How does distracted driving affect lateral position of older drivers?

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Abstract
The objective of this research is the analysis of the lateral position of drivers, while talking on the cell phone and conversing with another passenger with focus on older drivers. To achieve this objective, a large driving simulator experiment was carried out, in which 95 participants from all age groups were asked to drive under different types of distraction (no distraction, conversation with passenger, cell phone use) in rural/urban road environment, in low/high traffic. In the next step, an appropriate modelling methodology has been developed, including first descriptive analysis in order to explore the large database. Then generalized linear models as well as generalized linear mixed models regarding lateral position were implemented in order to estimate the effect of the examined distraction sources as well as of driver and road characteristics directly on the lateral control and indirectly on driving behaviour and road safety. Results indicate that both conversing with a passenger and talking on the cell phone, while driving, lead to increased lateral position for all drivers especially in urban areas. Female drivers, in rural areas with high traffic, were found to have the worst lateral position, while being distracted (either conversing with a passenger or talking on the cell phone). Furthermore, older drivers talking on the cell phone achieved the highest lateral variability.

1. Introduction

Taking into account that inappropriate lateral positioning is one of the primary factors leading to accidents [1], lateral control measures are some of the most commonly used driving behaviour metrics. In general, lateral control measures assess how well drivers maintain vehicle position within a lane. These include lateral position, standard deviation of lateral position, steering wheel metrics etc. Meanwhile, as there are a lot of different methods and measures that exist for evaluating driving performance, the selection of the specific measures for driver distraction research, as in other areas of research, should be guided by a number of general rules related to the nature of the task examined as well as the specific research questions [2].

Between the different experimental processes, driving simulators can give precise information regarding lateral vehicle positioning in a virtual world, often at high capture rates [3]. 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 [2].

Lateral position refers to the position of the vehicle on the road in the relation to the centre of the lane in which the vehicle is travelling. This measure is therefore an indicator of general driving strategy. When driving with extreme orientation towards one of the lane boundaries, the likelihood of a lane exceedance is increased. 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 [4, 5]. 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 [2].

Several researches have been implemented in the last decades examining the effect different types of distraction on selected lateral control measures, always depending on the specific research question. More specifically, similarly to the present study, in two meta-analyses of the effect of cell phone usage on driver performance, [6] and [7] 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 the above finding is that the effects of distraction on lane keeping performance depend on the modality and demand of the secondary tasks.

On the other hand, visual, manual and cognitive distraction apparently have different effects on lane keeping performance [8]. Authors found that the visual and combined distraction both impaired vehicle control, hazard detection, and resulted in frequent, long off-road glances. More specifically, during the combined task drivers processed the direction information almost continuously and intermittently looked at the in-vehicle interface. The effects of this intermittent visual demand are present in all vehicle lateral control hazard perception and eye scanning patterns.

In [9] et al. (2008) the trajectory control in terms of vehicle lateral position using an interactive fixed-base driving simulator was investigated. Authors examined the impact of four perceptual countermeasures (painted centre line, post-delineators, rumble strips on both sides of the centre line, and sealed shoulders) on lateral control when driving on crest vertical curves. Results showed that two measures, rumble strips on both sides of the centreline and sealed shoulders, were more effective others. Furthermore, in another similar study on the same driving simulator.

In turn, a lack of motion and visual cues has been shown to affect the precision of lateral position control to a greater extent in simulators than actual vehicles, because the absence of visual and kinaesthetic feedback leads to a decreased ability to select appropriate steering corrections [10, 11]. Thus, it appears that environmental fidelity and the precise replication of motion and visual cues in particular, is important for the accurate measurement of the effects of distraction on lateral control.

Taking into account that several driving performance measures as well the distraction sources examined are common investigated in the last decade, the present study is based on two scientific contributions. The first concerns the design and implementation of a large and rigorous driving simulator experiment and consists the basis of the originality of the overall research. The design and implementation of this experiment is a central component of the present work aiming to deal with the majority of limitations that have been noted in the assessment of the examined simulator studies on driver distraction. The second scientific contribution concerns the development and application of an advanced statistical analysis methodology. More specifically, as each driver completed several individuals driving trials, data involve repeated measures observations from each driver. For this purpose, generalized linear mixed models are considered and developed in the present research.

