm of speed was found to conform to a normal distribution. Moreover, binary logistic regression models were developed for accident probability; these are typical models for modelling the outcomes of binomial trials (i.e. accident occurrence vs. non occurrence), including the cases of rare events [15]. In each case, separate models were fitted for urban and interurban areas. However, preliminary attempts revealed that these separate models were not meaningful, due to the small sample size, and therefore two global models, one for speed and one for accident probability are presented; in these models, area type is included as an explanatory variable.

Moreover, the repeated measurements of driving behaviour (2 drives) on a small group of drivers may have induced some unobserved heterogeneity, which was tested in the early stages of models development by means of a random intercept but was not found to be significant.

In binary logistic regression models, parameter estimates β_k represent the mean change in the log-odds for a unit change in x_k, holding other explanatory variables fixed; therefore the odds ratios can be calculated as $\exp(\beta_k)$; these are used for the assessment of the relative effect of different variables on accident probability.

The variables were extracted either from the simulator's data recordings of the two routes or from the survey questionnaire. A large number of variables was available, as shown in Table 1, where the variables available from the output of the simulator range from 1 to 25, and the variables obtained from the questionnaire range from 26 to 50. Nevertheless, not all variables were considered in the analysis. A variables selection procedure was implemented as follows: univariate tests were initially carried out, in which each variable was tested alone and its statistical significance was determined by means of a t- or Wald test. Then, for the statistically significant variables of the univariate analysis, correlation tests were carried out in order to identify correlated variables. In case two or more variables were correlated, the variable to be included in the model was selected on the basis of its statistical significance and its relevance to the objectives of the analysis. In this way, the sets of explanatory variables to be included in the multivariate models were defined.

A variable was kept in the final model if the corresponding parameter estimate was significant at 90% confidence level, by means of t- or Wald- tests – a more relaxed confidence level was considered acceptable for the present analysis, given the relatively small sample size. The quality of the model was determined by means of the R^2 coefficient for the linear regression models and by means of the likelihood ratio test (LRT) for the binary logistic regression models. In particular, the final binary logistic regression models were compared to the 'null' (i.e. empty) ones, by comparing the likelihood ratio (i.e. the difference in log-likelihood) with the value of a chi-square distribution with degrees of freedom equal to the difference in the number of parameters between the 'null' and the final model [3].

Table 1 to be inserted here

3. Results

3.1. Descriptive analysis

The information collected from the questionnaire and the simulated drive (i.e. output variables of the simulator) is presented below. The self-reported frequency of mobile phone use while driving is shown in Table 2. It is observed that, while only 17% of the participants use their mobile phone for making or answering calls while driving many times per day, 67% of them use their mobile phone while driving at least once a day. This is a considerable proportion, when taking into account that 40% of the participants have driving experience less than 4 years and that the majority of participants (i.e. 70%) drive more than 5,000 Kilometres annually (also shown in Table 2). These findings suggest that most of the participants are active drivers and frequent mobile phone users while driving. Consequently, the experiment is not expected to be biased due to unfamiliarity of participants with the use of mobile phone while driving.

Moreover, a positive and statistically significant correlation coefficient was calculated between frequency of mobile phone use and annual mileage: more annual mileage was associated with more frequent phone use while driving (Spearman ρ=0.54, p-value=0.000). This suggests that annual mileage should be controlled for in the statistical analysis, as it is a covariate of the effect of mobile phone use while driving. Certainly, other measures, such as the frequency of trips and the patterns of using the mobile phone while driving (e.g. number and duration of calls) could have been informative. It is possible that the frequency of mobile phone use while driving is also related to the type and duration of daily trips (e.g. the daily use of phones while driving may suggest that many short trips are a more common pattern than a few long trips).

