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Investigation of the impact of weather conditions to young drivers' behaviour and safety in cities

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Abstract

Driving in adverse weather conditions is not only associated with a high risk of being involved in an accident, but it also affects the severity of an accident. The objective of this research is to investigate the impact of weather conditions on young drivers' behaviour and safety in urban areas. In order to achieve this objective, an experimental process on a driving simulator was carried out, in which 40 participants drove in different driving scenarios. Regression statistical models were developed to investigate the impact of weather conditions on the mean speed (linear) and the accident probability (logistic). The models' application shows that driving in the rain contributes to a small reduction in speed, but also to a significant increase in the probability of an accident. When driving in fog, drivers seem to be more cautious, resulting to a decreased accident probability.

Keywords: weather conditions; driving simulator; speed; road accidents; linear regression; binary logistic regression

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1. Introduction

Road safety is a complicated scientific field of transport research due to the multidimensional nature of accident occurrence. Since accidents impose serious problems to society in terms of human, economic, property damage and medical costs, it constitutes a major concern in the transportation industry. The most important risk factors recognized in literature (Pedden et al., 2004; WHO 2018) are human factors, unsafe road infrastructure, vehicle defects and inadequate enforcement of traffic laws. In addition, environmental factors, like rain, snow or darkness influence as well the risk of road accidents as they change in a way the "usual" driving environment. Several studies have proved that drivers' ability to avoid collisions is impaired in adverse weather conditions (Koetse and Rietveld, 2009; Theofilatos and Yannis, 2014).

The most common weather parameter that has been considered in literature is precipitation (rainfall, rainfall intensity, snowfall). The findings regarding precipitation are quite consistent. In most studies it was found that precipitation is associated with increased number of crashes (Andrey and Yagar, 1993; Chang and Chen, 2005). Driving in rain is safety critical situation, involving adversities like reduced pavement friction and impaired visibility. Rainfall increases crash risk and most weather-related accidents occur during rainfall and in wet pavement conditions (Andrey et al., 2003; Pisano et al., 2008). Wet pavement has been found to increase braking distance (Fambro et al., 2007) and consequently, crash frequency, when road factors that increase unexpected braking are present (Ivan et al., 2012). Apart from reduced pavement friction, rain results in decreased visibility by a combination of mechanisms produced by falling rain, sprayed water and light reflections on wet materials (Hautière et al., 2009).

However, some recent studies have found contradictory results concerning precipitation and accidents. It is found that the effect of rainfall is different in Mediterranean countries where rainfall occurs mainly in winter and is rarer than some U.S. states and other European countries. A number of studies (Karlaftis and Yannis, 2010; Theofilatos et al., 2012) suggest a negative relationship between adverse weather and road safety, mainly because drivers of these countries are not used to drive under adverse weather and consequently adjust their behaviour by driving more carefully. More specifically, drivers tend to compensate for the increased risk by adjusting their behaviour, namely they decrease their speed (Edwards, 1999; Jägerbrand and Sjöbergh, 2016) and increase headway (Dhaliwal et al., 2017).

Aside from rain, other weather variables that effect driving behaviour and safety consist of fog, snow, wind etc. Specifically, the effect of fog on driving behaviour has been widely studied. According to Al-Ghamdi (2007), fog-related crashes have remarkably higher injury and fatality rates. Abdel-Aty et al. (2011) studied the impact of low visibility due to fog and smoke on crashes using crash data from Florida between 2003 and 2007. Results indicated that compared to crashes under clear-visibility conditions, fog and smoke related crashes tend to result in more severe injuries and involve more vehicles, while head-on and rear-end crashes are the two most common crash types in terms of crash risk and severity. Another study (Wanvik, 2009) focused on the effect of road lighting on crashes and implied that the effect of lighting during foggy conditions may be underestimated in safety studies.

