Validation of an Eye-Tracking System for Use in Driving Simulator Research

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Abstract

Eye-tracking has been widely used for decades in vision research, language, and usability. In the area of road engineering, the eye-tracking system has been used both for on-field and in driving simulation studies. The overall advantage of using an eye-tracker is that different parameters regarding eye-movement towards visible stimuli in the environment can be measured, such as eye-fixations and saccades. Several studies have been developed by combining the benefits of the eye-tracking system with driving simulators to simultaneously investigate driving behaviour and the potential source of distraction. However, little effort has been spent in terms of eye-tracking validation in the driving simulator environment.

To fill this gap, both a field survey and a driving simulation experiment have been developed for a case study located in Rome, Italy. The selected road sections and events have been reproduced on the fixed-based driving simulator system at the Department of Engineering of Roma Tre University. A Tobii glasses eye-tracking system has been used to record the eye movements both on board of a real vehicle and on the simulator.

The eye movements of 14 participants in the field survey and 18 participants in the driving simulation tests, as well as their driving performances (speeds, accelerations, trajectories), have been investigated while approaching an urban intersection and in relation to two specific road events, both static and dynamic: i) the presence of a speed limit sign and ii) the presence of a crossing pedestrian. Eye tracker parameters and driving performances were compared between the real driving tests and driving simulator experiments in order to validate the eye-tracking system. Specifically, the eye-tracking system has been validated for both the events in terms of duration and distance of the eye fixation. Therefore, the results demonstrate that the eye-tracking system stands as an effective tool for studies and applications in a virtual reality environment.

Keywords: Eye-tracking; Driving Simulator; Driver's visual strategies; Driving behaviour; Urban intersection.

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1. Background

The overall advantage of using an eye-tracker is that different parameters regarding eye movement towards visible stimuli in the environment can be measured, such as eye-fixations and saccades. Nowadays, the use of such an instrument can play a strategic role in evaluating driving behavior. Several studies have been developed by combining the benefits of the eye-tracking system with driving simulators or real tests on instrumented vehicles to simultaneously investigate driving behaviour and the potential sources of distraction. However, little effort has been spent in terms of the validation of the eye-tracking tool in the driving simulator environment.

2. Aim and objectives

The overall aim of this study is to validate an eye-tracking system within the context of a virtual reality driving simulation environment by considering a specific urban context application. The validation of the system has been carried out by a comparison between the eye movements measured in real driving along a road section with those recorded in the same road environment reproduced in a driving simulator. In addition, some key objectives are set out by the comparison between the driving simulation and the on-field study: validating the simulator for speed measures specifically in a typical urban environment, while approaching and crossing an intersection. Considering the experiences conducted so far, this study is aimed at providing a significant contribution in the field of using the eye-tracking system within the context of both real driving and virtual reality driving simulation.

3. Methodology

Thanks to the equipment based on an eye-tracking system (Fig. 1.a) implemented in an instrumented vehicle (Fig. 1.c), a field survey has been developed for a case study located in Rome, Italy. The same selected road section and events were then replicated on the fixed-based driving simulator system (Fig. 1.b) at the virtual reality laboratory at the Department of Engineering of Roma Tre University, and the data collected was compared to the data collected during the field survey to validate the eye-tracking system for driving simulation applications.

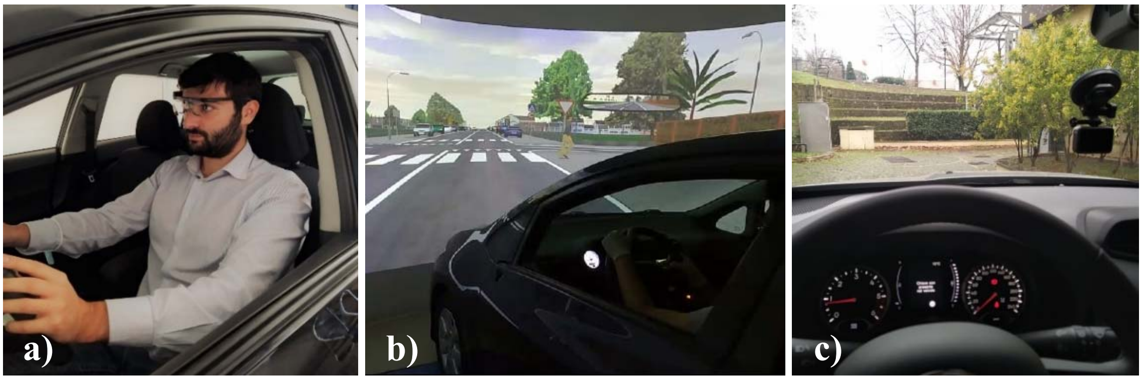

Figure 1: a) Eye-tracking, b) virtual reality driving simulator, and c) instrumented vehicle

