IS IT RISKY TO TALK, EAT OR SMOKE WHILE DRIVING? FINDINGS FROM A DRIVING SIMULATOR EXPERIMENT

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ABSTRACT

The objective of this research is the analysis of the effect of conversation, eating and smoking on driver behaviour and on road safety in rural roads. For that purpose, a driving simulator experiment was carried out, in which participants were asked to talk, eat or smoke while driving on a rural road during daytime. Driver behaviour was then analysed on the basis of three variables, namely speed, reaction time and distance from the central axis of the lane. Driver safety was analysed on the basis of accident probability. Especially as regards talking, two types of conversation were examined, a 'simple' one and a 'complex one'. Moreover, participants were asked to consume a light snack and smoke a cigarette at given points along the selected route. Unexpected incidents were also scheduled to occur at fixed points along the route. Driver speed, reaction time and distance from the central axis of the lane were modelled by means of log-normal regression models, whereas accident probability was modelled by means of binary logistic regression models. The results suggest that 'simple' conversation, 'complex' conversation, eating and smoking are all associated with decreased speeds. Moreover, 'complex' conversations were systematically associated with increased distance from the central axis of the lane, significantly increased reaction times at unexpected incidents and increased accident risk. Overall, 'simple' conversation, eating and smoking were 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. On the contrary, 'complex' conversation was found to lead to significantly higher accident probability. It can be said that the decrease in speed and the increase in distance from the central axis of the lane during the 'complex' conversations, which might be considered beneficial for road safety under certain conditions, cannot counter-balance the driver's distraction, leading to increased reaction time, and eventually increased accident probability, especially when unexpected incidents occur.

Keywords: driver distraction; driver behavior; road safety.

INTRODUCTION

According to human factors research, namely the Multiple Resource Model (Wickens, 1984), the human operator does not have one single information processing source, but several different pools of resources that can be tapped simultaneously. Depending on the nature of the task, these resources may have to process information sequentially if the different tasks require the same pool of resources, or can be processed in parallel if the task requires different resources. However, cognitive resources are limited and a supply and demand problem occurs when the individual performs two or more tasks that require a single resource. Excess workload caused by tasks using the same resource can cause problems and result in errors or slower task performance.

In this context, driver distraction occurs 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. More specifically, driver distraction involves a secondary task, distracting driver attention from the primary driving task (Donmez et al., 2006; Sheridan, 2004) and may include four distinct elements: visual (e.g. advertising signs), acoustic (e.g. radio), motor (e.g. mobile phone use) and mental distraction (Ranney et al., 2000), which are often difficult to isolate.

Driver distraction has been associated with an important proportion of road accidents, ranging from 10-15% (MacEvoy et al. 2007; Wang et al.1996) to 25% (Stutts et al., 2005). The analysis of the degree to which distraction factors may affect the behaviour and safety of drivers, has received increasing attention in the international literature. Moreover, visual and cognitive distractions affect various driving performance measures in a different way. Specifically, visual distraction (e.g. use of navigation systems) has a greater effect on lateral control measures, whereas cognitive distraction (e.g. conversation with passengers) affects visual scanning behavior to a greater degree than visual distraction (GHSA, 2011).

Driver distraction factors can be subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle). The distraction factors that occur inside the vehicle appear to have greater effect on driver behaviour and safety. Horberry et al. (2006) confirm that in-vehicle distraction sources have a more important effect on driver performance, compared to external ones. Other studies report that external distraction factors are less than 30% of the total distraction factors (Stutts et al. 2001; Kircher, 2007), or even less than 10% of all distraction factors (Sagberg, 2001; MacEvoy et al. 2007).

The in-vehicle sources of distraction include the use of mobile phone or navigation / recreation system, the conversation with another passenger, smoking, eating or drinking etc. (Johnson et al., 2004; Stutts et al. 2005; Neyens & Boyle 2008), and their effects are largely examined by means of simulator experiments (Horberry et al. 2006; Bellinger et al. 2008) or naturalistic driving experiments.

Existing research focuses on the effect of in-vehicle devices, such as mobile phones – hand-held (MacEvoy et al. 2007; Caird et al. 2008) and hands-free (Burns et al. 2002) -, navigation or other driver assistance systems and entertainment systems. The penetration of these new technologies inside the vehicle and the expected increase of use of such appliances in the next years, makes the further investigation of their influence on the attention of drivers, on traffic flow and on road safety very essential (Olsen et al. 2005).

On the other hand, the effect of other in-vehicle distraction factors has been found to be non negligible. Stutts et al. (2003) report that the frequency of driver distraction from conversation with the passengers is almost equal to the frequency of distraction by the use of mobile phone. Moreover, the results of the 100-car naturalistic driving study revealed that a driver-passenger interaction was observed in 20% of accident, near-misses and incidents recorded (Neale et al., 2005).

Haigney & Westerman (2001) suggest that, while mobile phone use and conversation are mainly distractions induced from additional mental workload, eating or drinking are “manual” activities that necessarily involve some additional motor workload; consequently, they are expected to significantly affect driving performance.

