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# How unexpected events affect lateral position variability?

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**Abstract**

A key advantage of driving simulator experiments refers to the fact that they can be used to examine driving behaviour in a controlled environment which helps provide insights into situations that are difficult to measure in a naturalistic driving environment such as unexpected incidents and cell phone use. In addition, driving simulators can give precise information regarding lateral vehicle positioning in a virtual world. The objective of the present research is to investigate the effect of distraction sources, driver and road characteristics on the difference of lateral position variability after an unexpected incident. 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 whereas in each driver 24 unexpected incidents where programmed to occur while his driving tasks. Then in the data processing a database is developed including the average values of several driving performance parameters for a time period of 30 seconds before and 30 seconds after the event. Results indicate that several parameters are found to significantly affect the difference of lateral position variability after an unexpected event. Focusing on distraction, cell phone use increased the difference of lateral position variability indicating that drivers while talking and holding the cell phone achieved significantly different positioning of the vehicle on the road after an unexpected event.


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*Keywords:* unexpected event; driver distraction; driving simulator; lateral position variability

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## 1. Introduction

While road accidents constitute a major social problem in modern societies, accounting for more than 1.2 million fatalities worldwide and 25.500 in the European Union in 2015 (WHO, 2016), unexpected events are part of everyday experience. They come in several varieties (action errors, unexpected action outcomes, and unexpected perceptual events) and they lead to motor slowing and cognitive distraction (Wessel and Aron, 2016). While different varieties of unexpected events have been studied largely independently, many different mechanisms are thought to explain their effects on action and cognition (Falkenstein et al., 2000; Bendixen et al., 2007; Bendixen and Schroger, 2008; Gentsch et al., 2009; Parmentier, 2014; Summerfield and de Lange, 2014; Wessel and Aron, 2014, Zavala et al., 2015).

In order to investigate unexpected incidents, a very useful tool is driving simulators mainly due to the fact that they allow the examination of a range of driving performance measures in a controlled, relatively realistic and safe driving environment. Within this framework, a large range of test conditions can be implemented in the simulator with relative ease, and these conditions can include hazardous or risky driving situations that would be too difficult or dangerous to generate under real driving conditions such as unexpected incidents and distraction sources (Regan et. al., 2008). Driving simulators have both advantages and disadvantages. The main advantages, that are crucial for the present research objectives, include that they have the capability to place drivers into crash likely situations without harming them, that they many confounding variables that occur in on-road driving can be controlled when driving simulation is used and that events or scenarios can be identically repeated for each participant (Regan et. al., 2008; 2006; Jamson, 2001). On the contrary the

In addition, the present research investigates driver distraction in terms of cell phone use and conversations with the passenger. Driver distractions 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, conversation with passengers, smoking, eating or drinking, listening to music and in-vehicle assistance 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).

In order to investigate driving performance either in undistracted or under distraction, a range of assessment measures that have been used in the literature including lateral control, longitudinal control, reaction time, gap acceptance, eye movement and workload measures. Considering that inappropriate lateral positioning is one of the primary factors leading to accidents (Riser, 2006, Papantoniou et al., 2017), 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 (Regan et al., 2008).

Several studies have examined the impact of driver demographic characteristics (age, gender) on lateral control of vehicle (Liu and 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.

Based on the above a gap has been identified in the literature which the present research aims to deal with. This gap concerns the fact that there are no researches implemented investigating the effect that has an unexpected incident in certain driving performance measures. More specifically this type of analysis needs to isolate the event and analyse driving performance before and after the event depending on the research question.

Based on the above, the objective of the present research is to investigate the effect of examined distraction sources, driver and road characteristics on the difference of lateral position variability after an unexpected incident. 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 whereas in each driver 24 unexpected incidents where programmed to occur while his driving tasks. The paper is structured as follows. In the next chapter the methodology and data part are provided including an overview of the experiment, the description of the driving simulator experiment and sample characteristics followed by data processing which is a core part of the research and 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 $\sigma^2$=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 $\sigma^2$=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% |

### 2.4. Data process

The experiment data storage was performed automatically at the end of each experiment. The simulator recorded data at intervals of 33 milliseconds (ms) which means that each second measured values for each variable 30 times. In order to achieve the objective of the present research, the final database consisted of one line per each event for all participants. Furthermore, the average value of all driving performance measures was estimated for a time period of 30 seconds before and 30 seconds after the event.

Based on the above, the key driving performance measure that consists an innovative output and is further investigated in the present research is the "difference of lateral position variability" and is estimated as the difference between the average lateral position variability after and before the event. More specifically, as bigger is this difference so higher is the effect of the unexpected evet in the positioning of the vehicle on the road.

### 2.5. Analysis background

The large dataset exploited in the present research makes the descriptive analysis of a large number of variables essential. Within this framework, box plots (also known as a box-and-whisker charts) 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 value. 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. This means that 50% of the cases lie within the box.

In the next step, 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 the framework of the present research the measure that is further investigated is the "difference of lateral position variability" after an unexpected incident.