There are few studies employing driving simulator, as well in order to investigate driving performance measures under adverse weather conditions (Chakrabartya and Guptab, 2013; Saffarian et al., 2012). Chakrabartya and Guptab (2013) studied the visual traits and psychomotor behaviour of the drivers along with their choice of speed, reaction time and driving behaviour during adverse weather under simulated and realistic environment conditions. The findings highlight drivers' state and pattern of crashes during rain and foggy conditions during simulated adverse weather conditions. Moreover, Mueller and Trick (2012) in order to investigate the influence of driving experience on behavioural compensations to fog, average speed, speed variability, steering variability, collision rate, and hazard response time were measured in a driving simulator. Results revealed that experienced drivers drove faster in clear visibility than novice drivers, yet they reduced their speed more in reduced visibility so that both groups drove at the same speed in simulated fog.

Within this context, driving simulators have become a widely used tool for examining the impact of various risk factors to driver behaviour and safety, with respect to individual driver differences and/or roadway design (Konstantopoulos et al., 2010; Yannis et al., 2014). They provide objective measurements of driving performance in a safe environment and can evaluate performance under hazardous driving tasks that would be impossible in open-road experiments. Several confounding variables can be controlled in a virtual environment, in contrast to what can be achieved in naturalistic driving. However, the use of driving simulators is not without methodological concerns. One of the issues that researchers are concerned with when using driving simulators is the fact the drivers' behaviour will not be the same under simulated driving since there is not any risk involved (Reimer et al., 2006).

The above described results indicate that adverse weather conditions have an important impact on driver behaviour and consequently on road safety. A rising issue is the degree to which young drivers are affected by this impact. Young drivers show a greater probability to get involved in an accident than other age groups (Jonah et al., 2001). They are equally likely to get involved in both fatal crashes as well as crashes with minor injuries. The young drivers' increased probability of getting involved in an accident can be attributed to reduced driving experience, risky behaviour and a tendency of overestimating their driving abilities. So far, there has been limited research on the impact of driving in adverse weather conditions as a single risk factor on young drivers' performance, as it is difficult to identify the unique contribution of a single risk factor, controlling perfectly for all other risk factors that tend to go together with the risk factor of interest.

Based on the above, this research aims to investigate the impact of weather conditions on different driving performance measures of young drivers on urban roads, through a driving simulator experiment. Particularly, mean speed and the probability of an accident are the dependent variables examined in order to render the impact of weather conditions. Additionally, the effect of driving in different weather conditions in combination with road type (urban road), traffic characteristics (high/low traffic) and driver characteristics (gender, annual mileage, and driving habits) is investigated, as well.

2. Data collection

Within the present research, a driving simulator experiment was conducted in order to examine the impact of weather conditions on young drivers' behaviour and safety in urban roads in combination with specific driver and road environment characteristics. The driving simulator experiment took place at the Department of Transportation Planning and Engineering of the National Technical University of Athens.

2.1. The driving simulator

The driving simulator used for the experiment (Driving Simulator FPF) was based in the Department of Transportation Planning and Engineering of the National Technical University of Athens. The driving simulator (Figure 1) consists of 3 screens LCD40'', an adjustable driver's seat and a support base. It includes a steering wheel, control pedals, a vehicle instrument panel. The three screens depict the road view, as well as the side and center mirrors, which display the view and real-time events that occur behind the "vehicle". The simulator's full dimensions are 230 X 180 cm and the base width is 78 cm.

