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Investigating which factors affect lateral position variability through a driving simulator experiment

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Abstract

The objective of the present research is to investigate the effect of several risk factors including distraction conditions, driver as well as road environment characteristics on lateral position variability. For this purpose, a large driving simulator experiment was carried out, in which 95 participants from three different age groups were asked to drive under different types of distraction in different road and traffic conditions. To achieve the research objectives, generalized linear mixed models were implemented regarding standard deviation of lateral position as the data used in this research involve repeated observations from each individual trial (each driver completes six drives in rural and six drives in urban environment). Results indicate that several parameters are found to significantly affect lateral position variability including driver characteristics such as gender and age and area type. Regarding distraction cell phone use slightly increased lateral position variability indicating that drivers while talking and holding the cell phone find difficult to maintain the vehicle probably.

Keywords: road safety; driving simulator; lateral position variability; distraction; risk factors

1. Introduction

Considering that inappropriate lateral positioning is one of the primary factors leading to accidents (Riser, 2006), lateral control measures are some of the most commonly used driving behaviour metrics. Lateral Control Measures assess how well drivers maintain vehicle position within a lane. These mainly include lateral position, standard deviation of lateral position and steering wheel metrics. Lateral control measures can be sensitive to eyes off the road from distractions, perceptual-motor declines, and some cognitive declines. However, lateral control measures are also affected by the handling characteristics of the driving simulator, and the simulator vehicle may differ markedly from the one that the participant normally drives. More specifically, drivers may have more problems adapting to these differences in handling, and this may be especially problematic when frequent right and left turns are required (Regan et al., 2008).

Lateral position or lane keeping refers to the position of the vehicle on the road in the relation to the center of the lane in which the vehicle is travelling. Decrements in lateral position control are used as a measure of secondary task load when evaluating the effect on in-vehicle distractions sources on driving performance (Greenberg et al., 2003; Green et al., 2004). Several studies have examined the impact of driver demographic characteristics lateral control of vehicle (Liu & Ou, 2011; Rumschlag et al., 2015). Especially with focus on cell phone use, the effect of gender is still not clear from previous researches (Rumschlag et al., 2015); but, while comparing different age groups, the impact of cell phone use during driving appears to be more detrimental for older drivers (Liu & Ou, 2011; Tractinsky, Ram, & Shinar, 2013). Furthermore, in two meta-analyses of the effect of cell phone usage on driver performance, Horrey & Wickens (2006) and Caird et al. (2008) found only a modest effect of distraction on lateral control, suggesting that cell phone conversation has minimal effect on lane keeping. A possible reason for these mixed findings is that the effects of distraction on lane keeping performance depend on the modality and demand of the secondary tasks. Visual, manual and cognitive distraction apparently have different effects on lane keeping performance (Liang & Lee, 2010)

Consequently, measures of steering wheel control have been used extensively in many forms of driving research. These include standard deviation of steering wheel angle, steering wheel reversal rate, steering wheel action rate, steering entropy. In driver distraction and workload research, steering wheel movements are considered to be an indicator of a secondary task load. When driving without any distraction source, drivers make a number of small corrective steering wheel movements to maintain lateral position while in distracted driving drivers often make a number of large and abrupt steering wheel movements to correct driving errors (Regan et al., 2008; Brooks et al., 2005). A research authored by Dozza et.al. (2015) utilized naturalistic driving data collected from 108 drivers in the Integrated Vehicle-Based Safety Systems program to assess the extent to which using a phone changes lateral or longitudinal control of a vehicle. The IVBSS study included drivers from three age groups: 20–30 (younger), 40–50 (middle-aged), and 60–70 (older). Results showed that while manipulating the phone (i.e., dialing, texting), drivers exhibited larger lateral safety margins and experienced less severe lateral threats than while conversing on the phone

Taking into account that driver distraction is a key area of the present research, it should be mentioned that driver distraction is defined as “a diversion of attention from driving, because the driver is temporarily focusing on an object, person, task or event not related to driving, which reduces the driver’s awareness, decision making ability and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes” (Regan et al., 2008). Driver distraction factors can be subdivided into those that occur outside the vehicle (external) and those that occur inside the vehicle (in-vehicle). The in-vehicle sources of distraction include the use of mobile phone (either for conversing or for texting), conversation with passengers, smoking, eating or drinking, listening to music and in-vehicle assistance systems (e.g. navigation systems) (Johnson et al., 2004; Stutts et al. 2001), and their effects are largely examined by means of simulator experiments (Horberry et al. 2006; Bellinger et al. 2008). For the purpose of this research, an extensive literature review was carried out, presenting driving simulator studies on driver distraction, with emphasis on the effects of mobile phone use and conversation with passengers.

