Abstract
Distracted driving may lead drivers to take wrong actions, possibly resulting in serious traffic accidents. The objective of this study was to apply a driving simulator to examine variations in driving behavior in presence of different secondary tasks. The driving behavior of 17 volunteers was determined by registering speed variations at selected positions of a curve in a virtualized highway. A comparison of driving performance between drivers fully aware of the driving activity and when they were engaged in a PASAT mental workload test was performed. Replicated analyses showed that distracted drivers did not recognize the beginning of the curve at the same level as they did while fully engaged in the driving task. They also drove through the curve at higher speed when distracted by the mental test. Driving performance was noticeably enhanced when drivers were aware of driving, thereby reaching high speeds in tangents, but noticing curves in advance to lessen acceleration. This study confirms that driving simulators are valuable for obtaining drivers’ behavior exposed to activities that could be very risky if in real situations.

Keywords
Driving simulator; distraction while driving; speed profile; drivers behavior; curve evaluation;

1 AIM

This study aimed to use a driving simulator to compare drivers’ behavior full aware of the driving task and under distraction while driving along a highway curve. The main variable adopted was the driver speed profile, which was punctually collected along the curve, and on tangent stretches located directly before and after it. All variables were collected in a virtual environment, and modifications were controlled by software and repeated identically to all participants.

2 METHODS

2.1 Simulated Location and Participants

The rural road simulated in this study was a 10 km stretch located in a Brazilian highway, connecting Sao Paulo and Curitiba, and it is the main connection between Brazil and other South American countries. The stretch is located in a mountainous region and its geometric design is windy, with curve radius inferior to the minimum set by Brazilian handbooks.
Seventeen volunteers took part in the study. All participants had driver license for 1 to 10 years (M = 3.7, SE = 2.2) by the time of the experiment and were aged between 18 to 37 years old (M = 22.5, SE = 1.9). Eight participants self-assigned as experienced drivers and nine as inexperienced. Experienced drivers had daily experience in driving and has held driver license for 5.1 years. Inexperienced drivers has held driver license for 2.4 years and three participants were used to drive weekly, three participants were used to drive monthly and the other three hardly drive.

### 2.2 Driving Simulator Properties

The driving simulator employed in this study was a microworld environment. Microworlds are computer-generated environments operated in real-time and controlled by an operator (Brehmer & Dîrner, 1993). The physical structure of the simulator was composed of a driving cockpit with car seat, steering wheel with paddle shift and force feedback and accelerator, brake and clutch pedals. The cockpit station also allowed adjustments of height and distance between the seat and the steering wheel. The simulated environment was projected on a 1.40 x 0.80 m flat panel with 1080p resolution and 60 Hz projection rate. The projected field of view was 120° and 50° on horizontal and vertical visions, respectively. Rear and lateral mirrors and speedometer were also projected on the panel. Speakers were used to reproduce sounds similar to vehicle engine, rain and wind in order to enhance immersion.

Two computers processed the real-time simulation. The first one, responsible for environment rendering and simulation running, was strengthened with two GPUs. The second computer modeled the vehicle dynamics, which included the road–vehicle interaction and the mechanical answers to the driver’s actions. Vehicle’s dynamics was similar to a Brazilian ordinary vehicle version. These characteristics allowed participants to perceive a medium fidelity immersion with visual and auditory stimuli similar to a real driving experience. It was achieved due to high computational capacity that modeled and rendered virtual environment in real-time.

### 2.3 Analysis of curve

The 10 km stretch of the highway comprises 20 curves. The analysis of drivers’ attention was performed in a selected curve of the segment. Curve’s length and its previous and afterward tangents were crucial to select the curve on which driver’s behavior could be recorded. A very short length stretch would increase outliers’ occurrence due to short time for collecting data. To run across 100 m along a highway, drivers at 120 km/h would take around 3 seconds. Short time to perform the curve and subjacent tangents would not provide a correct parameter for analysis. In this case, it was determined that the lengths of tangents and curves should be long enough so that drivers could stay at least 20 s at the entire segment: 10 s on the tangents and 10 s to perform the curve. For estimation, the current highway speed limit of 60 km/h was considered.

The main characteristic for curve selection was based on the car crash statistics of the road during the period of 2013 – 2015, Figure 1. The presumption is that these accidents may be related to drivers’ inability to fully concentrate on road’s demand at this spots.

![Car crash statistics 2013 - 2015](image)
Figure 1. Car crash statistics identified by curves.

Considering geometry, length and crash statistics, the analysis was performed in the 14th curve (previous tangent length: 570 m; curve sector: 205 m length and 130° deflection radius; afterward tangent length: 130 m) was selected for analysis in the virtual simulation.