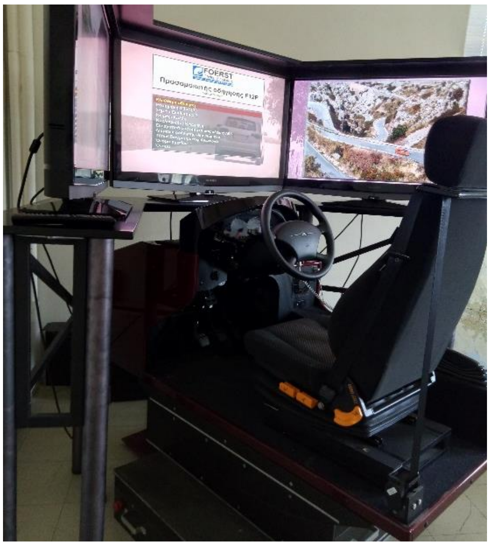

Figure 1. Driving simulator

2.2. Sample

Considering that the scope of the research is to investigate the behaviour of young drivers, the selection of participants was limited to drivers aged 18-30 years old. The experiment involved 40 participants (24 men and 16 women) with a valid driving license and an average driving experience of 5 years. Furthermore, participants completed a demographic questionnaire and did not take any benefit regarding the participation in the experiment.

2.3. Overview of the experiment

The driving scenario included driving on an urban road 2,1 km long, in different weather conditions (speed limit 60 km/h to match the geometric and road environment characteristics), specifically during rainy, foggy and good weather conditions. Furthermore, different traffic conditions were examined (low and high traffic conditions), thus the experiment was carried out only during daytime. Additionally, participants were requested to fill in a questionnaire about their driving habits and their driving behaviour, with regard to different weather conditions.

2.4. Familiarization

A familiarization session or ‘practice driving’ was the first step of the simulator experiment. During the familiarization with the simulator, the participant practiced in handling the simulator, keeping the lateral position of the vehicle, keeping stable speed, appropriate for the road environment and braking and immobilization of the vehicle. When all criteria mentioned above were satisfied the participant moved on to the next phase of the experiment (there was no time restriction). Furthermore, it should be noted that this procedure is a typical one that is being conducted in order the simulation sickness to be tested. As a result of the described process, five volunteers did not participate in the experiment due to simulation sickness, concluding to the final number of the 40 participants taking part to the driving simulator experiment.

2.5. Procedure

After the practice driving, each of the 40 participants was asked to drive the main part of the experiment. In this phase of the experiment, the driver was asked to drive successively, without pausing twice the predetermined route within the urban environment, during good weather conditions under low and high traffic conditions. Afterwards, the driver drove during rain and fog under low and high traffic conditions as shown in figure 2. Drivers were asked to maintain their usual driving behaviour throughout the entire experiment. It is noted that driving conditions in the virtual environment cannot be identical to those perceived by the driver in reality. However, the relative influence of the various parameters on driver’s behaviour and safety is considered not to be significantly affected by the use of a simulator.

Consequently, during each trial of the experiment, four unexpected events were scheduled to occur at fixed points along each drive (but not at the exact, same point in all trials, to minimize learning effects). More specifically, incidents concerned the sudden appearance of a pedestrian on the roadway. The objective of these incidents was to estimate the reaction time of the driver, a continuous variable defined as the time between the first appearance of the incident on the road and the moment the driver starts to brake in milliseconds. . Figure 3 illustrates the percentage of accidents occurred in the six different driving scenarios.

Figure 2. . Frames form the simulation environment in fog (left) and rain (right) scenarios.

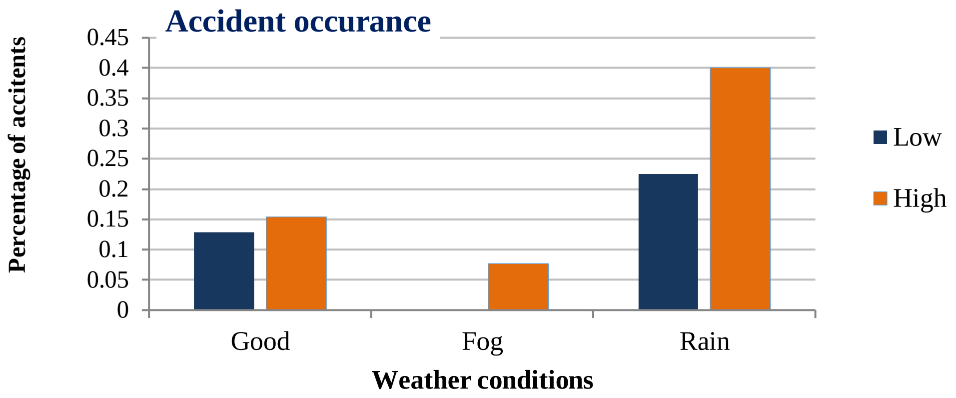

Figure 3. Percentage of accidents occurred in the three different driving scenarios under low and high traffic conditions