Considering the experimental methods, between the different processes, driving simulators can give precise information regarding lateral vehicle positioning in a virtual world, often at high capture rates. Furthermore, driving simulators have become a widely used tool for examining the impact of driver distraction 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 [Johnson et.al., 2011).

The objective of this research is the investigation of the effect of area and traffic conditions as well driver characteristics and distraction conditions on lateral position variability. For this purpose, a driving simulator experiment was carried out, in which 95 drivers from all different age groups (young, middle aged and older) were asked to drive under different types of distraction (no distraction, conversation with passenger, cell phone use) in rural and urban road environment, in low and high traffic conditions. The paper is structured as follows. In the next chapter the methodology and data part is provided including an overview of the experiment, the description of the driving simulator experiment and sample characteristics, followed by the statistical analysis theoretical background. Finally, the results are presented and discussed and some concluding remarks are provided.

2. Methodology and data

2.1. Overview of the experiment

Within this framework of the present research, a driving simulator experiment was carried out, in which 95 participants were asked to drive under different types of distraction (no distraction, conversation with passenger, cell phone use) in different road (urban/rural) and traffic conditions (high/low). Each participant aimed to complete 12 driving trials, while in each trial, 2 unexpected incidents were scheduled to occur at fixed points along the drive. Participants were also asked to fill in two questionnaires regarding their driving behaviour, as well as self-assessment and memory tests. The above stages were designed based on specific parameters and criteria as well as design principles that were appropriate for the research assumptions and objectives of the research.

The driving simulator experiment took place at the Department of Transportation Planning and Engineering of the National Technical University of Athens, where the FOERST Driving Simulator is located. The NTUA driving simulator is a motion base quarter-cab and 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 (Figure 1).

Figure 1. Driving simulator

2.2. Driving at the simulator

The driving simulator experiment started with a practice drive (approximately 10 minutes), until the participant fully familiarized with the simulation environment. Afterwards, the participant drove the two sessions (~20 minutes each). Each session corresponded to a different road environment:

- A rural route that was 2.1 km long, single carriageway and the lane width was 3m, with zero gradient and mild horizontal curves.
- An urban route that was 1,7km long, at its bigger part dual carriageway, separated by guardrails, and the lane width was 3.5m. Moreover, narrow sidewalks, commercial uses and parking were available at the roadsides.

Within each road / area type, two traffic scenarios and three distraction conditions were examined in a full factorial within-subject design. The distraction conditions examined concern undistracted driving, driving while conversing with a passenger and driving while conversing on a mobile phone.

The traffic scenarios were:

- QL: Moderate traffic conditions – with ambient vehicles' arrivals drawn from a Gamma distribution with mean m=12 sec, and variance σ^2=6 sec, corresponding to an average traffic volume Q=300 vehicles/hour.
- QH: High traffic conditions – with ambient vehicles' arrivals drawn from a Gamma distribution with mean m=6 sec, and variance σ^2=3 sec, corresponding to an average traffic volume of Q=600 vehicles/hour.

Consequently, in total, each environment (urban / rural) included six trials, i.e. six drives of the simulated route. During each trial of the experiment, 2 unexpected incidents were scheduled to occur at fixed points along the drive (but not at the exact same point in all trials, in order to minimize learning effects). More specifically, incidents in rural area concerned the sudden appearance of an animal (deer or donkey) on the roadway, and incidents in urban areas concerned the sudden appearance of an adult pedestrian or of a child chasing a ball on the roadway (Figure 2). The experiment was counterbalanced concerning the number and the order of the trials, on the basis of several combinations of the parameters of interest

Figure 2. Unexpected incident - donkey crossing the lane / child with ball crossing the road

2.3. Sample characteristics

In Table 1 the distribution of participants per age and gender is presented. It is shown that almost half of the participants are males (47) and half females (48) indicating that the there is a total balance in the sample regarding gender and age groups.

Table 1. Distribution of participants per age group and gender

Age group	Female		Male		Total	
18-34	9	19%	19	40%	28	29%
35-55	19	40%	12	26%	31	33%
55+	20	42%	16	34%	36	38%
Total	48	100%	47	100%	95	100%

In Figure 2 the distribution of driving trials is presented per area type and order of trials. It is shown that 95 participants started the experiment by driving in the first sessions in rural area. However, only 48 drivers managed to complete all 6 driving trials. The respective number is 41 regarding the 6 trials in urban area.