The points were identified from 500 m before the beginning of the curve (analysis of drivers’ behavior while they were approaching the curve path) to 50 m after the end of the curve (analysis of behavior when drivers sought the end of the curve and when they actually passed through it), with distance of 50 m from one another. The points gathered within the curve were used to measure speed at the inflection point found by drivers when they sought the beginning and the end of the curve (Brown, 1999).

2.4 General course of events

Participants took part in workload distraction experiment, performing two identical simulations, one with workload provided from PASAT and another one without any distraction task. The simulated scenario was exactly the same in terms of both geometry and traffic. Before starting simulations, participants were instructed of procedures and mechanical operations of the driving simulator. At first they drove in a sample road until they found themselves adapted to the simulator and felt comfortable with simulation. The adaptation simulation lasted, 5 min, at least, for each participant.

The “punctual speed” recorded at selected points along the curve and on nearby tangents was the parameter associated with the participants’ driving behavior in the selected curve. Further observation of simulation discarded results of drivers who followed another vehicle while driving through the curve. This was done with assistance of simulation video recording. Further analyses were performed to the remaining drivers, with univariate analyses on each dependent measure using repeated measures analysis. A significance level of 5 % ($p < 0.05$) was adopted for all inferential tests.

3 RESULTS

From the total of 17 participants who took part in the experiment, three were discarded for not being able to complete any of both simulations. Two participants overturned the simulated vehicle and the other did not adapt himself to the vehicle’s control. In addition, results of 4 participants who followed another car with a headway shorter than 9 seconds was discarded, as a driver following another car does not develop the self-expected speed, but follows the speed of the car ahead (Horberry, Anderson, Regan, Triggs, & Brown, 2006).

Preliminary analysis using the non-parametric Kolmogorov – Smirnov one-sample test rejected a normal distribution of speed values at the point on the 500 m ahead the curve position (Young, 1977). Additionally, the non-parametric Mann – Whitney U test rejected homogeneity and same distribution of speed values of drivers at positions from 400 m to 250 m ahead the curve (Nachar, 2008). Based on these preliminary analyses, the speed data considered for comparison between distracted or attentive drivers were those obtained from the positions between 200 m ahead and 50 m after the curve, spaced in 50 m (10 speed points).

Figure 2 shows the replicated results of speed variation considering distracted drivers with PASAT or fully attentive to the driving task. One-way MANOVA multivariable tests presented significant
variations of speed in positions Z(81.15.432) = 2.43 p < 0.05; Wilk’s Λ = 0.0, partial η² = 0.55 based on drivers’ paired variables (attentive or distracted with PASAT) with normal distribution and presents estimated marginal mean speed for each point, according to drivers’ concentration category. The interpretation of speed values is presented in locations’ box plots in Figure 3.

Repeated measures MANOVA was used due to the characteristics of the experimental procedures: the same driver repeated the driving task twice, with the single distinction of answering or not answering PASAT, which means attentive to the driving task or distracted by a secondary task, respectively. Speed variation was initially measured among drivers (Kolmogorov – Smirnov and Mann-Whitney U tests) and further among positions (Figures 2 and 3). This methodology is accepted for repeated experiments with a common variable under analysis. Recently, Repeated measures methodology has also been used to study driver’s behavior by different researches (Faure, Lobjois, & Benguigui, 2016; Horberry et al., 2006; Körber, Gold, Lechner, & Bengler, 2016)

4 CONCLUSION

The present study assessed the effects of secondary tasks on drivers’ behavior performing a curve by means of a driving simulator. Results showed that distraction provided by mental workload tests affected driver perception on a curve. Data also confirmed that distracted drivers did not anticipate the beginning of the curve and performed this segment with average speeds higher than that used when focused on the driving activity. Secondary tasks that generate mental workload, such as PASAT in this study, vary in
number of activities that drivers can perform while driving. These activities may not necessarily involve mechanical distraction, for example holding a mobile phone, turn the radio down or take visual focus off the road while driving, but any mental distraction that reduce attention to the primary task.

Focused drivers also increased their performance by driving at higher speed in tangents in comparison to the speed used while distracted by PASAT. Even reaching the highest speed in tangents ahead the curve (drivers’ speed at 200 m ahead of the curve, see Figure 3), drivers’ speed through the curve was reduced significantly, so that drivers could see and adjust the simulated vehicle speed to the curve.

Despite the significant reduction in speed among drivers without any disturbance in driving task, there were no conclusions on drivers’ behavior while answering PASAT. Driver behaved differently from one another, that is, either focusing on the driving task and not answering PASAT correctly or driving at low speed so they he could concentrate on the test. Further studies involving other scenarios and road geometries are underway to categorize distracted drivers’ behavior in different driving situations.

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REFERENCES