Around half of all drivers in the USA admit that they are systematically eat or drink while driving at around one third of their trips (NHTSA, 2003). Glaze & Ellis (2003) report that 4.2% of distraction related accidents in the US are due to eating or drinking, whereas respective related results from New Zealand range at around 3% (Gordon, 2005). Stutts et al. (2005) found that eating and drinking increased the hands-off-the-wheel time while driving and contributed to a difficulty in keeping vehicle position on the roadway axis. Their results further suggest that eating and drinking related accidents are almost equal to mobile phone use accidents. On the other hand, simulator experiments (Jenness et al. 2002; Young et al. 2007) have shown little effect of eating or drinking on driver behavior and safety.

Moreover, some studies report a relationship between driver smoking and distraction or accident occurrence. Stutts et al. (2001) report that, on the basis of the CDS -Crashworthiness Data System, around 1% of accidents are due to driver smoking. The 100-car naturalistic driving study associated 2% of distraction or inattention related accidents with smoking (Neale et al. 2005). Gordon (2005) reports that 2.2% of accident in New Zealand are due to smoking-related distraction. Furthermore, about half of these accidents took place while reaching out for a cigarette, another one fourth while lighting a cigarette and another one fourth while searching for a dropped cigarette (Road Safety Committee, 2006).

Within this context, the objective of this research is the analysis of the effect of conversation, eating and smoking on driver behaviour and on road safety in rural roads. For that purpose, a driving simulator experiment was carried out, in which participants were asked to talk, eat or smoke while driving on a mountainous road during daytime. Driver behaviour was then analysed on the basis of three variables, namely speed, reaction time and distance from the central axis of the lane, whereas driver safety was assessed on the basis of accident probability. These measures of driving performance were selected as most appropriate on the basis of the international literature (Neale et al. 2005; GHSA, 2011).

METHOD AND DATA

Simulator Experiment

A simulator experiment was designed and carried out for the objectives of the present research (Bairamis & Sklias, 2010). The experiment concerned the behaviour of 42 young drivers aged between 18 and 30 years, out of which 20 were males and 22 were females, and almost all were smokers. All drivers held a driving license, while in their majority they were students of the National Technical University of Athens. No considerable variation of the sample of drivers per age and driving experience is thus to be expected. The simulator of the Traffic Engineering Laboratory of NTUA was used, which includes an actual vehicle cabin with all the related instruments including mirrors, as well as 3 wide screens LCD40'', creating a visual field from 60 to 180 degrees.

Before driving the simulator, the participants completed a questionnaire comprising questions related to their personal characteristics, their driving habits, especially as regards distraction (e.g. frequency of talking, eating or smoking while driving, behaviour during these tasks etc.), and their perception on the risk associated with smoking, eating or talking while driving. Thereafter, they were informed about the process of the experiment, i.e. that they would have to drive in three separate situations, namely while eating, while smoking, and while in a conversation with a 'passenger' sitting next to them. Moreover, they were asked to drive in different simulated scenarios as they would do in actual conditions.

The experiment included three simulated drives in a rural road environment during good weather conditions. More specifically, the drives took place on a mountainous two-way rural road, without a median or roadside barriers, and included one bridge and one tunnel. Moreover, there was traffic on both road directions, and the speed limit was from 50 to 70 km/h. This type of road is quite typical in the Greek mainland, as several interurban or rural roads have such design characteristics. The first drive concerned a 6 minute test drive so that the participant became familiar with the simulator.

The second drive had a total length of 3.95 kilometres; during that drive, the participant had to be involved in a conversation with a surveyor, who was sitting right next to him as he would be in an actual vehicle. The conversation was simple, including basic questions on the drivers' characteristics (e.g. age, name, everyday activities, jobs, hobbies, news etc.).

A few minutes after the end of the simple conversation, the surveyor left his seat, so that his presence would not affect the driver's behaviour during the following stages of the experiment (i.e. distracted driving by eating or smoking). Then, at a fixed point along the route (i.e. same for all the participants), the participant was asked to open and consume a light snack while driving, namely a chocolate bar, which was located next to him, within his immediate reach, as would be the case inside his own vehicle.

After a few minutes break, the third drive took place, which had a total length of 4 kilometres and included a complex conversation with the surveyor who resumed his seat next to the driver. During that conversation, the participant was asked to answer specific questions which required increased concentration, as well as some logical and mathematical reasoning. More specifically, the drivers were first to indicate 5 European capitals starting with ‘B’; then, they were asked to answer the following question: ‘if a water lily in a lake doubles its surface every day so that all the lake surface is covered in 22 days, in how many days will half of the lake be covered?’. Finally, if the previous questions were answered before the end of the section, the driver was engaged in a conversation concerning the costs of throwing a party according to the number of guests.