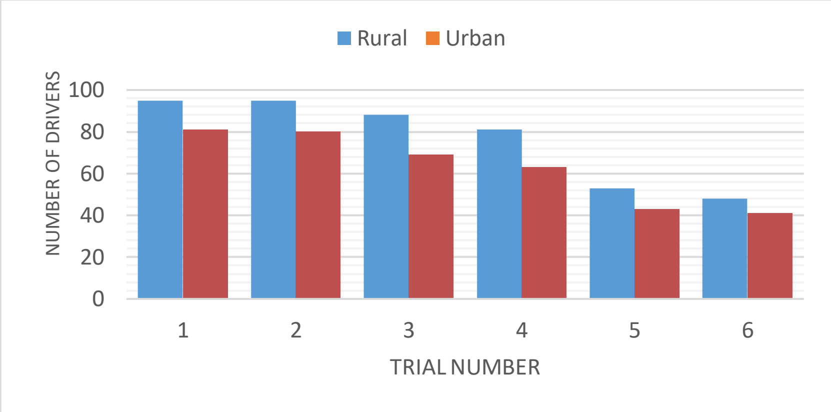

Figure 2. Distribution of number of driving trials

This is explained by the fact that a significant number of participants came up with simulator sickness symptoms during the experiment and did not manage to complete all the trials. In addition, the complex driving simulator environment in urban area enhanced these symptoms resulting in fewer number of participants that drove all urban driving scenarios.

2.4. Analysis background

Linear regression is used to model a linear relationship between a continuous dependent variable and one or more independent variables. Furthermore, the generalized linear model (GLM) is a flexible generalization of ordinary linear regression that allows for inclusion of dependent variables that have error distribution models other than a normal distribution. The GLM generalizes linear regression by allowing the linear model to be related to the response variable via a link function. It also allows the magnitude of the variance of each measurement to be a function of its predicted value (Washington et al., 2011).

The structure regarding each individual regression analysis is the following. Starting with the description of the model, both the dependent and independent variables are recorded in order to set the target of each analysis. Then, the parameter estimates are summarized along with the standard errors, t- and p-values. Before accepting the results of the model, it is important to evaluate their suitability in explaining the data. One way to do this is to visually examine the residuals. If the model is appropriate, the residual errors should be random and normally distributed. In addition, removing one case should not significantly impact the model's suitability. That statistical software R provides four graphical approaches for evaluating the models as follows: The residual errors plotted versus their fitted values, the square root of the standardized residuals as a function of the fitted values, the standard Q-Q plot, and each point's leverage.

Furthermore, as presented in the description of the driving simulator experiment, the data used in this research involve repeated measured observations from each individual drive, as each driver completes six drives in rural and six drives in urban environment. For this reason, in order to deal with the heterogeneity across individuals, generalized linear mixed models are implemented and presented next for each model. Then, the likelihood ratio test is taking place in order to examine the goodness-of-fit for each pair of models. The purpose is to prove that the random effect contributes significantly to the fit of the model and therefore, the fit of the generalized linear mixed models outperforms respective generalized linear models.

3. Results

As already indicated, lateral position variability is a critical lateral measure which indicates how well drivers maintain vehicle position within a lane and it is estimated as the standard deviation of the lateral position of each driver. Within this framework, the present analysis is exploring lateral position variability while explanatory variables include driver characteristics, road environment characteristics as well as driver distraction sources. The generalized linear model parameter statistics are summarized in table 2.

Table 2. Parameter estimates of the GLM of lateral position variability

Variables	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	0,26	0,03	7,47	< 0,000
Distraction - Cell phone	0,06	0,03	1,75	0,08
Age group - Middle Aged	0,11	0,03	3,01	< 0,000
Age group - Older	0,08	0,04	2,12	< 0,000
Area type - Urban	1,30	0,03	45,44	< 0,000
Gender - Male	-0,13	0,03	-4,32	< 0,000
Summary statistics				
AIC	888,62			
Log-restricted-likelihood	139,33			
Degrees of freedom	837			

Following the evaluation of the suitability of the model, the following graphs are provided (Figure 3). In the upper left graph, the residuals are randomly distributed around the horizontal line. In the upper right graph there is no obvious trend in the standard deviation of the residuals. In the Q-Q plot, residuals are on the dotted line while the last diagram is a measure of importance in determining the regression results. All graphs indicate the suitability of the model.

