Experiments and usability tests of a VR-based driving simulator to evaluate driving behavior in the presence of crossing pedestrians

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Abstract. Road accidents are among the leading cause of death worldwide, with developing countries paying the highest toll. Among the different road users, pedestrians are the most vulnerable. A better understanding of the relation occurring between car drivers and pedestrians when they interact is necessary for the development of new research approaches and their fall in education/prevention. Given the risks involved in the study of car-pedestrian interactions, experimental studies are difficult and only simulators represent a feasible alternative. However, the high cost of driving simulators prevent developing countries from investing on these tools. In this research, we considered the possibility to use a simple low-cost (below 500$) virtual reality (VR) based driving simulator to study the interaction between cars and pedestrians at unsignalized crosswalks. Young adults and elderlies were asked to drive in a virtual environment where simulated pedestrians would pass randomly on crosswalks. Driving behavior was numerically determined for both age groups using speed, time gap and driving accuracy. The obtained results fit with the behavior observed in real conditions, suggesting the empowerment of the application of low-cost VR-based systems for traffic safety research. Results on usability indicated the existence of discomfort during the use of VR tools, suggesting deeper studies on digital-divide issues.

Keywords: crosswalk, driving simulator, virtual reality, traffic safety

1 Introduction and background

As highlighted by the WHO [16], road accidents represent the eighth leading cause of death in the world population (and the leading one for children and young adults): 1.35 million people are killed on roads every year, with most fatalities occurring in developing countries. In particular, pedestrians and cyclists are some of the most vulnerable road users, with a percentage of fatalities corresponding to 26% of the overall victims.

To contrast pedestrian-car accidents it is necessary to identify which factors influence traffic safety to support public institutions in the design of transportation infrastructures and traffic policies. Risky driving behavior is essentially caused by human factors and environmental factors. On one hand, traffic accidents are linked to the lack of coordination among motor, perceptive and attentional skills and, on the other side, on individual psychological disposition towards hazardous situations [6]. As a consequence, very often these factors could affect non-compliance of drivers to traffic norms.

Table 1. Road traffic fatalities and expenditure on R&D (research and development) and education by population for different countries (selection is based on the significance for this study and availability of reliable data) [1, 2, 10, 14, 12, 15, 16, 13].

Indicator	Japan	Italy	Turkey	China	Thailand
Road traffic related fatalities per 100’000 people (year)	4.1 (2016)	5.6 (2016)	12.3 (2016)	18.8 (2013)	32.7 (2016)
Expenditure on R&D per capita (year)	1349 $ (2017)	557 $ (2017)	271 $ (2017)	357 $ (2017)	48 $ (2017)
Education expenditure per capita (year)	1372 $ (2014)	1172 $ (2016)	470 $ (2015)	491 $ (2018)	253 $ (2013)

The study and data collection of human factors (in a selected road environment) is difficult in real conditions. Supervised experiments are limited due to ethical and safety concerns, and data obtained from observation are often biased by several intrinsic variables. Driving on traffic simulators could be a viable alternative, but two main aspects come into effect upon their use: cost and reliability of the results. As Table 1 shows, the regions which would need more investment on education and research on traffic safety lack the financial resources. On the other hand, it is also questionable whether expensive driving simulators are necessarily needed to perform such studies. A report by the Swiss Army [11] (which employed truck simulators as part of the training of its soldiers) concluded that one hour in the simulator would cost about 420$, while the same time would cost 150$ in driving school (with real trucks). Thanks to the recent trend in relation to virtual reality (VR) technologies, costs have decreased and it is now possible to consider the development of driving simulators at an accessible price for research using commercial components.

Within this framework, we present a set of preliminary experimental results on driving behavior achieved through a low-cost VR driving simulator. The obtained results allowed assessing potentials and shortcomings, and considering a more systematically use of VR tools to study the impact of considered human factors in driving behavior.

2 Experimental equipment, participants and procedure

The developed VR system consists of a driving simulator in an ad hoc designed urban scenario (see Fig. 1, the virtual environment) representing a slightly asymmetrical

8-shaped road intersecting multiple unsignalized pedestrian crosswalks (see Fig. 2). Standard commercial devices were used (a Oculus Go headset, a Thrustmaster T80 wheel and pedal set and a low-cost router and PC for communication between the devices). The virtual environment has been developed with the Unity software package, freely available for academic research and education.