A few minutes after the end of the complex conversation, at a fixed point along the route (i.e. same for all the participants), the participant was asked to smoke a cigarette as he or she would usually do inside his / her own vehicle. It is noted that the three non-smokers among the participants did not take part in this part of the experiment, i.e. they drove the respective road section with no distraction. The participant could use either an ashtray located ‘inside’ the simulator vehicle, at the exact position that this would be in an actual vehicle, or the area on the floor next to the simulator vehicle; the second option aimed to create realistic conditions for those drivers who do not use the in-vehicle ashtray but throw their cigarette ashes off the window – a rather common practice by several Greek drivers.

During both drives, another surveyor located inside the simulator room scheduled for unexpected incidents to occur at fixed time points. The unexpected incidents, for which the drivers had not been informed beforehand, 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). In total, eight incidents were scheduled at fixed points along the route for each participant, two during each conversation (simple and complex), one during the eating and one during the smoking, and four during the remaining driving phases. It is noted that, apart from accidents resulting from these triggered incidents, no accident occurred during the four drives for none of the participants.

The exact process of the experiment is summarized in Table 1, including the length of each section and the points of incident occurrence.

Table 1 Simulator experiment characteristics

Type of section	**Sections length** (Km)				**Incidents**	
Free driving 1	Begin:	0.00	End:	0.70	Kilometer	0.47
Simple Conversation	Begin:	0.70	End:	1.90	Kilometer	1.13 and 1.65
Free driving 2	Begin:	1.90	End:	2.50	Kilometer	2.10
Eating	Begin:	2.50	End:	3.60	Kilometer	3.32
Free driving 3	Begin:	3.60	End:	4.45	Kilometer	3.86
Smoking	Begin:	4.45	End:	6.04	Kilometer	5.37
Free driving 4	Begin:	6.04	End:	6.84	Kilometer	6.39
Complex Conversation	Begin:	6.84	End:	8.10	Kilometer	7.21 and 7.76

It is noted that, during the experiment, data recording was continuous, i.e. driver's speed, reaction time, position on the lane etc. were also measured during the 'without distraction' intervals, so that driver's performance with and without distractions could be compared. Moreover, the 'with' and 'without' distraction sections of the experiment were approximately equal in length, and the road and traffic features of the simulated drive remained unchanged.

Variables and values

The participants' driving experience was distributed as follows: 43% held a driving license from 1 to 4 years and 57% held a driving license from 5 to 9 years. Moreover, 26 % of the participants were between 19-22 years old, 67% were between 23-26 years old and 7% were between 27-30 years old. Moreover, 14% of the participants had been involved in a road accident while talking to other passengers inside the vehicle. Finally, 71% of all participants stated that they particularly enjoy driving.

Table 2 presents all the variables and their values collected during the present research, either from the simulator experiment or from the questionnaire responses.

Analysis methods

In the framework of the present research, driver behaviour was analysed on the basis of three variables, namely speed, reaction time and distance from the central axis of the lane (Alm and Nilson, 1993). Driver safety was analysed on the basis of accident probability.

Driver speed, reaction time and distance from the central axis of the lane were modelled by means of log-normal regression models, as the logarithms of all three variables were found to conform to a normal statistical distribution. Accident probability was modelled by means of binary logistic regression models. The selection of variables was initially carried out on the basis of univariate tests. 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. In this way, the sets of meaningful and uncorrelated variables to be included in the final (multivariate) models could be identified.

For the comparative assessment of variable effects within and across the models, dimensionless relative effects were estimated, by calculating the variables' elasticities. In linear regression models, elasticities are defined as the percentage change in the dependent variable y_i resulting from a 1% change in the explanatory variable x_{ik}. These are point elasticities, concerning small, incremental changes in the examined variables and may be estimated as follows:

$$E_{x_{ink}}^{y_i} = \frac{\partial y_i}{\partial x_{ink}} \frac{x_{ink}}{y_{ik}} = \beta_k \frac{x_{ink}}{y_{ik}} \qquad (1)$$

where:

β_k: is the model parameter estimate for variable x_k.