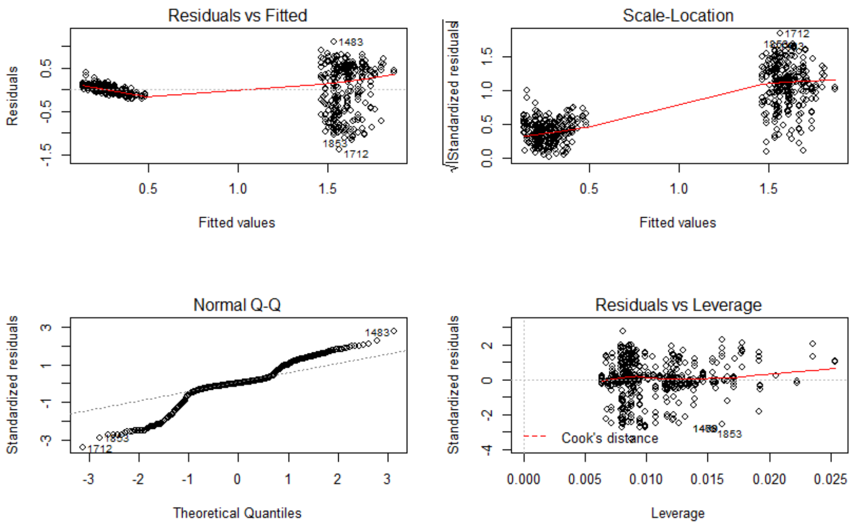

Figure 3. Graphical approach of residuals

Since the data involve repeated measured observations from each individual drive, the generalized linear mixed model is implemented and presented in Table 3.

Table 3. Parameter estimates of the GLMM of lateral position variability

Variables	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Intercept	0,23	0,05	4,41	< 0,000
Distraction - Cell phone	0,07	0,03	2,30	0,022
Age group - Middle Aged	0,13	0,06	2,25	0,027
Age group - Older	0,10	0,06	1,79	0,074
Area type - Urban	1,29	0,03	49,71	< 0,000
Gender - Male	-0,11	0,05	-2,35	< 0,021
Random effect				
By Person ID (stdev)	0,18			
Summary statistics				
AIC	839,16			
Log-restricted-likelihood	-411,58			

The likelihood ratio test with a value of LRL.pos.var= -24,20 (1 degree of freedom) indicates that the random effect contributes significantly to the fit of the model and therefore the generalized linear mixed model outperforms the respective generalized linear model.

Results indicate that several parameters are found to significantly affect the standard deviation of lateral position during the driving simulator experiment. Focusing on the distraction sources examined, cell phone use slightly increased lateral position variability indicating that drivers while talking and holding the cell phone find difficult to maintain the vehicle probably due to the fact that they hold the steering wheel with one hand while the second hand holds the cell phone. On the contrary, conversing with a passenger was not found to affect significantly the lateral position variability of the vehicle.

Regarding driver characteristics male drivers were found to achieve lower lateral position variability than the female ones indicating that males drive more steadily compared to female drivers, a fact that is confirmed in the literature. Moreover, two age groups, middle aged and older drivers, have a statistically significant increase in lateral position variability, proving that these types of drivers find difficulties in maintaining the driving simulator vehicle compared to young drivers, probably explained by the higher physical abilities of young drivers to maintain the simulator.

Finally, area is the parameter with the highest effect on lateral position variability indicating that lateral position variability is higher in urban areas, which could be explained by the fact that the urban environment is more complex with much more interactions between vehicles.

4. Discussion

The present research analyzed lateral position variability, aiming to investigate the effect of several driver and road characteristics as well as the effect of distraction. For this purpose, 95 participants from three different age groups were asked to drive under different types of distraction in urban and rural road environment with low and high traffic volume.

Results confirm the initial hypothesis that cell phone use has a negative effect on driving performance and road safety as it was proved that while talking on the cell phone lateral position variability was significantly increased. On the other hand, conversation with the passenger did not significantly affected the position of the vehicle indicating the different distraction mechanism between cell phone and conversation with the passenger which is correlated with driver's age. Mobile phone use distraction is consisted of prolonged and repeated glances to the mobile and drivers (especially middle-aged and older) have difficulty in maintaining mobile devices while driving because they are not as practiced and efficient as technological multi-taskers when compared to younger drivers. On the other hand, when conversing with the passenger, drivers' glance is out of the road very often and this has a direct effect on lateral position variability.

Regarding the explanatory variables that were examined through the experiment, are type had the highest effect on the smooth positioning of the vehicle, probably explained by the fact of the complicated driving environment of a city which is further emphasized by the urban scenario of the driving simulator. As a result, drivers find more difficult to maintain the vehicle in urban than in rural area. Finally, regarding driver characteristics two age groups and the gender of drivers have a significant effect indicating that the best performance regarding lateral position variability is achieved my young male drivers.

In the next steps of the present research it would be important to investigate the impact of mobile phone use, not only when the drivers talk on mobile phone using a hand-held device but also when they use a hands-free device, a Bluetooth, or when they type messages. In addition, it would be interesting to investigate and correlate all lateral measures that are recorded by the driving simulator in order to extract concluding remarks regarding the overall positioning of the vehicle on the road under distraction

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