As a first step, the next figure presents the effect of age (Young, Middle-aged, Older) and gender (Male, Female) on the difference of lateral position variability for different types of distraction (undistracted driving, conversing with the passenger and talking on the cell phone).

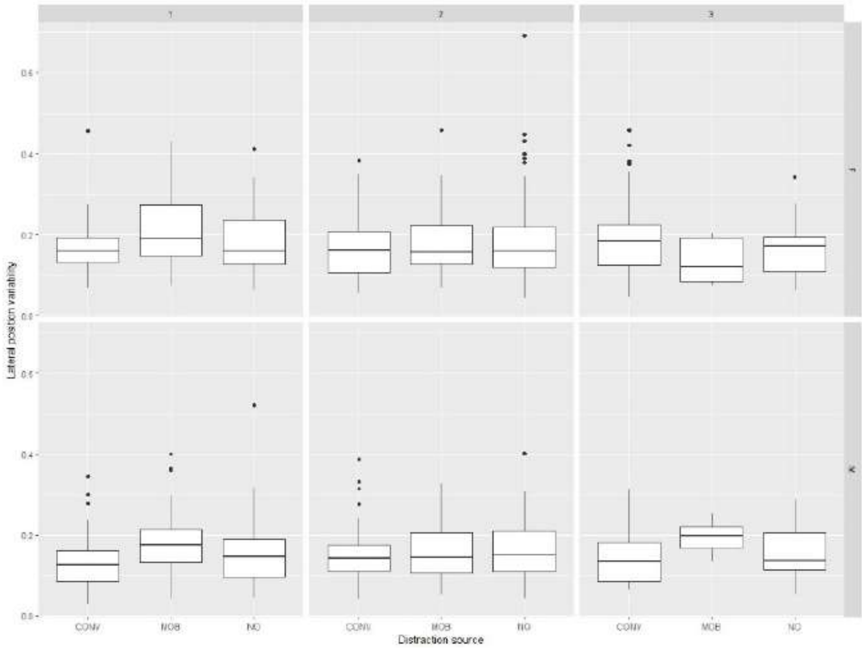


Figure 3. Difference of difference of lateral position variability per distraction factor, age group and gender

Boxplots in Figure 3 illustrate that difference of lateral position variability after an unexpected incident is lower in young drivers which prove to be affected less than middle aged and older drivers due to an unexpected event. Furthermore, the examined measure has the highest value on older drivers especially when driving while talking on the cell phone which indicates that the change in the behavior after an event is significant.

Then, the histogram of the examined variable is presented, showing that it approximates the normal distribution and can be further investigated through linear model analysis.

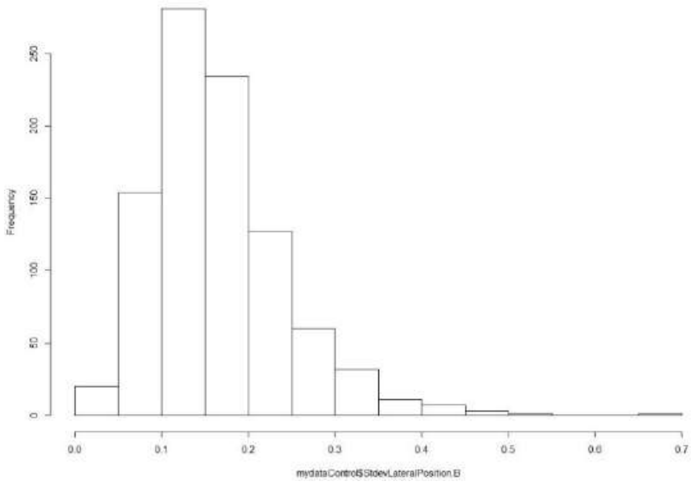


Figure 4. Histogram of difference of lateral position variability

In table 2 the regression analysis is presented in which the difference of lateral position variability after an unexpected event is investigated while explanatory variables include driver characteristics, distraction sources and difference in average speed. The model parameter statistics are summarized in table 2.

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

| Variables | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| Intercept | 0.033 | 0.007 | 4.266 | < 0,000 |
| Distraction – Cell phone | -0.029 | 0.0087 | -3.370 | 0.001 |
| Distraction– No | -0.032 | 0.007 | -4.339 | < 0,000 |
| Age - Young | 0.014 | 0.007 | 2.022 | 0.043 |
| Difference Speed | 0.002 | 0.001 | 5.879 | < 0,000 |
| **Summary statistics** | | | | |
| AIC | -1,626.00 | | | |
| Log-restricted-likelihood | 9,3842.00 | | | |
| Degrees of freedom | 926 | | | |

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.