Table 2 to be inserted here

Table 3 shows the mean and standard deviation of speed and the frequency and percentage of incidents that resulted in accidents by area type, mobile phone use and weather conditions, as recorded in the simulator experiment. Mean speed appears to be higher in interurban areas compared to urban areas; moreover, mean speed is higher when not using a mobile phone while driving, both in urban and interurban areas. There appears to be no difference in mean speed in relation to weather conditions.

However, the standard deviations of speed in all cases (i.e. interurban vs. urban area, with or without mobile phone) are rather large, suggesting that statistical analysis is required in order to assess whether these differences are significant.

As regards accident occurrence, a clear pattern is identified. In particular, unexpected incidents are more likely to result in accidents when using a mobile phone, especially in rainy weather conditions. Overall, out of 117 incidents that occurred to all drivers in total during the simulator experiment, 19 (i.e. 16%) resulted in a road accident. It should be remembered that that incident occurrence during the simulator experiment was random, i.e. not scheduled to take place at fixed points along the route. Moreover, the length of the drives in interurban areas was longer than the length of the drives in urban area, and this accounts for the larger number of incidents in interurban areas.

Table 3 to be inserted here

3.2. Models development

The model developed for mean speed is presented in Table 4, in which the parameter estimates (β) and the related p-values are presented for each variable, together with the R^2 coefficient. The respective model for accident probability is presented in Table 5; in this case LRT results and odds-ratios are reported for each model.

3.2.1. Modelling mean speed

Three different log-normal linear regression models were initially developed for drivers' mean speed: one for the total route which comprised both urban and interurban areas, one for the urban section of the route and one for the interurban section. However, the separate models for urban and interurban areas included very few significant parameters, and are not presented here. It is noted that given the log-transformation, mean speed is the geometric means instead of the customary arithmetic means. Mean speed was calculated for each combination of conditions, i.e. interurban / urban, good weather / rain, using a mobile phone or not.

As mentioned above, the explanatory variables were tested in univariate models first. The statistically significant variables in the univariate analysis included the use of mobile phone, the annual mileage, the lateral position (i.e. distance from the central axis and the right road board), the headspace and time to collision, and several variables directly related to drivers speed, namely the acceleration, the % use of the gears, the motor revolutions per minute, exceeding the speed limit, the ran-off road and the accident occurrence, the self-reported driving speed in urban and interurban areas etc. They also included the self-reported speeding behaviour of drivers when using a mobile phone.

These variables were tested for multicollinearity. The lateral position (i.e. distance from the central axis, distance from the right border) and the ran-off road were found to be correlated with one another, and with exceeding the speed limit. Time to collision and headspace were found to be correlated with the acceleration and the use of the gears. All the variables related to drivers' speed, as outlined above, were found to be correlated with one another. These correlations were confirmed by means of the calculation of the related correlation coefficients.

On the basis of these results, exceeding the speed limit was selected as a most useful and representative variable of driver speeding behaviour, to be included in the final model. The parameter estimates, and their p-values - indicating the confidence level at which each variable can be considered statistically significant - in the final model are summarized in Table 4.

Table 4 to be inserted here

The results suggest that mean speed is generally lower in urban areas, which is intuitive. Moreover, young drivers exceeding the speed limit have higher mean speeds overall; however, this effect was not found to be significant in urban areas, possibly due to lower speed limits, lower speeds and less frequent exceeding of speed limits in urban areas.

The use of mobile phone is found to lead to statistically significant decrease on the mean speed in total, confirming many previous studies. The effect of the use of mobile phone was however more pronounced in urban areas; young drivers decreased their speed more during the phone calls in urban areas, making thus a stronger effort to compensate for the distraction caused by the use of mobile phone while driving in a more complex road and traffic environment. In interurban areas, the effect of mobile phone use on speed was not statistically significant at 90% confidence level.