Table 2 Data sources, variables and values

Dependent variables	Source
mean speed (Km/h)	Simulator
reaction time (sec)	Simulator
mean distance from the central axis of the lane (m)	Simulator
accident occurrence (1:yes, 0:no)	Simulator
Explanatory variables	Simulator
incident occurrence (1:yes, 0:no)	Simulator
driver eating while driving (1:yes, 0:no)	Simulator
driver smoking while driving (1:yes, 0:no)	Simulator
driver engaged to simple conversation while driving (1:yes, 0:no)	Simulator
driver engaged to complex conversation while driving (1:yes, 0:no)	Simulator
tangent road section (1:yes, 0:no)	Simulator
downhill road section (1:yes, 0:no)	Simulator
mean speed (km/h)	Simulator
deviation of speed from the mean speed of all drivers (km/h)	Simulator
absolute difference between the maximum and the minimum speed	Simulator
exceeding speed limit (1:yes, 0:no)	Simulator
deviation of point speed from mean point speed of all driver's	Simulator
absolute difference from the mean speed of all drivers (m)	Simulator
mean acceleration (m/sec^2)	Simulator
minimum acceleration (m/sec^2)	Simulator
% route the brake was used	Simulator
% route the 1st, 2nd, 3rd, 4th, 5th gear was used	Simulator
mean motor revolution per minute	Simulator
deviation of motor revolution from mean motor revolution	Simulator
maximum distance from the right board (m)	Simulator
minimum distance from the right board (m)	Simulator
deviation of distance from then right border from mean distance from the right border (m)	Simulator
mean headway (sev)	Simulator
minimum headway(sec)	Simulator
mean time to collision (sec)	Simulator
minimum time to collision (sec)	Simulator
person age (years)	Questionnaire
person gender (1:male, 0:female)	Questionnaire
person driving experience (1: <5 years, 2: 5-9 years)	Questionnaire
annual mileage (km)	Questionnaire
frequency of driving on rural roads (1:never, 2:rarely, 3:frequently, 4:always)	Questionnaire
accident involvement while talking to passengers	Questionnaire
accident involvement while eating (yes / no)	Questionnaire
accident involvment while smoking	Questionnaire
frequency of talking while driving (1:never, 2:once per month, 3: once per week, 4:daily, 5: several times daily)	Questionnaire
frequency of eating while driving (1:never, 2:once per month, 3: once per week, 4:daily, 5: several times daily)	Questionnaire
frequency of smoking while driving (1:never, 2:once per month, 3: once per week, 4:daily, 5: several times daily)	Questionnaire
change of driving behaviour while eating (1:none, 2:pull over, 3:reduce speed, 4: stop)	Questionnaire
change of driving behaviour while smoking (1:none, 2:pull over, 3:reduce speed, 4: stop)	Questionnaire
change of driving behaviour on rural roads (yes / no)	Questionnaire
enjoy driving (yes / no)	Questionnaire

It is noted that, although elasticities are most meaningful when comparing the effects of continuous variables, they may also be used for discrete variables, as a means for the assessment of relative effects in the linear regression models. In this case, they may be interpreted as the percentage change in the dependent variable y_i resulting from a transition of one category of the discrete explanatory variable x_{ik} to another.

In logistic regression models, point elasticities may be estimated as follows (Washington et al. 2003):

$$E_{x_{ink}}^{P(i)} = \frac{\partial P_n(i)}{\partial x_{ink}} \frac{x_{ink}}{P_n(i)} = \frac{\partial \ln P_n(i)}{\partial \ln x_{ink}} = [1 - \sum_{i'=1}^{I} \mathrm{P_n}(i)]\, x_{ink} \beta_k \tag{2}$$

Where:
P(i): is the probability of alternative (i) and
x_{ink}: the value of variable (k) for alternative (i) of individual (n) and I the number of alternatives including x_{ink}.

Moreover, pseudo-elasticities may be calculated for the discrete variables (Shankar & Mannering, 1996; Chang & Mannering, 1999). These 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 as follows (Ulfarsson & Mannering, 2004):

$$E_{x_{ink}}^{P(i)} = e^{\beta_{ik}} \frac{\sum_{i'=1}^{I} e^{\beta'_i x_n}}{\sum_{i'=1}^{I} e^{\Delta(\beta'_i x_n)}} - 1 \tag{3}$$

Where:
I: is the number of possible outcomes,
$\Delta(\beta' x_n)$: is the value of the function determining the outcome when x_{nk} has changed from 0 to 1,
$\beta' x_n$: is the related value when x_{nk} is 0,
β_{ik} : is the parameter estimate of x_{nk}.

The above disaggregate elasticities are estimated for each observation (i) of each individual (n) in the sample; in order to calculate the aggregate elasticity, the average over the sample is taken in linear regression models, whereas the following formula is applied (Ben-Akiva & Lerman, 1985) in logistic regression models:

$$E_{x_{ik}}^{P(i)} = \frac{\sum_{n=1}^{N} P_n(i) E_{x_{ink}}^{P_n(i)}}{\sum_{n=1}^{N} P_n(i)} \tag{4}$$

It is important to note that, due to differences in their definitions, elasticities of continuous variables are not directly comparable to elasticities of discrete variables in the same model. Elasticity analysis has the advantage that it allows comparing the effects of different variables within the same model, or between different models, on the basis of a standard and dimensionless measure.

RESULTS

Modelling driver's speed

Four different log-normal regression models were developed for drivers' mean speed, one for each distraction factor (i.e. simple conversation, complex conversation, eating and smoking), given that each distraction factor was examined separately during the experiment. The significant parameter estimates β_i, their t-test values and their elasticities e_i are summarized in Table 3. It can be seen that the statistically significant explanatory variables in the final models include road design characteristics (e.g. vertical alignment, horizontal alignment, lane width), driving behaviour characteristics (mean distance from the right border, mean acceleration, mean motor revolutions), as well as personal driver characteristics (e.g. gender, enjoying driving). Moreover, all four distraction factors were included as explanatory variables.

As regards conversation, a significant decrease in speed was observed both during the simple and the complex conversation, revealing an attempt of drivers to counter-balance the increased mental workload resulting from the conversations. Moreover, sensitivity analysis suggested that the mean speed of men during a simple conversation is practically equal to the mean speed of women without conversation. On the contrary, men during a complex conversation have higher speeds than women without conversation (Bairamis & Sklias, 2010). It is possible that, while driving and being involved in a complex conversation, adrenaline increases and affects driving behavior of men to a more significant degree.