The case study, chosen for the field survey and then reproduced in the simulated environment, was an urban intersection located in Rome. The entire route was 4500m, designed as a circular pattern; two road events, one static and another dynamic, were designed in order to assure the same driving conditions both in the field survey and in the simulation experiment: i) the presence of a speed limit sign; and ii) the presence of a pedestrian who crossed the road. Figures 2 and 3 show the realism of the virtual reality simulation by referring to the two designed events: the presence of a speed limit sign and a crossing pedestrian, respectively.

Twenty-two drivers took part both in the real driving and simulation experiments (15 men and 7 women; ages ranging from 22 to 59 years, with a mean age of 31.9 years). In the real tests, eight participants were excluded from the analysis due to technical issues related to the equipment. As a result, the final sample included 14 drivers (9 males and 5 females), with an average age of 27.7 years (SD = 9.3). Instead, in the driving simulation tests, four participants were excluded from the further analysis of the data because they experienced symptoms related to simulation sickness. As a result, the final sample included 18 drivers (12 males and 6 females) with an average age of 30.3 years (SD = 10.1).

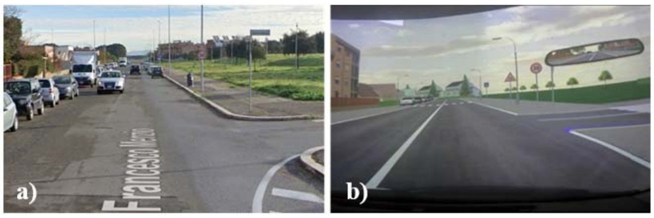

Figure 2: Speed limit sign in a) the real- environment setting and b) the virtual scenario

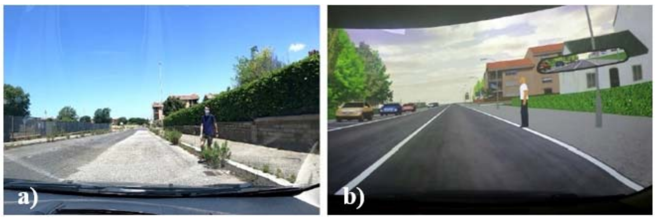

Figure 3: Crossing pedestrian in a) the real- environment setting and b) the virtual scenario

Eye movement data, such as distance and duration of the first fixation, and driving speed profiles at the approach to the events were collected, analyzed, and compared between the two drives, in the real environment and in the simulation environment, in order to study the differences in driver behavior in terms of both driving performance and eye movements. Thanks to the eye-tracking system, some acknowledged indicators were collected and studied. More specifically, the first fixation has been investigated in terms of duration and distance.

4. Results

4.1 Speed limit observation

The comparison between the number of drivers that have looked at the speed limit sign revealed that in the field survey, around 50% of drivers looked at the sign; in the simulation, this percentage was lower than 40%. By comparing the distribution of fixation durations and distances, it is possible to highlight that the fixation distance is quite similar between the two samples. The average value is around 60 meters in both cases, namely 10 meters after the first point where the sign was visible; furthermore, the fixation durations demonstrate that the average values in the real and simulation surveys are not considerably different. Finally, concerning the speed limit observation, no significant differences in the fixation duration have been recorded between the real and simulated experiments. In terms of the duration of the eye fixation, this finding verifies the validity of the eye-tracking technologies used in the virtual reality driving simulation experiment. Also the fixation distance was found to be not statistically significant, confirming the validation of the eye-tracking systems also in terms of the distance of the eyes' fixation.