According to the results of the simulator experiment, mobile phone use results in speed decrease for most young drivers, but not for all of them; some young drivers increased their speed while using their mobile phone, as also observed in Rosenbloom et al. [36]. In the present experiment, an increase of speed while using the mobile phone was observed in 8 out of 60 observations[2] in interurban areas and in 3 out of 60 observations in urban areas (i.e. around 10% in total). This small proportion of drivers increasing their speed might not be worth noting given that, overall, the use of mobile phone was statistically associated with a decrease in driver speed. However, the case of speed increase while using the mobile phone, even by a small proportion of drivers, has received very little attention in the literature, although the consequences may be very important, as will be shown later in this paper.

The modelling results also reveal that young drivers who reported that they reduce their speed when making or answering mobile phone calls, drive at slightly higher mean speed overall. These drivers may be more likely to acknowledge that their increased speed needs to be adjusted when using a mobile phone while driving. Moreover, it is observed that young drivers with increased annual mileage drive at higher speeds in total, probably because of increased confidence due to their driving experience. This effect was statistically significant in the separate model for urban areas (not presented here) but in interurban areas the effect was not statistically significant. It is noted that preliminary analysis indicated that the annual mileage is correlated with driver age and gender, and therefore these effects may be reflected in the effect of annual mileage as well.

Moreover, it was found that drivers who were tested in good weather on the 1st drive and in rainy weather on the 2nd drive had lower mean speed overall. This may be attributed to unfamiliarity with the road on the 1st drive and to adverse weather on the 2nd drive. It is noted however that the rainy weather by itself was not found to be statistically significant in any speed model. It is thereby indicated that the combination of good weather conditions and familiarity with the road environment may result in increased driving speed. It is also noted that, although the experiment was counterbalanced for rainy conditions, there was still an order effect which was captured by this variable.

3.2.2. Modelling accident probability

Accident risk was modelled as a binary variable, equal to one when an accident occurred as a result of an unexpected incident during the simulated drive, and equal to zero otherwise. Since incidents were triggered at random locations and were not designed as within-subject variables, it should be underlined that the estimated accident probability does not correspond to the individual driver accident risk, but to the global road network accident risk, for the examined population and the examined conditions.

Three different binary logistic regression models were initially developed, one for each driving environment (urban and interurban) as well as a global one. However, due to the low number of accidents that occurred in the urban section, the separate models were not particularly meaningful and are not presented here.

In order to model the interrelation between mobile phone use, young driver speed and accident probability, a new variable was defined and tested in the models, namely the reduction in driver's speed during mobile phone use. This variable was found to be statistically significant in the univariate analysis. Consequently, given that the change in driver speed is included as explanatory variable in the model, all other variables that are strongly correlated with driver speed (e.g. acceleration, headspaces, lateral position, annual mileage, etc.) were not considered.

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[2] 60 observations correspond to 1 observation per weather conditions (good or rainy) for each one of the 30 participants.

The final results of the models are shown in Table 5, which includes the parameter estimates, their p-values, the estimated odds-ratios and their 95% confidence intervals.

Table 5 to be inserted here

The occurrence of an incident while using a mobile phone increases the odds of being involved in an accident during the drive. More specifically, incident occurrence while talking on the mobile phone results in increased odds of having an accident in total. It is observed that the odds of accident occurrence when an incident occurs while talking on the mobile phone are almost 5 times higher (odds ratio equal to 4.76) in relation to the odds of accident occurrence while not talking on the mobile phone.

It was also found that the percentage reduction of speed while using a mobile phone leads to slight decrease of the odds of accident occurrence in total (odds-ratio equals 0.95). In fact, a higher speed reduction when using a mobile phone results in lower odds of accident occurrence. It is likely that participants who drove slower while talking on their mobile phone compared to not talking may have had more time to react to incident occurrence. This effect can also be attributed to drivers' attempt to compensate the increased requirements for cognitive effort during the use of a mobile phone while driving, especially in urban areas. It is therefore noted that, despite the significant speed decrease during the mobile phone conversation, leading to an initial decrease of the odds of accident occurrence, the accident risk increases in case of incident, especially when using the mobile phone. In particular, the odds of accident occurrence is reduced by 5% for each percentage unit reduction in speed; it is reminded, however, that the odds of accident occurrence at incidents are almost 5 times higher while talking on the phone compared to not talking. It is thereby indicated that the effect of incident occurrence on accident risk is much stronger than the effect of speed reduction, during the mobile phone use.