3. Methodology

Two models were developed to analyze the impact of weather conditions on young drivers' behaviour and safety in urban roads in terms of speed and accident probability. Specifically, lognormal linear regression model was developed for mean speed and binary logistic regression model for accident probability. Accident probability was modeled as a binary variable, equal to one when an accident occurred during the simulated drive, otherwise, equal to zero. Furthermore, it is mentioned that apart from these two models, a variety of different driving behavioural measures were investigated as well (e.g. reaction time, headway distance, lateral position) but it was found that they did not meet the criteria of the model's quality.

Lognormal Linear Regression:

$$yi = \beta_0 + \beta_1\chi_{1i} + \beta_2\chi_{2i} + \cdots + \beta_\kappa\chi_{\kappa i} + \varepsilon_i \quad (1)$$

$$log(yi) = \beta_0 + \beta_1\chi_{1\iota} + \beta_2\chi_{2i} + \cdots + \beta_\kappa\chi_{\kappa i} \quad (2)$$

Binary Logistic Regression:

$$y = logit(P) = \ln\left(\frac{Pi}{1 - Pi}\right) = B_0 + B_i\chi_i \quad (3)$$

$$\frac{Pi}{1 - Pi} = e^{B_0 + B_i\chi_i} = e^{B_0} * e^{B_i\chi_i} \quad (4)$$

$$\frac{Pi}{1 - Pi} = e^{B_0 + B_i\chi_{i+1}} = e^{B_0} * e^{B_i\chi_i} * e^{B_i} \quad (5)$$

The selection of variables was based on univariate tests and on t-test or Wald test to determine their statistical significance. Correlated statistically significant variables were identified. If two or more variables were correlated, the variable to be included in the model was selected based on its statistical significance and its relevance to the objectives of the analysis. A variable was used in the final model if the corresponding parameter estimate was significant at 95% confidence level, by means of t-test or Wald test. This 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 lognormal linear regression model and by means of the likelihood ratio test (LRT) for the binary logistic regression model.

The elasticity of the independent variables was also calculated in order to estimate the responsiveness and sensitivity of each dependent variable which are connected with the changes in each independent variable (Washington et al., 2010). This allowed the comparison of the impact of different variables on rainy or foggy driving conditions. The relevant elasticities were also calculated to classify variables with respect to the magnitude of their effect on the dependent variable in a straightforward way.

In particular, point estimates of elasticities (ei) are provided by the following formula, for each value (i) in the sample:

$$ei = \left(\frac{\Delta Y_i}{\Delta X_i}\right) * \left(\frac{X_i}{Y_i}\right) = \beta_i * \left(\frac{X_i}{Y_i}\right) \quad (6)$$

Then the mean estimate (e) is calculated as the average of (ei) values. It is noted that, although elasticities are most meaningful when comparing the effects of continuous variables, the formula was also applied for the categorical variables, as a means for the assessment of relative effects.

4. Results

The final dataset obtained from this study consisted of several types of variables regarding driver characteristics, parameters extracted from the driving simulator experiment as well as parameters extracted from the questionnaire and included driving performance nominal and ordinal variables such as average speed, lateral position of the vehicle, driving in rainy/ foggy conditions, traffic conditions, gender, age etc. that were analysed in the current research. For each model, the dependent variable was the mean speed for the lognormal linear regression model and the accident probability for the binary logistic regression model, respectively. Regarding the independent variables that were used in the models, they are the following: Driving in rain, Driving in fog, Traffic conditions, Gender, Age, Average of Revolutions per minute, Lateral position of the vehicle, Average of headway distance, Self-reported accident with material damages, Enjoy driving, Speed reduction while driving in rain. Table 1 provides a description of the independent variables that were found to be significant in the two developed models.