As regards eating, it was found that the distracting manual (and possibly also visual) task of consuming a snack while driving leads drivers to reduce their speed. Lighting and smoking a cigarette leads to similar speed reducing behaviour. In this case, however, the elasticity value is very small, indicating a minor effect of smoking on driver speed, compared to other variables.

Overall, men drive at higher speeds than women, regardless of eating or smoking, which is in accordance with the results of previous research (Yannis et al. 2010). Moreover, drivers who stated that they enjoy driving drive at higher speeds regardless of the various distractions considered, possibly because the enjoyment results from the speeding behaviour itself – which is not surprising for young drivers.

The other explanatory variables that were found to significantly affect drivers' speed can be analysed as follows: acceleration is directly associated to increased driver speed. Moreover, the mean motor revolution also reflects drivers' speeding behaviour, given that increased motor revolutions correspond to more acceleration time and thus to even increased speeds. Mean speed is also significantly affected by lane width; wider lanes are associated with higher speeds.

Table 3 Parameter estimates, t-test and elasticity values of the mean speed models

	simple conversation			complex conversation		
Explanatory variables	β_i	t	e_i	β_i	t	e_i
			Continuous Variables			
mean motor revolution	8.000E-05	14.8	0.139	8.200E-05	15.4	0.142
mean acceleration	-	-	-	0.030	4.0	0.002
% use of brake	-	-	-	-	-	-
lane width	0.068	4.3	0.182	0.069	4.1	0.187
% of the route the 4th gear was used	-	-	-	-	-	-
max distance from the right road board	-	-	-	-	-	-
			Discrete Variables			
driver eating while driving	-	-	-	-	-	-
simple conversation	-0.024	-3.8	-0.004	-	-	-
complex conversation	-	-	-	-0.014	-2.0	-0.003
driver smoking while driving	-	-	-	-	-	-
tangent road section	-0.149	-21.3	-0.022	-0.175	-24.3	-0.035
gender	-0.026	-4.4	-0.008	-0.036	-6.3	-0.011
downhill road section	-	-	-	0.044	4.3	0.003
driver enjoys driving	0.046	4.9	0.025	-	-	-
R^2	**0.60**			**0.73**		

The use of the 4th gear for longer is also associated with increased speeds, which is not surprising when considering that the 4th gear may be the maximum gear that is expected to be used in a rural road setting as the one of the present experiment.

On the other hand, drivers using the brakes for longer drive at lower speeds, as would be expected (i.e. more deceleration). Moreover, smaller distance from the right road border is associated with lower mean speed. Tangent road sections and downhill road sections are also associated with increased mean speed. These results are certainly intuitive; however, it was important to control for their effect on driver's speed while not distracted, so that the estimates of the effects of the various distractors are accurate.

Table 3 (cont.) Parameter estimates, t-test and elasticity values of the mean speed models

	eating while driving			smoking		
Explanatory variables	β_i	t	e_i	β_i	t	e_i
mean motor revolution	8.600E-05	14.6	0.148	-	-	-
mean acceleration	0.045	6.0	0.003	-	-	-
% use of brake	-	-	-	-0.163	-3.0	-0.003
lane width	0.077	4.4	0.205	-	-	-
% of the route the 4th gear was used	-	-	-	0.097	7.9	0.011
max distance from the right road board	-	-	-	0.010	2.0	0.015
driver eating while driving	-0.024	-2.7	-0.003	-	-	-
simple conversation	-	-	-	-	-	-
complex conversation	-	-	-	-	-	-
driver smoking while driving	-	-	-	-0.011	-1.5	-0.002
tangent road section	-0.182	-21.7	-0.023	-0.139	-15.9	-0.020
gender	-0.027	-4.3	-0.008	-0.039	-5.8	-0.011
downhill road section	0.067	6.5	0.006	-	-	-
driver enjoys driving	0.038	3.7	0.021	0.035	3.0	0.019
R^2	**0.70**			**0.48**		

The results suggest that all four distraction factors bring a statistically significant decrease in drivers' speed. Lower speeds are generally associated with positive road safety outcomes (e.g. fewer road accidents and fatalities). The four distraction variables were also proved to be highly correlated, sharing an important amount of variance in driver's speed. It was attempted to include all four distractors in one model, but this was not efficient due to the correlation mentioned above. However, the relative effect of the four distractors on driver speed can be estimated on the basis of their elasticities, which are dimensionless and thus comparable across different models.

In the next sections, additional driver behavior parameters are analysed, namely the distance from the central axis of the lane and the reaction time.

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

Out of the four distraction factors examined, only the complex conversation was found to have a significant effect on drivers' distance from the central axis of the lane. The other three distraction factors were found to be non significant in both univariate and multivariate models. The significant parameter estimates, their t-values and elasticities in the final models are summarized in Table 4.