The self-reported driving behaviour concerning mobile phone use was also strongly related with the odds of accident occurrence. It was found that those participants, who reported that they never use their mobile phone while driving, presented almost 30 times higher odds of being involved in an accident (odds-ratio equals 29.375). Obviously, young drivers who were not used to answering their mobile phone while driving could not cope with the compulsory use of mobile phone during the simulated drive.

Additionally, it appears that participants have higher odds of being involved in an accident in rainy conditions in total (although the effect of rain in the separate models for urban and interurban areas was not significant). In particular, the odds of accident occurrence in rainy weather are more than 3 times higher than the respective odds in good weather (odds-ratio equals 3.26). Given that rainy weather was not found to affect drivers' speed, the increased accident risk in rainy weather may be attributed to poor visibility, pavement conditions etc.

Moreover, it was found that young drivers presented in total by 75% lower odds of accident occurrence during the first drive of the experiment (i.e. 1st drive odds-ratio equals 0.26) and this could be explained by the fact that accidents may be more likely to happen when drivers feel accustomed with the route and thus drive with less attention. Again, a "residual" order effect is captured by this variable.

It is noted that, although odds ratios and probabilities are related, they are not the same; an odds ratios is mathematically more extreme (i.e. farther from 1) than the corresponding ratio of probabilities. In order to assess the effect of the examined variables on accident probability, the estimated outcomes of the binary logistic regression were further explored.

Figure 2 presents a sensitivity diagram summarizing the interrelation between the effects of mobile phone use while driving, change in speed, and accident probability. More specifically, the results presented in Figure 2 concern the estimated probability of accident at road network level, in case of incident occurrence when using a mobile phone while driving, in good and in rainy weather conditions. It can be seen that speed reduction decreases the probability of an accident, but it can not fully compensate for the increased risk of using a mobile phone while driving. As mentioned previously, some young drivers may as well increase their speed while using the mobile phone; it can be seen in Figure 2 that these drivers have a very low probability of avoiding accident occurrence, in case of an unexpected incident.

It is noted that speed increase during the mobile phone conversation was generally observed in cases of relatively low initial speeds. For instance, the maximum speed increase was from 49 to 56 km/h (15% increase) in interurban areas and from 31 to 45 km/h (45% increase) in urban areas. Accordingly, the maximum speed decrease was from 63 to 41 km/h (34% decrease) in interurban areas and from 75 to 30 km/h (60% decrease) in urban areas. However, due to the small number of observations towards the limits of the range of the changes in speed, these minimum and maximum values are not considered in the sensitivity diagram of Figure 2.

It is also shown that the probability of an accident is higher when young drivers use their mobile phone in rainy conditions, as they have to deal with two risk factors at the same time, plus the occurrence of an incident. In this case, the accident risk slope rises rapidly even for a small change on speed while talking on mobile phone. It is also noted that the accident probability in rainy conditions when not using a mobile phone is lower than the accident probability in good weather when using a mobile phone.

Figure 2 to be inserted here

4. Conclusion

The research replicates previous findings, but also contributes some new insights:

- the change in speed, as a compensatory strategy when using mobile phone is introduced as an explanatory variable in the accident probability model, directly linking the speed change due to mobile phone use with crash risk;
- this allows for the first time to examine a particular type of behaviour, namely of drivers who increase their speed during the mobile phone use. In existing studies, an overall speed reduction is typically identified, and the fact that some of the drivers may increase their speed is overlooked;
- the effect of weather in mobile phone use while driving has received practically no attention in previous studies, and is examined in the present study (with the known weaknesses of a simulated weather).

