Rethinking transport
27–30 April 2020

TRA 2020 HELSINKI

Proceedings of 8th Transport Research Arena TRA 2020, April 27-30, 2020, Helsinki, Finland

Analysis of the impact of nighttime driving to drivers' behavior in rural roads through a driving simulator experiment

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Abstract

Low light conditions, glare, darkness adjustment, age and driver experience and visibility are just some of the factors that may have a negative impact on driving performance and may lead to an increased accident probability. This study aims at analyzing the impact of night-time driving on driver behavior and safety of young drivers, in rural areas, through a driving simulator experiment. A driving simulator experiment was designed and carried out, in which 35 participants went through different driving scenarios in a rural road. Regression methods were used to analyze the impact of driving at night on the mean speed, reaction time and accident probability. Results suggest that night-time driving leads to slight, but significant, decrease of the mean speed, which however cannot outweigh the significant increase of the mean reaction time in case of an accident and therefore resulting to an increased accident probability.

Keywords: driving at night; reaction time; unexpected incident; driving simulator

1. Introduction

Road safety is a complicated scientific field of transport research due to the multidimensional nature of accident occurrence. One factor, which has not been given the necessary weight, is driving during the night and its influence on the behavior and driving safety. Early research results showed that a number of factors could adversely affect road safety at night (Fors and Lundkvist, 2009). Drowsiness, low brightness conditions, glare, darkness adjustment, signs and markings, age and driver experience and visibility are just some of the factors that affect night driving. Although it is not possible to attribute accidents to poor visibility, there is no doubt that a disproportionately large number of accidents occur at night: the rate of fatal accidents (reported per million) has been reported to be three to four times higher at night rather than during the day (Owens and Andre, 1996), especially since traffic flow is significantly lower at night than during the day.

An important factor in linking the potential increased risk of accidents due to low visibility with driving experience is the visual problems that result in slower reaction times for stimuli (Fors and Lundkvist, 2009). Driving is often described as "visual work", while some researchers have argued that the visual stimulus includes 90% of the information used in driving (Evans, 1991). There is broad agreement that good vision is essential for safe driving and there is no doubt that vision is diminished during night-time driving.

Driver behaviour research often makes use of driving simulators, as they allow for the examination of a range of driving performance measures in a controlled, relatively realistic and safe driving environment. Despite these limitations, driving simulators are an increasingly popular tool for measuring and analyzing driving performance, driver distraction, weather conditions etc., and numerous studies have been conducted, particularly in the last decades Within this context, driving simulators have become a widely used tool for examining the impact of driver distraction, with respect to individual driver differences and/or roadway design, as examining distraction causes and impacts in a controlled environment helps provide insights into situations that are difficult to measure in a naturalistic driving environment. (Regan et al. 2008).

In a driving simulator research (Bella et al., 2014) speeds were recorded for 40 drivers under simulated driving conditions during the day and night. The study referred to a section of an existing two-lane rural road consisting of 39 tangent-curve configurations. Driving speeds for all drivers were collected every 4 meters along all the geometric elements of the road and the results indicated that there were significant differences in driving speed along the curves, probably because the turns in the experiment were quite sharp, so drivers had to reduce their speed during the day. Therefore, the expected additional driving difficulty at night did not affect the choice of driving speed, which was already influenced by the sharp curves. In contrast, there were significant differences in driving speed along independent tangents greater than 200m, with the lowest average speed observed in the night scenario. This can be explained by the lower visibility at night, which did not allow drivers to realize properly the entire length of the tangent. Thus, drivers had a lower speed than in the day scenario when the full length of the tangent was visible.

In another study, Plainis & Pallikaris, 2005 found that driving during night, in the absence of ambient light, visual information in the driver's field of view is dramatically reduced, with the result that the driver faces two main problems: (a) difficulty in perceiving "potential" risks; and (b) - mainly from the lights of upcoming vehicles (which cause increased noise), both closely related to the significant reduction of "functional" low-light vision. In that context, the objective of this study is to investigate and specify in mathematical terms, the impact of night-time driving on different driving performance parameters on drivers' behavior in rural areas through a driving simulator experiment.