Table 4 Parameter estimates, t-test and elasticities of the distance from the central axis of the lane model

Explanatory variables	β_i	t	e_i
	Continuous Variables		
absolute difference between the maximum and the minimum speed	0.018	5.270	1.372
mean motor revolution per minute	-2.5000E-05	-2.639	-1.123
lane width	0.148	5.511	9.800
deviation of speed from the mean speed of all drivers	0.002	3.085	-0.088
mean acceleration	-0.035	-2.979	-0.102
	Discrete Variables		
incident occurrence	-0.030	-2.978	-0.253
deviation of speed from the mean speed of all drivers	0.037	2.291	0.039
complex conversation	-0.032	-2.832	-0.074
not frequent horizontal curves	0.026	2.110	0.049
R^2=0,153			

A complex conversation while driving appears to lead drivers towards pulling over to the right road border, which may be explained by the fact that drivers are aware of the risks involved during that type of multitasking and attempt in this way to reduce their risk. This behavior may be more pronounced in such rural undivided roads, where the risk of head-on collision is increased.

As regards the other explanatory variables, the range of vehicle speeds (e.g. absolute difference between minimum and maximum speeds) appears to affect the position of the vehicle on the roadway, given that increased range of vehicle speeds is associated with reduced distance from the central axis of the lane. An increased range of speed in this research implied increased maximum speed, and the above effect can be thus attributed to the common practice of higher-speed vehicles to drive towards the left part of the lanes (e.g. for easier overtaking etc.). Accordingly, increased motor revolutions and acceleration correspond to reduced distance from the central axis of the lane, for the same reasons. This pattern is also reflected to the positive effect of the difference of the driver's speed from the mean speed of all drivers.

On the other hand, wider lanes result in increased distances from the central road axis, indicating that, when increased lane width is available, vehicles can be positioned more centrally on the lane. This variable has by far the highest elasticity with respect to the distance from the central axis of the lane, which is intuitive. Uphill road sections and frequent and closed curves are related to increased distance from the central axis of the lane, obviously due to lower speeds. Finally, the occurrence of unexpected incidents appears to lead drivers towards the right road border, given that they are expected to opt for accident avoidance without entering the opposite road direction.

From these results, it is deduced that the distance from the central axis of the lane is clearly correlated with driver's speed, since drivers tend to follow different paths within their lane (with higher radii) in an effort to better compensate for centrifugal force. It is however interesting to note that, although all distraction factors examined in this research were found to affect speed, only the complex conversation was found to affect the distance from the central axis of the lane. In the next section, the effects of distraction factors on reaction time are examined.

Modelling driver's reaction time

Only the complex conversation was found to have a significant effect on drivers' reaction time in case of unexpected incident. The significant parameter estimates, their t-test values and their elasticities in the final model are summarized in Table 5.

Table 5 Parameter estimates, t-test and elasticities of the reaction time model

Explanatory variables	β_i	t	e_i
	Continuous Variables		
deviation of motor revolution from mean motor revolution	-3.000E-05	1.74	-0.234
deviation of point speed from mean point speed of all driver's	0.002	2.37	-0.016
deviation of distance from then right road border from mean distance from the right road border	-0.119	4.13	0.670
	Discrete Variables		
driving licence for more than 5 years	-0.057	3.44	0.744
% route the 2nd gear was used	0.332	3.43	0.013
complex conversation	0.031	1.8	-0.160
R^2=0,271			

More specifically, driver's engagement to a complex conversation was found to increase reaction time in case of unexpected incident. It is reminded that complex conversation included some concentration and required mathematical thinking. It can be therefore concluded that driver's attention is focused on the complex conversation, resulting in a delayed identification of the unexpected incident and the related collision risk.

Moreover, the difference in motor revolutions at the time of the incident from the mean motor revolutions corresponds to improved reaction time, perhaps because a higher difference suggests more efficient deceleration i.e. timely braking at the time of the incident. The difference in distance from the right border from the mean related distance corresponds to reduced reaction time, suggesting that drivers of vehicles positioned on the center of the lane may detect the incident earlier and this perform a smaller avoidance manoeuvre. An increased use of the 2nd gear was also found to significantly affect driver's reaction time, implying a favourable effect of lower speeds on reaction time. Finally, it is interesting to note that less experienced drivers present lower reaction times, even within the relatively small range of driving experiences recorded in the present experiment; this can be attributed to the fact that they may be less familiar with dealing with incident occurrence while driving.

The relatively low elasticities of all variables examined, and the less satisfactory model's fit may indicate that driver reaction time cannot be fully explained by road and traffic parameters, and additional parameters e.g. on human factors, may be required. However, the results allow to conclude that a complex conversation while driving, although reducing driver speed, increases reaction time, which is obviously detrimental for road safety. In the next section, the above effects are jointly examined within an accident probability model.

It is noted that, given that the driving scenarios were always realized in the same order, a training effect might appear regarding unexpected incidents, which can be more surprising in the first scenario but less in the last one. A control variable labeled 'first drive' was tested to account for this possible bias, but was not found to be significant, suggesting that the first incidents were not less surprising in the last ones.