It was concluded that driving behaviour and safety are both affected by the use of mobile phone. Most drivers decrease their speed while using their mobile phone, especially in urban areas. The experiment data analysis showed that mobile phone use leads to lower speed by approximately 28% in urban environment and 7% in interurban environment. This effect is in line with results from several previous researches (see meta-analysis in [8]) and can be attributed to the fact that drivers attempt to compensate for the increased requirements for cognitive (and motor) workload and effort coming from the use of a mobile phone while driving. However, the experiment results also suggest that some young drivers may also increase their speed during a mobile phone conversation.

Speeding behaviour was found to be correlated with vehicle lateral position and headspaces, further reflecting the effects of mobile phone use on driving behaviour (i.e. reduced speeds are correlated with smaller distance from the road right border and longer headspaces). Additionally, it was observed that the mean speed was also affected by drivers' characteristics and self-reported behaviour. The compliance to the speed limits, the annual distance travelled and the drivers' habits referring to the use of mobile phone while driving were found to influence mean speed.

Overall, it can be said that there are two basic variables affecting driver speed, namely the road environment (urban or interurban) and the tendency to exceed the speed limit. These variables capture the general speeding behaviour of young drivers. Additional effects related to personal characteristics and particular behaviours on speed were estimated. These additional effects include annual mileage, self-reported behaviour as per the use of mobile phone, actual use of the mobile phone and familiarity with the road during good weather conditions.

The use of mobile phone while driving was found to have an impact on accident probability. More specifically, young drivers' attempt to compensate for the increased workload while talking on the mobile phone, by reducing their speed (and possibly adjusting their headspace and lateral position), cannot counterbalance the increased probability of an accident. It was further indicated that the combination of use of mobile phone, increase in speed and adverse weather conditions in case of an unexpected incident, makes accident avoidance very difficult.

Young drivers, who reported that they never use a mobile phone while driving, were more likely to be involved in an accident during the simulator experiment, obviously due to the fact that they were obliged to answer their mobile phone during the experiment, a dual task to which they were not accustomed.

In rainy conditions, most drivers did not present different driving behaviour in terms of speeding compared to good weather conditions, but still had increased odds of being involved in an accident. In fact, a combination of good weather conditions and familiarity with the road was the only case of significant effect of weather on driver speed.

Overall, when an unexpected incident occurs the mobile phone use constitutes an important accident risk factor, as accident probability is almost 5 times higher compared to not using a mobile phone. It is thus indicated that the negative effects due to mobile phone use cannot be compensated by the drivers' attempts to reduce their speed. Several studies suggest that distracted drivers attempt to self-regulate by reducing their speed [8, 28, 42]. These studies clearly suggest that these strategies very often fail, as the critical performance measure that affects accident probability if is reaction time at unexpected incidents (e.g. abrupt or in contrary sluggish brake reactions), which is significantly impaired by mobile phone use.

5. Limitations and future research

The present research has some limitations: the sample of participants may not be representative of the general young drivers' population (due to all of them being NTUA students or graduates) and no formal screening tools were used to validate the participants' fitness (e.g. visual acuity tests). Due to the small sample size for the development of statistical models, the number of selected explanatory variables was kept at a minimum. The thorough analysis of the correlations among many of the selected variables was necessary for this purpose. Moreover, although individual heterogeneity was tested and found non significant, an alternative – yet more computationally demanding – approach might have been to consider some random parameters, i.e. allowing the parameter estimates to vary across the individuals. This would also allow to better address the quasi-random representation of the incidents occurrence, and this will be pursued in the future.