Based on above the objective of this research is the analysis of the lateral position of drivers while talking on the cell phone and conversing with another passenger with focus on older drivers based on a driving simulator experiment. In the next chapters, the driving simulator experiment is presented, in which participants from three different age groups were asked to drive under different types of distraction (no distraction, conversation with passenger, cell phone use) in rural and urban road environment. Then, all statistical steps of the analyses are presented and discussed while some concluding remarks are provided.

2. Methodology

2.1 Overview of the Experiment

Within this research, a driving simulator experiment was including different driving scenarios. The design of the distracted driving scenarios is a central component of the experiment and includes driving in different road and traffic conditions, such as in a rural, urban area with high and low traffic volume. More specifically, this assessment includes an urban driving session with up to six trials and a rural driving session with up to six trials. These trials aim to assess driving performance under typical conditions, with or without external distraction sources. The driving simulator experiment takes place at the Department of Transportation Planning and Engineering of the National Technical University of Athens, where the Foerst Driving Simulator FPF is located. It is a quarter-cab simulator with a motion [12].

Participants

Within the framework of the present driving simulator experiment 95 participants took place the driving simulator experiment. In Table 1 the gender, age, and experience distribution of participants 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. Furthermore, in order to investigate age characteristics, three age groups were created. Out of the 95 participants, 28 were young drivers aged 18-34 years old, 31 were middle-aged drivers aged 35-54 years old and 36 older driver aged 55-75 years old. In addition, the average years of education were 15.5 for the whole sample while the average years of driving 25.45 indicating that the majority of participants were experienced drivers.

Table 1 Distribution of participants per age group and gender

Age group	**Female**		**Male**		**Total**		**Years' Education**	**Years' Experience**
18-34	9	19%	19	40%	28	29%	16	6
35-55	19	40%	12	26%	31	33%	15	25
55+	20	42%	16	34%	36	38%	14	37
Total	48	100%	47	100%	95	100%	-	-

Exclusion criteria

People who participated in the present experiment met certain basic criteria. Each participant should:

- have a valid driving license
- had driven for more than 3 years
- had driven more than 2500km during the last year
- had driven at least once a week during the last year
- had driven at least 10km/week during the last year
- not had any important kinetic disorder that prevent them from basic driving moves
- not be pregnant
- not be an alcoholic or had any other drug addiction

In case one participant failed even in one of the above criteria, was eliminated from the experiment from carrying out the experiment.

Familiarisation

A familiarization session or 'practice drive' is typically the first step of all simulator experiments. During the familiarization with the simulator, the participant practiced in handling the simulator (starting, gears, wheel handling etc.), 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 (there was no exact time restriction), the participant moved on to the next phase of the experiment.

Driving at the Simulator

The first action of the coordinator of the experiment is to brief the driver orally and in writing regarding the full procedure of the experiment (completion of the questionnaire, total duration, driving preparation etc.). Emphasis is given to the participants in the maintenance of their usual driving behaviour without being affected from any other factors (stress, fear, etc.). After the practice drive, each participant drives the two sessions (approximately 20 minutes each). Each session corresponds to a different road environment (Figure 1):

- A rural route that is 2.1 km long, single carriageway and the lane width is 3m, with zero gradient and mild horizontal curves.
- An urban route that is 1.7km long, at its bigger part dual carriageway, separated by guardrails and the lane width is 3.5m. Moreover, narrow sidewalks, commercial uses and parking are available at the roadsides.

Figure 1. Urban / rural route

Within each road / area type, two traffic scenarios and three distraction conditions are 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 cell phone.

The traffic scenarios are:

- QL: Moderate traffic conditions - with ambient vehicles' arrivals drawn from a Gamma distribution with mean m=12 sec, and variance σ2=6 sec2, 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 σ2=3 sec2, corresponding to an average traffic volume of Q=600 vehicles/hour.

Consequently, in total, each session (urban or rural) includes six trials, i.e. six drives of the simulated route.