2. Data collection

Within the framework of the present research, a driving simulator experiment was designed and conducted in order to analyse the impact of night-time driving on young drivers' behavior and safety in rural 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, Greece. The NTUA driving simulator is a motion base quarter-cab manufactured by the FOERST Company. The simulator consists of 3 LCD wide screens 40'' (full HD: 1920x1080pixels), 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. It's worth mentioning that the simulator is validated against a real world environment (Yannis et al., 2015).

The selection and recruitment of the participants concerned in total 35 participants (23 men and 12 women). All these participants successfully completed the whole experimental procedure. The average age of men was 24,6 ± 2,5 years old and the average age of women was 23,4 ± 2,8 years old.

The methodology of the experimental procedure started by filling in a questionnaire about the driving habits and the self-recorded driving behaviour of the participants, with regard to night-time driving. Afterwards, they were asked to drive at the simulated routes. The driving scenario included driving on a rural road 2,1 km long, in different lightning conditions (speed limit 60 km/h to match the geometric and road environment characteristics), specifically during day and night. Furthermore, different traffic conditions were examined (low and high traffic conditions), and the experiment was carried out only under good weather conditions. During each trial, 2 unexpected incidents were scheduled to occur at fixed points along the drive. More specifically, incidents in rural area concern the sudden appearance of an animal (deer or donkey) on the roadway. After completing the driving simulator experiment, a master database was developed in order to be used in the statistical analyses which follow.

Figure 1. Experimental procedure - Driving during nigh-time conditions and driving during day time conditions

During, night-time driving the real conditions of the simulator room were adjusted in order to follow these scenarios. More specifically a dark curtain blocking all external light from entering the simulation area was applied for the night-time driving scenarios. In Figure 1, the night-time conditions at both simulated environment and simulator room are presented in contrast with the day-time driving. In Figure 2 below, two screenshots from the simulated environment in night-time and day-time driving conditions are presented, in order to visualize the visual differences between the two scenarios.

Figure 2. Screenshots from the simulated environment in night-time and day-time driving conditions

3. Methodology

At first preliminary statistical approach was carried out in order to have a first indication of which, probably, will be the impact of night-time driving on several driving parameters. Then, three regression models were developed to analyze the impact of night-time driving on young drivers' behaviour and safety in rural roads in terms of a) speed, b) accident probability at the unexpected incident, and c) reaction time at the unexpected incident. More specifically, log-normal linear regression models were selected to be developed for mean speed, normal linear regression for reaction time and binary logistic regression models for accident probability. Accident probability was designed 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 four statistical models, a variety of different driving behavioral measures were investigated as well (e.g. lateral position and wheel average) but it was found that they did not meet the criteria of the model's quality and they didn't have any statistically significant impact on any model, and for that reason they were eliminated from the analysis.

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 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., 2003).

This allowed the comparison of the impact of different variables on driving at night. 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. For the comparative assessment of variable effects within and across the three models, relative effects (e*) were calculated, on the basis of elasticities (e). In particular, point estimates of elasticities (ei) are provided by the following formula, for each value (i) in the sample:

$$ei = (\Delta \text{ Log } yi \ / \ \Delta xi)\ (xi / yi) = \beta i\ (xi / yi) \quad (1)$$

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

Before moving on to the main statistical part of this study which are the statistical models, a preliminary statistical approach was carried out. The main finding was that the night-time driving in both high and low driving conditions increases the accident probability to more than 70%, whereas the accident probability in day time is 3 times lower. Figure 3 illustrates the percentage of accidents occurred in the different driving scenarios.