Another point that should be noted is that the specific experiment was quite demanding in terms of the use of the mobile phone while driving. As in several simulator experiments on mobile phone use, the distracted driving task may be heavy in terms of number and duration of phone calls [20, 6, 38], due to the need to measure adequately the parameters of interest while keeping the duration of the experiment to a minimum. Although most of the participants were very active drivers, and they reported a relatively high frequency of mobile use while driving, the number and length of phone calls in relation to the length of the drives may have been somewhat heavy in relation to the everyday driving habits for some of the participants. It should be also acknowledged that, in the present experiment, the smaller overall length of the urban section, compared to the interurban section, may have induced increased workload on participants, due to lower familiarity with the urban area during the mobile phone task; this is an interesting topic for further investigation.

In general, even in an optimally designed simulator experiment, drivers may not fully perform as they would in actual conditions, as the feeling of speeding, rainy weather etc. can not be fully represented, and this is a know limitation of simulator experiments.

It would be interesting for further research to be carried out using a similar experiment on a larger sample with participants of different age groups. Research results suggest that, while young drivers may show an increased ability to share attention between two concurrent tasks than older ones, they are more vulnerable to the effects of distraction [46]. Moreover, different driving environments and different traffic conditions should be further investigated, given that impairment due to mobile phone use appears to increase in more complex road environments (e.g. urban areas, unfamiliar environment), more traffic density, adverse weather conditions etc. [9, 41].

In this framework, it will be pursued to examine to whole 'chain' of driving behaviour and safety, from changes in speed (e.g. mean speed, speed variability) to resulting adjustments in lateral position (indirectly considered in the present research), to driver response at incidents (e.g. reaction time, reaction type etc.) and to the eventual accident probability. Reaction time models were attempted in the present research, but the effect of mobile phone use on reaction time was not found to be significant; this could be partly attributed to the simulator failure to properly record reaction time in several of the incidents triggered in this experiment. Nevertheless, this is a most critical question for further research, in order to complete the picture of driver distraction, behaviour and risk.

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Table 1. Variables and values examined in the analysis

	Variable	Values
1	RAINY	rainy weather (1:yes, 0:no)
2	URBAN	urban area (1:yes, 0:no)
3	MOBILE	mobile phone use (1:yes, 0:no)
4	spur_av	mean distance from the central axis (m)
5	sp_av	mean speed (Km/h)
6	sp_max	maximum speed (Km/h)
7	brk_D	% route the brake was used
8	acc_D	% route the accelerator was used
9	g1, g2, g3, g4, g5	% route the 1st, 2nd, 3rd, 4th, 5th gear was used
10	rpr_av	mean motor revolution per minute
11	HW_av	mean headspace (m)
12	DL_av	mean distance from the right board (m)
13	TH_av	mean headway (sev)
14	TTC_av	mean time to collision (sec)
15	ACC_max	mean acceleration (m/sec^2)
16	EVENT	occurrence of an incident (1:yes, 0:no)
17	RT_av	mean reaction time (sec)
18	A3	accident occurrence (1:yes, 0:no)
19	OUT	ran off road (1:yes, 0:no)
20	FAST	exceeding speed limit (1:yes, 0:no)
21	speed_mob	mean speed while using mobile phone (Km/h)
22	speed_nm	mean speed while not using mobile phone (Km/h)
23	percentage_ change_speed	% reduction in speed while using mobile phone
24	event_m	occurrence of an incident while using mobile phone (1:yes, 0:no)
25	event_nm	occurrence of an incident while not using mobile phone (1:yes, 0:no)
26	age	person age (years)
27	male	person gender (1:male, 0:female)
28	d_experience	person driving experience (1: 1-4 years, 2: 5-9 years, 3:>10 years)
29	mileage	annual mileage (km)
30	USE	type of mobile phone use (1:hand-held, 2:hands-free, 3:bluetooth, 4:speaker, 5:none)
31	CALLS	frequency of mobile phone use while driving for calls (1:never, 2:once per month, 3:one per week, 4: once per day, 5: more than once per day, 6: many times per day)
32	SMS	frequency of mobile phone use while driving for sms (1:never, 2:once per month, 3:one per week, 4: once per day, 5: more than once per day, 6: many times per day)
33	ANSWER	answering mobile phone calls while driving (1:never, 2: seldom, 3:often, 4:nearly always, 5:always)
34	STOP-CALL	stopping the vehicle for making calls (1:never, 2: seldom, 3:often, 4:nearly always, 5:always)
35	STOP-SMS	stopping the vehicle for writing/reading sms (1:never, 2: seldom, 3:often, 4:nearly always, 5:always)
36	DANG-C	perceived risk of using mobile phone for calls while driving (1: very low, 2:low, 3:medium, 4:hihg, 5:very high)
37	BM_1	change of behaviour when using mobile phone and driving (1: reduce speed, 2: pull over, 3: keep right, 4:none)
38	BR_1	change of behaviour when driving at rainy weather (1: reduce speed, 2: pull over, 3: keep right, 4:none)
39	SP-U	self-reported mean speed when driving in urban areas (km/h)
40	SP-INTER	self-reported mean speed when driving in interurban areas (km/h)