Table 1. Description of the parameters used in the models

Independent Variables	Description	Values or units
Driving in rain	Driving during the rainy conditions scenario	(1: yes, 0: no)
Driving in fog	Driving during the foggy conditions scenario	(1: yes, 0: no)
Traffic conditions	Traffic conditions simulated in the scenarios	(1: high traffic load, 0: low traffic load)
Gender	Driver's gender	(1:female, 0:male)
Age	Driver's age	(1:24-28, 0:20-23)
Average of Revolutions per minute	Mean motor revolution per minute	(1/min)
Lateral position of the vehicle	Mean distance from the right edgeline	(m)
Average of headway distance t	Distance from the rear bumper of the vehicle ahead	(m)
Accident with material damages	Self-reported accident occurrence with material damages while driving in rain in urban roads	(1: yes, 0: no)
Enjoy driving	Driver enjoying driving	(1: yes, 0: no)
Speed reduction in rain	Driver's statement of speed reduction while driving in rain	(km/h) (1: none, 2: 0-20, 3: >20)

4.1. Modelling Mean Speed

The first model investigates the effect of several parameters on mean speed of the driver. Results are presented in Table 2.

Table 2. Model results for mean speed

Independent variables	Mean driving speed			
	βi	*t*	Elasticity *(ei)*	Relevant elasticity *(ei)*
Driving in rain	-0,01	-1,66	-0,01	1
Gender	-0,02	-3,55	-0,01	2,88
Age	0,02	3,08	0,01	-3,09
Average of Revolutions per minute	0,01	10,78	0,06	-24,27
Lateral position of the vehicle	0,01	2,64	0,02	-7,45
Accident with material damages	-0,02	-2,87	-0,01	1,75
Enjoy driving	-0,04	-4,11	-0,03	10,57
Speed reduction in rain	-0,02	-2,69	-0,01	4,71
R^2	0,501			

Driving in an urban environment in rainy conditions leads to slightly decreased mean speeds compared to driving in good weather conditions. Results indicate that Driving in rain variable was not the one with the highest impact on mean speed. In both traffic conditions, this was the Average of Revolutions per minute of the vehicle. Its impact on mean speed is 24.27 times higher than that of Driving in rain. The variable "Enjoy driving" significantly affects the average driving speed and even 10.57 times higher than driving in rain variable. Regarding the participant's age and gender, they seem to have a similar effect on mean speed, 3.09 and 2.88 times higher than driving in rain respectively. More specifically, this research reveals that the vast majority of male drivers displayed a more unsafe behaviour during their simulated routes, developing higher speed than female drivers. The negative value of the gender coefficient implies that as the value of the variable increases (males coded as 0, females as 1), the mean driving speed gets lower.

Sensitivity analysis conducted is presented in figure 4.It shows to what extent the increase in the lateral position of the vehicle influences the mean driving speed for males and females during the driving in rain scenario of the experiment. For this purpose, the values of all independent variables except from the lateral position remained fixed and the average speed is plotted for these two circumstances.

Regarding the R^2 of the regression, it is high enough to indicate that the examined independent variables can predict the dependent one. The examination of additional independent variables, either not recordable or partially recorded and thus, excluded from this analysis, may provide more insight on the examined dependent variables.