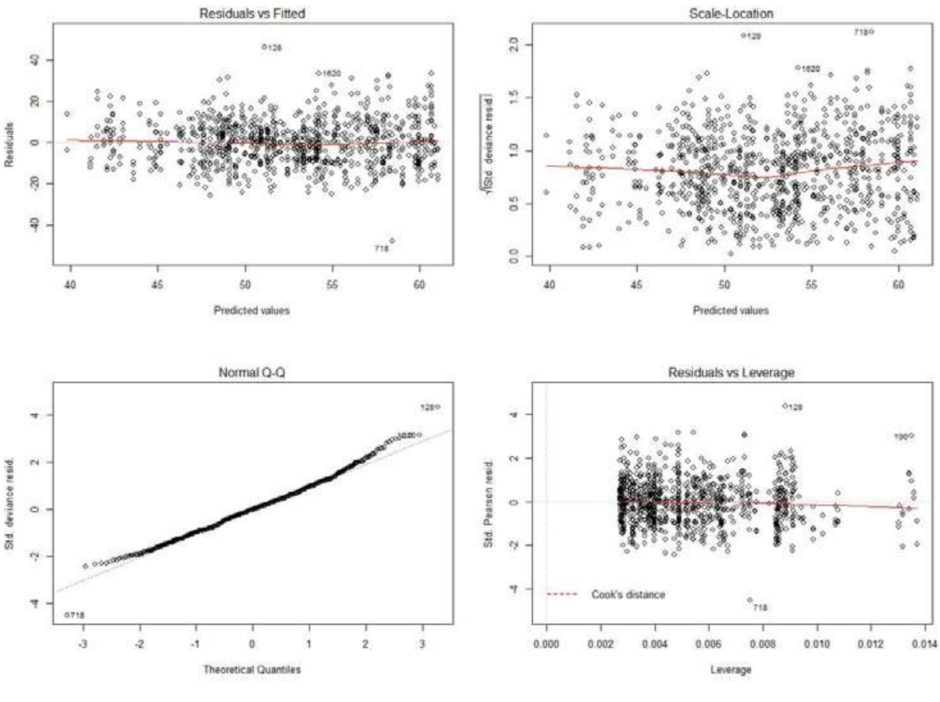


Figure 3. Graphical approach of residuals

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 difference of lateral position variability

| **Variables** | **Estimate** | **Std. Error** | **t value** | **Pr(>\|t\|)** |
|---|---|---|---|---|
| Intercept | 0.136 | 0.006 | 20.819 | < 0,000 |
| Distraction - Cell phone | 0.022 | 0.006 | 3.395 | 0.001 |
| Distraction - No | 0.001 | 0.005 | 2.292 | 0.022 |
| Age – Young | -0.008 | 0.007 | -1.847 | 0.047 |
| Difference Speed | -0.002 | 0.001 | -5.915 | < 0,000 |
| **Random effect** | | | | |
| By Person ID (stdev) | 0,026 | | | |
| **Summary statistics** | | | | |
| AIC | -2,126.61 | | | |
| Log-restricted-likelihood | 1,070.31 | | | |

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 difference of lateral position variability after an unexpected event while driving at the driving simulator. Focusing on the distraction sources examined, cell phone use increased the difference of lateral position variability indicating that drivers while talking and holding the cell phone achieve a different position of the vehicle on the road after an unexpected event. On the contrary, conversing with a passenger was not found to affect significantly the dependent variable indicating that drivers do not change their driving behaviour significantly while conversing with the passenger.

Focusing on driver characteristics, only age has a significant effect on the model indicating that younger drivers do not change their lateral position variability before and after an incident, which probably means that they have a lack of risk due to the event. Finally, another ingesting finding is that neither area type (urban/rural) nor traffic conditions (low/high) are in the model indicating that the change in the positioning of the vehicle on the road before and after is not affected by road conditions.

## 4. Discussion

The present research analyzed the difference of lateral position variability after an unexpected incident, aiming to investigate the effect of several driver and road characteristics as well as the effect of cell phone use and conversation with the passenger on this change in driving behaviour. 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.

A first key innovation of the research concerns the development of a database including the average values of several driving performance parameters for a time period of 30 seconds before and 30 seconds after the event. Through this data processing which required deep data coding in order to transfer the aggregated data from the simulator to the new before/after the incident database format, it is achieved to create new variables concerning the difference in all recorder driving performance measures before/after the event.

Results indicate that cell phone use increased the difference of lateral position variability indicating that drivers while talking and holding the cell phone achieved a different position of the vehicle on the road after an unexpected event. This is probably explained by the fact that the sudden shock that occurs through the unexpected event is higher while talking on the cell phone due to the compensatory behaviour that occurs to the driver who feel guilty by his action. On the other hand, conversing with a passenger was not found to affect significantly the difference of lateral position variability indicating that drivers do not change their driving behaviour significantly while conversing with the passenger.

Regarding the other explanatory variables that were examined through the experiment, are type and traffic conditions do not have a significant effect on the model indicating that the change in the driving behaviour due to an unexpected incident is affected more by the age and the distracted conditions than by the road conditions. This consists a very interesting approach to distinguish the present research with researchers on lateral control measures where are type is one of the most important factors that affect lateral control of the vehicle. The present research indicates that this effect does not exist in the difference of driving behaviour before and after the event.

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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