Table 2. Driving experience, annual mileage and self-reported frequency of mobile phone use while driving by the experiment participants

Driving experience	**Frequency**	**Percentage**
1-4 years	12	40,0%
4-10 years	16	53,3%
>10 years	2	6,7%
Annual mileage (Km)		
< 5000	9	30,0%
5000-10000	8	26,7%
10000-15000	5	16,7%
15000-20000	4	13,3%
20000-25000	3	10,0%
>25000	1	3,3%
Frequency of mobile phone use while driving		
Never	2	6,7%
Once a month	4	13,3%
Once a week	4	13,3%
Once a day	5	16,7%
More than once a day	10	33,3%
Many times per day	5	16,7%

Table 3. Mean speed and accident occurrence per area type, mobile phone use and weather conditions

		interurban area		**urban area**		**Total**
Speed (km/h)		**no mobile phone**	**mobile phone**	**no mobile phone**	**mobile phone**	
	Mean	53	49	45	32	
	Std deviation	9.0	9.2	11.0	8.2	
good weather	Mean	53.0	50.7	44.2	32.2	
	Std deviation	8.4	10.9	7.8	9.5	
rain	Mean	51.8	50.1	44.9	32.2	
	Std deviation	9.7	11.3	10.4	6.8	
Number of incidents						
good weather		24	15	12	10	
rain		27	8	12	9	117
% **of incidents resulting in accidents**						
good weather		8.3%	20.0%	8.3%	0.0%	
rain		18.5%	25.0%	25.0%	33.3%	16.2%

Table 4. Modelling results for log-mean speed: parameter estimates and p-values

	Total	
Variables	**Parameter estimates B**	**p-value**
Constant	1.687	0.000
Urban area	-0.046	0.000
Mobile phone use	-0.160	0.000
Exceeding speed limit	0.132	0.000
Annual mileage	1.749E-06	0.034
Reduces speed when using mobile phone	0.030	0.021
2nd drive in rainy conditions	-0.024	0.027
R^2	0.781	

Table 5. Modelling results for accident probability: parameter estimates, p-values and odds-ratios.

	Total			
Variables	**βk**	**p-value**	**Odds ratio**	
			exp(βk)	**95% CI**
Constant	-2.856	0.000	-	
% reduction in speed while using mobile phone	-0.047	0.011	0.95	[0.920- 0.989]
Rain	1.180	0.045	3.26	1.028- 10.307]
occurrence of an incident while using mobile phone	1.561	0.012	4.76	1.407- 16.110]
Never using mobile phone while driving	3.393	0.000	29.75	.738- 154.193]
1st drive	1.328	0.029	0.26	[0.080- 0.875]
Null Log-likelihood	121.396			
Final log-likelihood	85.656			
Degrees of freedom	6			
Note: CI= Confidence Interval				