Randomisation

The first principle of an experimental design is randomization, which is a random process of assigning treatments to the experimental units. The purpose of randomization is to remove bias and other sources of extraneous variation, which are not controllable. Another advantage of randomization (accompanied by replication) is that it forms the basis of any valid statistical test [14]. In this experiment randomization was implemented in the order of area type (urban/rural) in which the participant was going to drive, as well as in the order of the traffic scenarios and distraction scenarios

Conversation topics

As already mentioned, each trial corresponds to different driving distractor and different area type and traffic volume. The trials that demand conversation as a distractor were covered by the following topics: Family, Origin, Accommodation, Travelling, Geography, Interests, Hobbies, Everyday life, News and Business. More specifically, one researcher was responsible for performing the distraction tasks during the experiment: the conversation task and the phone call with the participant.

2.2 Analysis methods

To achieve the objectives set out in this paper, an appropriate modelling methodology has been developed, regarding lateral position, which consists of the following steps.

In the first step, a descriptive analysis took place through box plots. A box plot (also known as a box-and-whisker chart) is a convenient way to show groups of numerical data, such as minimum and maximum values, upper and lower quartiles, median values, outlying and extreme values. The spacing between the different parts of the box plot indicates the degree of dispersion (spread) and skewness in the data and identifies outliers. More specifically, regarding box plots: The line in the middle of the boxes is the median. The bottom of the box indicates the 25th percentile. Twenty-five percent of cases have values below the 25th percentile. The top of the box represents the 75th percentile. Twenty-five percent of cases have values above the 75th percentile. Consequently, half of the cases lie within the box.

In the second step, generalized linear models were developed as they facilitate the analysis of the effects of explanatory variables in a way that closely resembles the analysis of covariates in a standard linear model, but with less confining assumptions. This is achieved by specifying a link function, which links the systematic component of the linear model with a wider class of outcome variables and residual forms. A key point in the development of GLM was the generalization of the normal distribution (on which the linear regression model relies) to the exponential family of distributions. In the third step, generalized linear mixed models were developed as the data used in this research involve repeated measures observations from each individual drive (each driver completes six drives in rural and six drives in urban environment). In statistics, a generalized linear mixed model (GLMM) is an extension to the generalized linear model in which the linear predictor contains random effects in addition to the usual fixed effects [13]. When dealing with such panel data it is often useful to consider the heterogeneity across individuals, often referred to as unobserved heterogeneity. The generalized Linear mixed Model generalizes the standard linear model in three ways: accommodation of non-normally distributed responses, specification of a possibly non-linear link between the mean of the response and the predictors, and allowance for some forms of correlation in the data [15].

In the third step, in order to confirm that the random effect was statistically significant, and therefore the Generalized Linear Mixed Models were superior to the respective Generalized Linear Models, likelihood ratio test [16] were performed between each set of models. The likelihood ratio test (LRT) is a statistical test of the goodness-of-fit between two models. A relatively more complex model is compared to a simpler model to see if it fits a particular dataset significantly better. If so, the additional parameters of the more complex model are often used in subsequent analyses. The LRT is only valid if used to compare hierarchically nested models. That is, the more complex model must differ from the simple model only by the addition of one or more parameters. Adding additional parameters will always result in a higher likelihood score.

All statistical analyses have been implemented and estimated in the R language for statistical computing [17].

3. Results

In this section, all stages of the statistical analyses are presented together with an interpretation of the modelling results. Beginning with the descriptive analyses, in Figure 2, the lateral position of drivers is presented per distraction factor (no distraction, conversation with the passenger, cell phone use), per age group (young, middle aged, older) and per gender. It should be noted that lateral position refers to the position of the vehicle on the road in the relation to the right border of the lane in which the vehicle is travelling and it is an indicator on how well the driver maintains the vehicle on the driving simulator environment. The value of the lateral position is estimated as the absolute distance between the right wheel of the car and the right border of the lane and is scaled in meters.