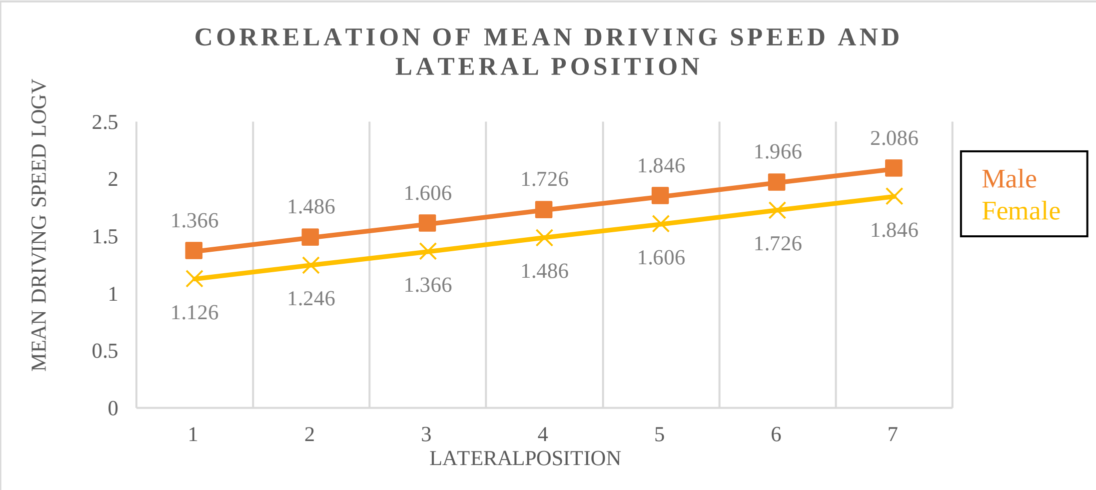

Figure 4. Correlation of log-mean driving speed and lateral position while driving in rain for male and female participants

4.2. Modelling Accident Probability

Regarding the accident probability, it 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. The respective model for accident probability is included in Table 3; in this case, LRT results and Wald test values are reported for each variable. The elasticity and relevant elasticity values for each independent variable used in the model are also shown.

Table 3. Model results for accident probability

Independent variables	Accident probability			
	βi	*Wald*	Elasticity *(ei)*	Relevant elasticity *(ei)*
Driving in rain	0,872	4,084	0,646	3,329
Driving in fog	-1,738	6,140	-0,690	-3,556
Traffic conditions	-1,172	6,397	0,194	1,000
Gender	0,693	2,675	-0,478	-2,466
Average of Revolutions per minute	0,002	3,843	2,031	10,469
Average of headway distance	0,014	2,841	0,445	2,296
Enjoy driving	-1,145	4,091	-0,420	-2,163
Null log-likelihood	214,316			

Final log-likelihood	172,595
Degrees of freedom	6

Results indicate that driving in rain leads to a statistically significant increase of accident probability compared to driving during good weather conditions. However, contradictory results were found concerning driving in fog, as the negative value of the βi coefficient indicates reduction of the accident probability when driving in fog. This finding could be due to the adjustment of drivers' behaviour by driving more carefully in an unfriendly foggy environment. Regarding traffic conditions, results show that the accident probability increases with the increase of the traffic density, low to high traffic conditions. Additionally, it is found that the female participants have a high probability to get involved to an accident, compare to male candidates. Two driving behavioural measures that have a negative effect on accident probability seem to be the average of revolutions per minute and the average of headway distance. Finally, results show that drivers who claim to enjoy driving tend to have low accident probability.

Sensitivity analysis conducted is presented in figure 5. It shows to what extent the increase in the average of revolutions per minute of the vehicle influences the accident probability during the driving in rain and the driving in fog scenario of the experiment, respectively. For this purpose, the values of all independent variables except from the average of revolutions per minute remained fixed and the accident probability is plotted for these two circumstances. It is remarkable that for low revolutions per minute, there is an obvious difference between the two scenarios, as the driving in rain scenario increases the accident probability in a much greater extent than the driving in fog scenario.