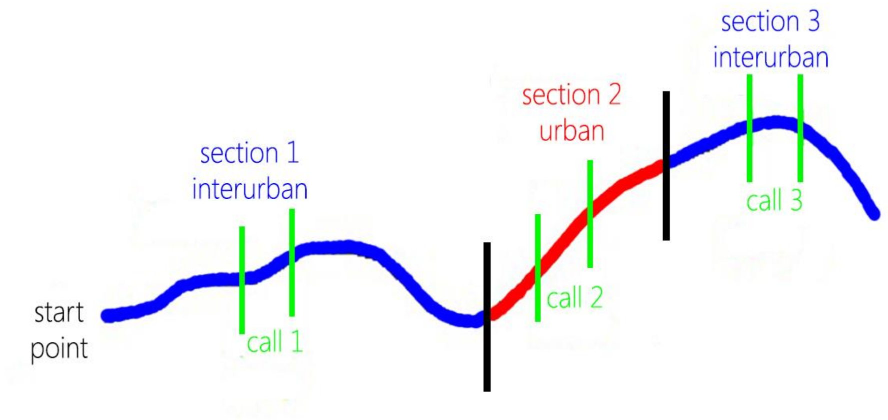

Figure 1. Alignment and characteristics of the simulated drive

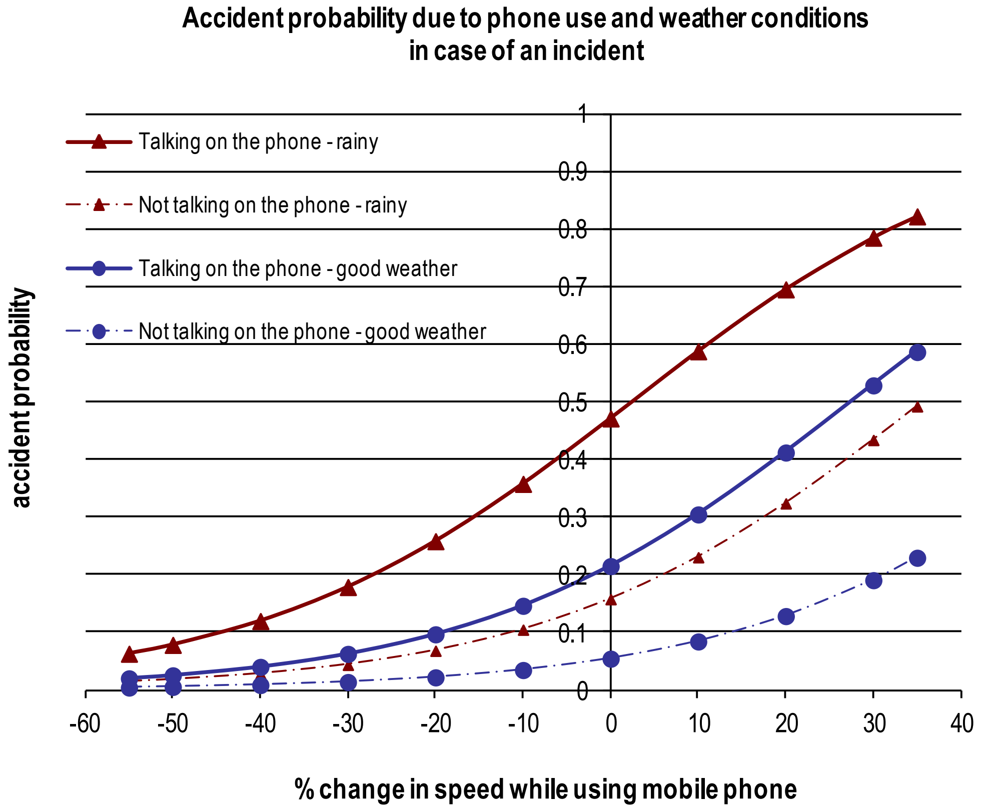

Figure 2. Accident probability in case of incident in relation to mobile phone use, change of speed and weather conditions