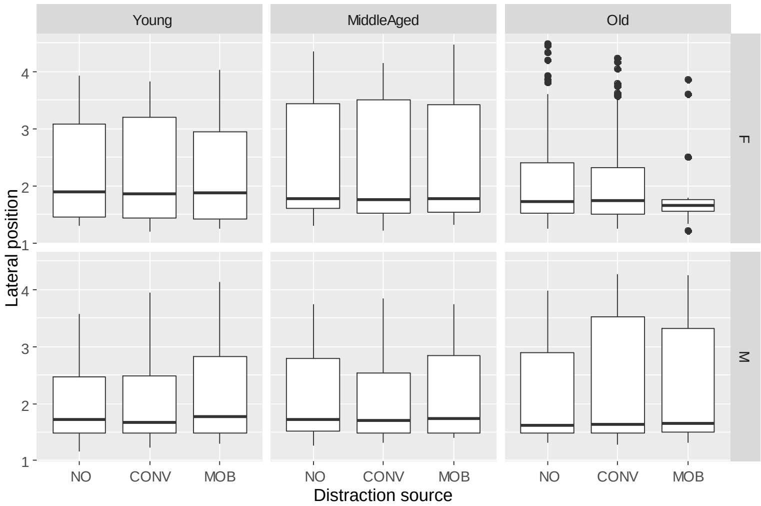

Figure 2 – Lateral position per distraction factor, age group and gender

It is observed that while talking on the cell phone drivers of all age groups have higher lateral position compared with undistracted driving. However, these differences are not very clear indicating that further analysis should me implemented in order to investigate the specific effect of each parameter on lateral position of the vehicle. In the next step, the following regression model investigates the lateral position of the vehicle as a function of driver characteristics such as age group and gender, road environment characteristics such as area type and traffic conditions, as well as the use of cell phone. The model parameter estimates are summarized in table 2.

Table 2 Parameter estimates of the GLM of Lateral Position

Variables	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Intercept	1,49	0,04	37,75	< 0,000
Distraction – Cell phone	0,07	0,04	1,86	0,064
Age group – Middle Aged	0,19	0,04	5,17	< 0,000
Age group - Older	0,128	0,04	4,80	< 0,000
Area type - Urban	1,54	0,03	50,67	< 0,000
Traffic – Low	-0,11	0,03	-3,57	< 0,000
Gender – Male	-0,10	0,03	-3,26	0,001
Summary statistics				
AIC	989,23			

Log-restricted-likelihood	-486,61
Degrees of freedom	810

Before accepting the results of both generalized linear models it is important to evaluate their suitability at explaining the data. One of the many ways 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. R provides four graphical approaches for evaluating the model of reaction time as presented in Figure 3.

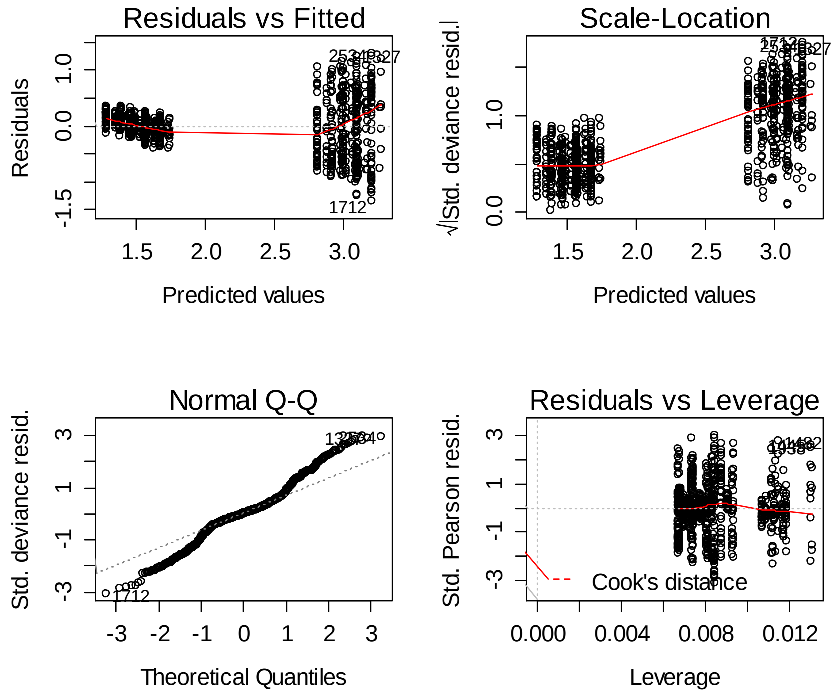

Figure 3 Lateral position GLM graphical approach of residuals

The plots in the upper left of each Figure show the residual errors plotted versus their fitted values. The residuals should be randomly distributed around the horizontal line representing a residual error of zero (there should not be a distinct trend in the distribution of points). The scale location plots in the upper right show the square root of the standardized residuals as a function of the fitted values. Again, there should be no obvious trend in this plot. The plots in the lower left are standard Q-Q plots, which should suggest that the residual errors are normally distributed, if the residuals fall on the dotted line. Finally, the plot in the lower right shows each point's leverage, which is a measure of its importance in determining the regression results. In Figure 2 all graphical approaches confirm the suitability of the model of reaction time.