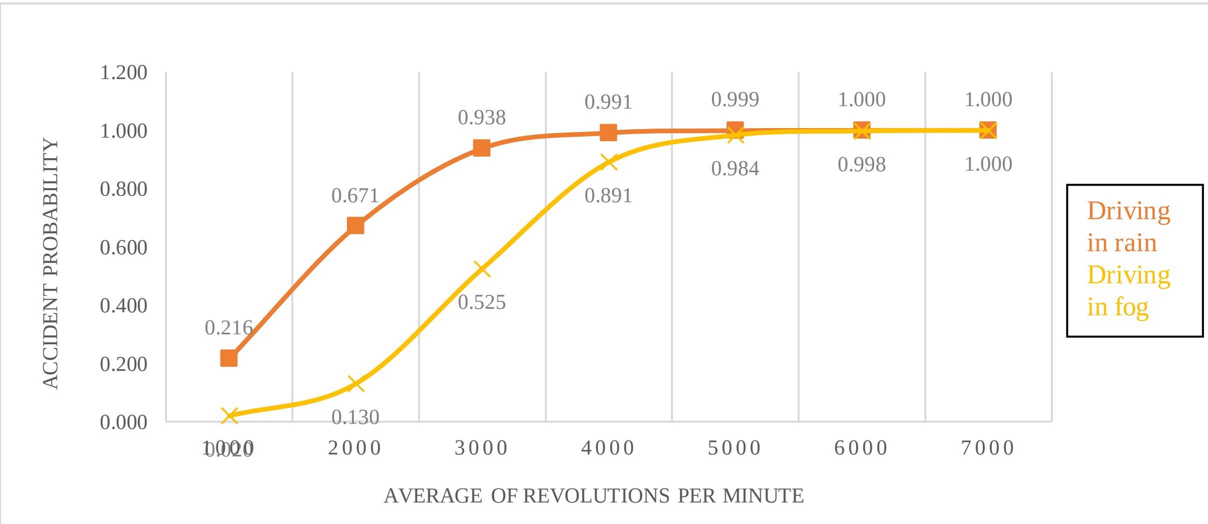

Figure 5. Correlation of accident probability and average of revolutions per minute during the driving in rain and the driving in fog scenario

5. Conclusions

Investigating the effect of weather conditions to driver behaviour and road safety through a driving simulator experiment has revealed some important results. It is shown that driving in rain leads to a small reduction of the mean speed, which however cannot outweigh the increase of the probability of getting involved in a road accident. These findings are in agreement with previous research studies that indicate that driving in rain is associated with increased number of crashes (Andrey and Yagar, 1993; Chang and Chen, 2005). On the other hand, driving under foggy conditions leads to a decreased accident probability, indicating drivers' compensation in adverse weather. More specifically, there are studies that have also shown that mainly because drivers of Mediterranean countries are not used to drive under adverse weather, they consequently adjust their behaviour by driving more carefully (Karlaftis and Yannis, 2010; Theofilatos et al., 2012), explaining the negative relationship between accident probability and driving in fog.

Considering the method used, it is noted that no matter how well a simulator experiment is designed, it is rather unlikely that drivers perform exactly as they would in actual conditions (Governors Highway Safety Association (GHSA), 2011). This is because several issues such as the feeling of speeding a known limitation of simulator experiments. Other issues such as the adoption of different driving behaviours when observed; the feeling of safety while driving on the simulator and ”simulator sickness” due to long drives should also be taken into consideration.

The results of this study may serve as a basis for further research using a similar experiment on a larger sample with participants of various age groups. Moreover, different driving environments and different traffic conditions should be further investigated, to explore the impairment caused by adverse weather conditions in different road environments (e.g., rural roads, and unfamiliar environment), more traffic density, nighttime driving, and so forth. Finally, for further statistical analysis and export of additional models, the implementation of other statistical methods would seem useful, which will belong to a different family from the one already selected.

Finally, it is highlighted that analyzing the driving performance during adverse weather conditions can lead to the identification of measures to improve driving performance, such as restrictive measures, training and licensing, as well as information campaigns.

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