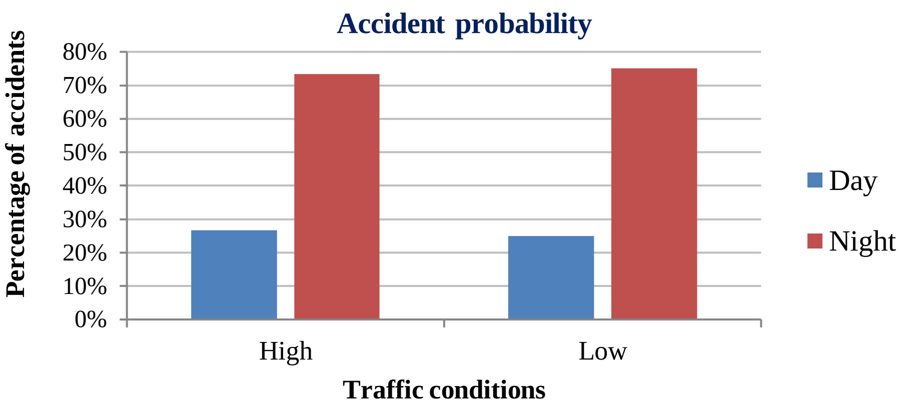

Figure 3. Percentage of accidents occurred in the two different driving scenarios under low and high traffic conditions

4.1. Mean Speed

The first regression analysis investigates the effect of several parameters on mean speed of the driver. Results are presented in Table 1.

Table 1. Model results for **mean speed**

Independent variables	*βi*	*t*	Elasticity *(e)*	Relevant elasticity *(ei)*
Night-time driving	-0,022	-6,317**	-0,007	4,155
Traffic conditions	-0,007	-1,987**	-0,002	1,344
Percentage of the route the driver was braking	0,008	5,813**	0,015	-9,283
Standard Deviation of the Wheel Average	0,030	18,971**	0,362	-23,700
Age	0,003	1,703**	0,004	-2,754
Driven kilometers per week	7E-05	2,134**	0,002	-1,391
Driver Avoids Driving At Night	-0,013	-2,749**	-0,002	1
R^2	0,876			

** statistically significant at 95% confidence level

Driving on a rural road during the night, results in a significant reduction in mean driving speed. In high traffic conditions, the speed was lower than when the road prevailing low traffic conditions. Results indicate that the impact of the independent variable "Nighttime Driving" on the mean speed is more than 4 times higher than the "Driver Avoids Driving At Night" variable and more than 3 times higher than the "Traffic conditions" variable. The "Nighttime Driving" variable has a 4.16 higher influence on the mean speed model than the "Driver Avoids Driving At Night" variable and 3.09 times higher than the "Traffic conditions" variable. The R^2 of the regression is relatively high and that indicates that the examined independent variables can predict the dependent one. Summarizing, the above results indicate that standard deviation of the wheel average, braking, the nighttime driving and the age have a significant impact on mean speed.

4.2. Accident Probability

The second regression analysis indicated that driving at night increases significantly the accident probability. Results are presented in Table 2.

Table 2. Model results for **accident probability**

Independent variables	*βi*	*t*	Elasticity *(e)*	Relevant elasticity *(ei)*
Night-time driving	1,426	9,194**	1,720	4,733
Driving Experience	-0,779	-3,695**	-1,204	3,316
Age	-0,700	3,694**	0,363	1,000
Standard Deviation of Time headway	0,006	6,470**	0,410	1,129
Gender	0,793	2,246**	0,647	1,780
R^2	0,128			

** statistically significant at 95% confidence level

The higher the driver's driving experience, the lower the accident probability. It was also observed that the increase of variation in the average time headway brings increased likelihood of accident and accident probability was increased for men compared to women. The variable "Night-time Driving" had the greatest influence compared to the other variables in the accident probability model. It has a 4.73 times greater influence over the "Age" variable and 1.43 times greater than the "Driving Experience" variable, which the second most influential in the likelihood of an accident is occurring. The "Gender" variable has a 1.78 greater influence on the model than the "Age" variable and 1.58 times greater than the "Standard Deviation of Timehead" variable.