However, as described in the methodology chapter, the data used in this research involve repeated measures 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 in table 3.

Table 3. Parameter estimates of the GLMM of Lateral Position

Variables	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Intercept	1,47	0,06	24,20	< 0,000
Distraction – Cell phone	0,07	0,03	2,30	0,021
Age group – Middle Aged	0,20	0,07	3,11	< 0,000
Age group - Older	0,32	0,06	3,19	< 0,000
Area type - Urban	1,53	0,03	56,71	< 0,000
Traffic – Low	-0,10	0,03	-3,97	< 0,000
Gender – Male	-0,10	0,05	-1,78	0,077
Random effect				
By Person ID (stdev)	0,21	-		
Summary statistics				
AIC	920,51			
Log-restricted-likelihood	-451,26			

The goodness-of-fit is investigated through the likelihood ratio test. The likelihood ratio test regarding lateral position LRlat.pos= -70,71 (1 degree of freedom) shows that the random effect contributes significantly to the fit of the model. As a result, the fit of the generalized linear mixed model outperforms the respective fit of the generalized linear model.

4. Discussion

The present paper analyzed the driving performance of 95 drivers in order to investigate the effect of cell phone use and conversation with the passenger on how well drivers maintain vehicle position within a lane position of the vehicle with focus on older drivers. For this purpose, 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. Model results indicate that several parameters had a statistically significant effect on the lateral position of the vehicle during the driving simulator experiment as explained below.

Regarding the distraction sources examined, cell phone use slightly increased lateral position indicating that drivers find difficult to keep the vehicle in a constant distance from the right board of the lane probably due to the fact that while talking on the cell phone they hold the steering wheel with one hand. On the contrary, conversing with a passenger was not found to affect significantly the lateral position of the vehicle proving that drivers do not change their overall performance significantly while conversing with a passenger compared to undistracted driving. This finding can be explained by the assumption that the passengers are able to follow the road and traffic conditions and the related workload of the driver and adjust their interventions (distraction) to the driver. This a first key contribution of the present research regarding the different distraction mechanism between the examined distraction sources examined on how drivers maintain the vehicle.

A second key contribution concerns the methodological approach of the research both regarding the experimental procedure as well regarding the statistical methodology implemented. More specifically, the described driving simulator experiment managed to deal with the majority of limitations that have been noted in the assessment of the examined simulator studies on driver distraction namely a large and representative sample, randomisation of trials, several exclusion criteria as well adequate practice drive. Regarding the statistical methodology, the results of the goodness-of-fit measures proved the in driving simulator experiments were drives are implementing more than one common driving scenarios the development of generalised linear mixed models is essential in order to deal with the heterogeneity across individual drivers.

Finally, with regard to driver characteristics that significantly affect lateral position, male drivers were found to achieve lower lateral position than the female ones confirming the literature that males drive more steadily compared to female drivers. Moreover, two age groups, middle aged and older drivers, have a statistically significant increase on lateral position, proving that they find difficulties in maintaining the driving simulator vehicle compared to young drivers. This is probably explained by the higher physical abilities of young drivers in maintain the steering wheel with only one hand. Last but not least area type has the highest effect on lateral position indicating that lateral position 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.

The methodological as well as statistical results of the present research should be further processed in order to provide more valuable findings in the field of driver distraction especially regarding older drivers. Concentrating on the effect of driver distraction, in the present research conversation with the passenger and cell phone use where deeply examined. However, several other distraction sources both inside and outside the vehicle are estimated to play a crucial role in driving behaviour and accident probability and should be further investigating regarding their effect on lateral position of the vehicle and more general on driving performance.

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