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 6.

Table 6 Parameter estimates, Wald-test and (pseudo-) elasticities of the accident probability model

Explanatory variables	β_i	Wald	e_i
	Continuous Variables		
deviation of speed from the mean speed of all drivers	0.139	11.17	0.95
mean motor revolution per minute	-0.001	4.93	-2.26
minimum distance from the central axis of the lane	-0.846	7.89	-0.47
	Discrete Variables		
incident occurrence	3.118	14.32	15.09
complex conversation	1.205	4.58	1.69
Likelihood Ratio = 47.588 (4 degrees of freedom)			

It can be seen that complex conversation increases accident probability, whereas none of the other distraction factors examined was found to have a significant effect on accident probability. It is thereby deduced that the decrease of speed observed during the engagement to a complex conversation, and the shifting of the vehicle towards the right road border, cannot compensate the distraction caused by the additional mental workload, leading to increased reaction time in case of unexpected incident, as shown in the previous section, and eventually to increased accident probability.

As regards the other explanatory variables, the occurrence of an unexpected incident is obviously associated with increased accident risk. Moreover, a larger difference in speed from the mean speed of all vehicles is associated with increased accident probability, as is generally the case in road safety. Lower motor revolutions are also associated with increased accident probability; this may initially seem counter intuitive, but may be interpreted as follows: lower motor revolutions may be associated with less experienced or less confident drivers, who may not react appropriately in case of unexpected incident.

It is interesting to note that incident occurrence has by far the highest pseudo-elasticity with respect to accident probability, and the complex conversation also presents a high elasticity.

In Figure 1, the results of the present research as regards accident probability are summarized in a sensitivity diagram, presenting the effect of a combination of explanatory variables on the response variable. It is demonstrated that accident probability increases with an increase of the difference from the mean speed (top panel), and with an increase of the distance from the central axis of the lane (bottom panel).

For example, a difference of 20 km/h from the mean speed of all vehicles results in an increase of accident probability from zero to 30% when the driver is not in a conversation and to 60% when involved in a complex conversation. It is further noted that a difference of 30km/h from the mean speed makes accident avoidance in case of unexpected incident almost inevitable. It can be also noted that the closer to the right road border one drives, the lower the accident risk in case of incident occurrence. Even when the vehicle is located on the centre of the lane, a complex conversation almost doubles the accident risk.

CONCLUSIONS

The results of the present research suggest that 'simple' conversation, 'complex' conversation, eating and smoking are all associated with decreased speeds, indicating that drivers attempt to compensate for these distraction factors by driving at lower speeds. Moreover, 'complex' conversations were systematically associated with an increase of the distance from the central axis of the lane, suggesting that drivers engaged to a complex conversation tend to pull over to the right. However, 'complex' conversations were also associated with significantly increased reaction times at unexpected incidents and with increased accident risk.

It was found that drivers driving at low speeds during a conversation, drive on the same position on the roadway with drivers driving at higher speeds not during a conversation. Moreover, drivers eating or smoking while driving on larger lanes have similar speeds with drivers not eating or smoking while driving on narrower lanes. Moreover, the accident probability of drivers who drive with smaller difference from the average speed during a conversation is practically undistinguishable from the one of drivers who drive with larger difference from the average speed not during a conversation.