4.3. Reaction time

The last model concerned reaction time at unexpected incident. It was noticed that drivers had a significantly worse reaction time during night-time driving than driving during the day. Results are presented in Table 3.

Table 3. Model results for **reaction time**

Independent variables	*βi*	*t*	Elasticity *(e)*	Relevant elasticity *(ei)*
Night-time driving	101,03	1,806**	0,078	1,907
Driven kilometers per week	0,969	2,058**	0,069	1,697
Driver Avoids Driving At Night	141,628	2,001**	0,041	1,000
Gender	148,983	2,307**	0,271	6,618
Standard Deviation of Driving Speed	-24,145	-2,167**	-0,387	-9,431
R^2	0,226			

** statistically significant at 95% confidence level

The results extracted from the model indicate that night-time driving has a statistically significant and negative impact on the reaction time of the drivers at an unexpected incident. Moreover, the riskiest profile of a driver regarding the reaction time during night-time is a male driver who self-declare that they avoid driving at night because he considers this as a dangerous condition. Specifically, it has 9.43 times more influence than the variable "Driver Avoids Driving At Night" and 1.43 times greater than the variable "Gender" that is the second in command influence to the average driver reaction time. The variable "Gender" significantly affect the average driver's reaction time and especially by 6.62 times as compared with the variable "Driver Avoids Driving At Night". It also affects 3.9 times the model from the "Driven kilometers per week" variable and 3.47 times from the "Nighttime Driving" variable. The "Nighttime Driving" variable has a 1.91 greater influence on the model than the "Driver Avoids Driving At Night" variable and 1.12 times higher than the "Driven kilometers per week" variable. Summarizing, the above results indicate that standard deviation of driving speed, gender and night-time driving have a significant impact on the reaction time. The relatively low R^2 values indicate that the examined independent variables can partially predict the dependent. Still they are acceptable and might be improved with the examination of additional independent variables, which were either not recordable or partially recorded, and thus excluded from this analysis.

5. Conclusions

The present research aims to analyze the impact of nighttime driving on the behavior and safety of young drivers on rural roads through a driving simulator experiment. The effects of nighttime driving were examined in combination with traffic conditions and driver characteristics. Variables were identified based on a number of tests and also correlations between variables were checked. The variables were selected on the basis of their statistical significance and their relevance to the objectives of the analysis.

Results indicate that nighttime driving, clearly increases the accident probability and the reaction time in case of an accident in a significant level. At the same time, results indicate a small reduction in driving speed when driving at night-time conditions. This is explained by the fact that drivers seem to have a compensatory behavior, as they consider driving at night as a dangerous condition due to limited visibility and for that reason they reduce their speed in order to increase their attention to the driving environment. This compensatory strategy, however, is not successful as indicated by the worse reaction time and higher accident probability that they have.

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. This is because several issues such as the feeling of speeding and braking cannot be fully represented, which is a known limitation of simulator experiments. Other issues such as the adoption of different driving behaviors, the feeling of safety while driving on the simulator and simulator sickness due to long drives should also be taken into consideration.

This study may serve as a basis for further similar experiments on rural and urban roads with larger sample and participants of various ages with various years of driving experience. According to previous studies, although young drivers show increased ability to share attention between concurrent tasks, they are more vulnerable to distraction. Moreover, the impairment caused by night-time driving should be explored in a larger sampler of drivers, different age groups and traffic conditions. 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 already selected.

Finally, in future studies on-road or naturalistic driving experiment could also be conducted with drivers using smartphones and smart wearables in order to study their safe (or not) driving performance during night-time in a more holistic approach.

The ultimate goal of this study and of future relevant approaches, regarding road safety, is to highlight the driving difficulties emerging when driving at night and to suggest and promote several interventions in order to enhance lighting engineering at both infrastructure and vehicles. More specifically, lighting should be improved at the majority of the road network, with emphasis to motorways and rural roads with high speed limits where an unexpected incident is very probable to result to a serious accident, and lighting should also be improved at the vehicle itself with new technologies with stronger and “smarter” lights.

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