4.2 Crossing pedestrian analysis

In terms of the crossing pedestrian's fixation, a comparison of real and simulation surveys in terms of fixation durations and distances was conducted. In contrast to the analysis of the static object (speed limit sign), the pedestrian, which can be considered as a dynamic object, has been observed by all the drivers, both in the real environment and in the simulation survey. Comparing the distribution of fixation durations, it is possible to highlight that the average values of the fixation durations are different between the real and the simulation surveys. Conversely, the fixation distance is quite similar between the two samples. The statistical analysis revealed that the difference between the average values of the fixation duration was found to be statistically significant, while the difference between the average values of the fixation distance was not statistically significant, confirming the validation of the eye-tracking systems for the experiment in virtual reality driving simulation, in terms of the distance of the eyes' fixation, also for dynamic objects like pedestrians.

4.3 Speed analysis

The drivers' speed values have been plotted and studied in two different sections: 50 meters and 10 meters before the "intersection point". The speed comparison has been performed for the two turning manoeuvres (manoeuvre 1 left-turn and manoeuvre 3 right-turn). Figures 4a and 4b clearly show that the distributions of values between the two sections and the two manoeuvres were comparable; specifically, lower speeds were recorded close to the intersection. In both sections, the speed differences between the real and simulation surveys were small, demonstrating that risk perception is similar in the real environment and in the simulation experiments. Moreover, in the real survey, the standard deviation was very low in both the manoeuvres and in both sections. On the contrary, in the simulation context, these values reached more than 35km/h. This could be due to drivers in the simulated driving environment having varying speed perceptions.

The difference between the average values of speed data was not statistically significant in both the sections, confirming that the simulator is a very efficient tool to investigate drivers' behaviour in terms of speed, also in approaching intersections that involve left-turn and right-turn manoeuvres.

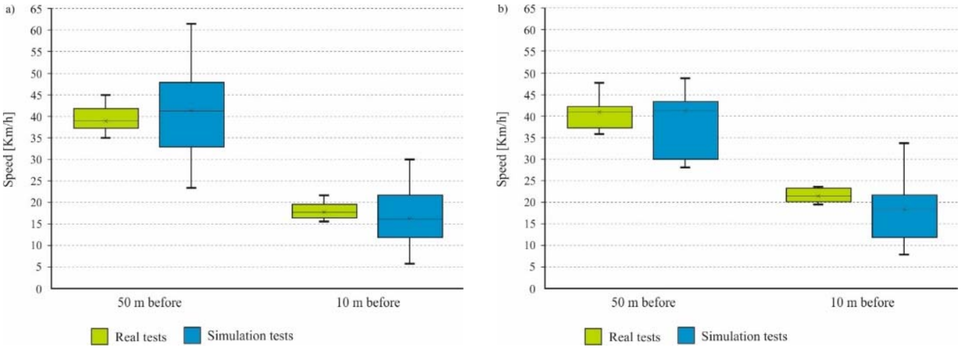

Figure 4: Speed comparison between real and simulation surveys: a) Manoeuvre 1; b) Manoeuvre 3

5. Conclusions and Future Research

This study has examined an application of an eye-tracking system in a real and simulated driving environment in order to validate the tool in driving simulation concerning the urban context investigated by the present study. Eye movements have been measured and compared in real driving along a road section with those recorded in the same road environment reproduced in a driving simulator. Drivers' behaviors and reactions in both driving contexts have been analyzed with respect to the presence of a speed limit sign and a crossing pedestrian. Furthermore, a speed analysis at the approach of an urban intersection was collected to compare the drivers' behaviors in real and simulation driving and achieve the set key objective, namely the validation of the simulator for speed measures specifically in typical urban environments.

The eye-tracking system has been confirmed as a very effective tool to understand and study drivers' visual behaviour in an application in a driving simulated environment. Statistical findings show that, especially for static objects, the driver's response in real and simulated driving is the same in terms of fixation distance and duration. Finally, with respect to speed, the findings confirm the validation of the simulator to investigate drivers' behaviour in terms of speed and also in approaching an intersection where critical manoeuvres, such as crossing and turning, are performed by the drivers.

In future research, the investigated case study can be enlarged with different additional features. First of all, the sample of participants could be expanded to consider a greater sample size, by reducing technical issues and by including other age classes, both young and old drivers, whose visual strategies could be quite different. Moreover, the behaviour of drivers who have already experienced the use of the eye-tracking system in the driving simulation environment will be studied for other test cases and events both in urban contexts and in other road environments (rural roads, highways) that involve different visual stimuli and further details and analysis on eye movement and driving data can be provided. Lastly, different eye-movement indicators will be explored to describe more in depth the drivers' visual behaviour.