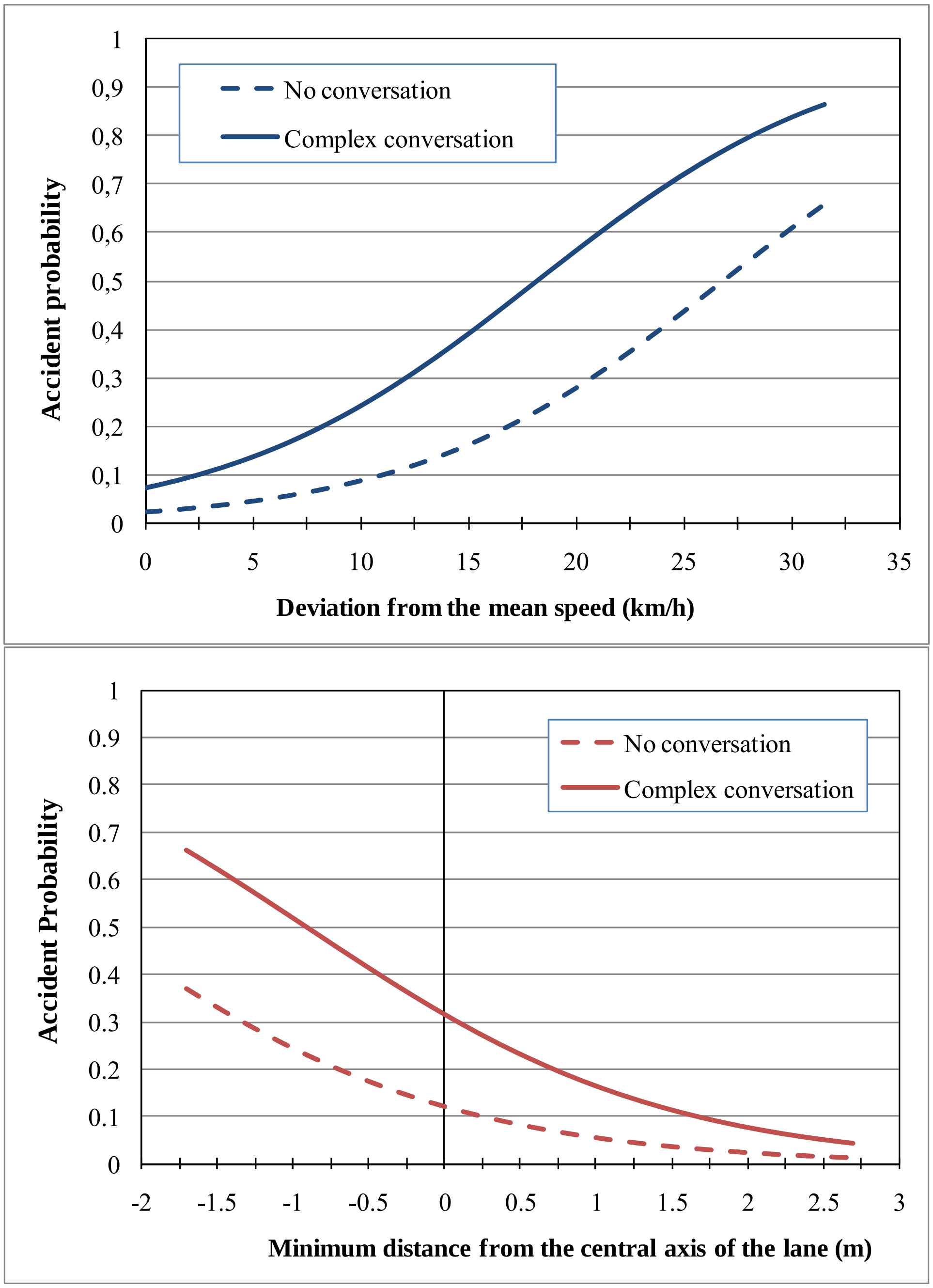

Figure 1 Effect of complex conversation and deviation from the mean speed (top panel) / minimum distance from the central axis of the lane (bottom panel) on accident probability (incident occurrence: yes, motor revolutions: 2000 rpm)

Overall, 'simple' conversation, eating and smoking were 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. On the contrary, 'complex' conversation was found to lead to significantly higher accident probability. It can be said that the decrease in speed during the 'complex' conversations, which might be considered beneficial for road safety, cannot counter-balance the driver's distraction, leading to increased reaction times, and eventually increased accident probability, especially when unexpected incidents occur. Moreover, the related increase in distance from the central axis of the lane, which may be considered as an attempt to compensate for the distraction from the ‘complex’ conversation, may increase the probability of ran-off-road accidents.

It is interesting to note that, from the various self-reported driving habits, preferences and other personal characteristics, recorded on the basis of the survey questionnaire, only a couple were found to affect driver observed behaviour. It appears therefore that the effect of distractions while driving is only marginally affected by driver characteristics, namely the driver’s experience and the degree to which he or she enjoys driving.

The results of the present research are in accordance with previous research results, which suggest that conversation while driving may indeed constitute a risk factor (Stutts et al. 2003; Drews et al. 2008). Research results also confirm previous findings concerning eating or smoking, despite the small number of related studies. Young et al. (2007) report that driving performance measures are relatively unaffected by eating and drinking, however perceived driver workload is significantly higher and there were more incidents result in accidents, when compared to driving normally. Neyens & Boyle (2003) found increased injury severity associated with mobile phone or passenger conversation, whereas the effects of smoking, eating or drinking were not significant. The present research contributes the distinction between simple and complex conversation, as well as the linkage between driver speed, incident reaction time and accident risk while distracted.

In the next stages of this research, additional in-vehicle distraction factors will be examined, such as listening to music and using driver assistance systems. It may be particularly interesting to compare the distraction caused by mobile phone conversation with the one caused by conversation with passengers. For instance, an issue that has appeared in relevant research is the phenomenon of conversation suppression, that is, the tendency for passengers to slow their rates of conversation as the driver approaches a hazard, which is not observed with remote speakers (Crundall et al. 2005; Drews et al. 2008). The use of mobile phone while driving has been examined in previous research on the same driving simulator (Roumpas, 2010), indicating a significant effect on driver speed and accident probability. The analysis may be extended to external driver distraction factors, such as billboards and other types of advertising etc.

Finally, the effect of the examined distraction factors on driving performance should be further analysed by means of naturalistic driving experiments. It is underlined that, even in an optimally designed simulator experiment, drivers may not fully perform as they would in actual conditions (GHSA, 2011). On the other hand, the simulator experiment has the advantage of allowing the representation of incident occurrence at fixed points and with the exact same conditions for all drivers, so that changes in driving performance (e.g. slower reaction time) can be correlated with accident risk.

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