Fig. 1. Left: picture of the VR driving simulator including headset, steering wheel, pedals and the PC used to transfer data between them. Total cost of the whole equipment was below 500$. Right: screenshot of the scenario represented in VR; a pedestrian is seen crossing the road from inside the car.

The selection of the scenario has been based on the combination of multiple factors: scientific relevance, relation with the real world, technical aspects and accumulated scientific experience within this topic. In particular, a previous study on pedestrian-driver interaction at unsignalized crosswalk allowed to gain empirical knowledge on the decision-making process related to the crossing task performed by pedestrians [6]. Previous research also led to the creation of different simulation models, capable to estimate time-gap and fatalities occurring at unsignalized crosswalks based on a variety of parameters (speed limit, vehicular and pedestrian flow, etc.) [4, 5]. Psychological studies in relation to decision-making by pedestrians where also performed using a VR approach [3].

A sample of 16 participants (composed by 12 young adults and 4 elderly drivers) were recruited for the experiments and received a remuneration for the time spent. Before actually having them wearing the VR headset, a questionnaire was handed them to eventually exclude people with a medical history presenting risks in relation with VR and those who came by car or bicycle (one young participant was excluded). In the initial questionnaire we also collected general information (age, gender, driving history, etc.) and asked on previous experiences with VR.

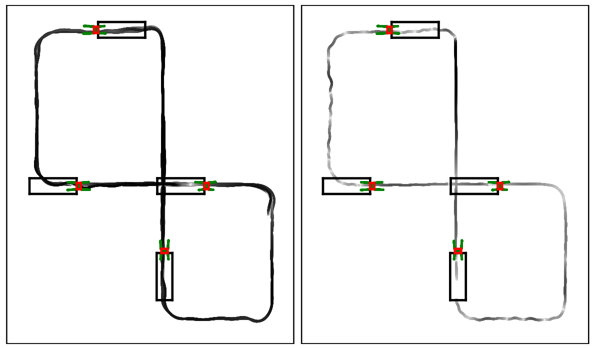

Fig. 2. Trajectories representing the driving behavior of two participants during the experiment. Car trajectories are given in gray gradations with the darkness representing the speed (the darker the fastest). Green trajectories are the paths used by crossing pedestrians, with the crosswalk represented in red. The black area before the crosswalk represents the region where drivers and pedestrians interact.

After completing the initial questionnaire, participants had to drive in a straight road where they would practice on accelerating/stopping and lane change. To reduce discomfort, participants had to rest for about 5-10 minutes before actually starting the real experiments (whose results are presented below) where they would drive through the urban scenario (see Fig. 1 on the right) for about 3-5 minutes. We did not give particular instructions beside telling them to drive safely as they would in the real world.

After the experimental session, to more fruitfully evaluate the performance of the VR tool in terms of user experience, we administered to participants two validated psychological measures, focusing on: usability [8] and feeling of sickness due VR by itself [9].

3 Results

In this preliminary analysis, we focused on the driving behavior in the presence of crossing pedestrians, collecting data on aspects such as: driving compliance to pedestrian right-of-way, driving speed and driving accuracy. Driving accuracy was evaluated by computing the standard deviation of the yaw angle error from the road direction in the straight sections of the circuit. Under these conditions, 0 would represent a completely straight perfect driving. The time gap (the ratio between the distance to the crosswalk and the speed of the car) was evaluated for every frame when both car and pedestrians were inside the interaction region given in black in Fig. 2 (the maximum was later used). Data collected from the questionnaires were also used to study limitations of VR in relation to user experience.

Some initial qualitative results can be obtained by inspecting Fig. 2. It appears clear that each participant has a different driving style, some are confident and fast (left side of Fig. 2), sometimes leading to imperfections when turning; others are less confident (right) and reduce their speed to avoid collisions and stay well within the roadway.

Table 2. Results relative to the driving behavior of participants depending on the age group and most important indicators from the questionnaires (normalized to a 0–1 scale).

Age group	Average speed	Maximum speed	Maximum time gap	Driving accuracy
Adults (19–33)	48.86 km/h	76.12 km/h	0.351 s	10.05°
Elderlies (67-70)	20.78 km/h	59.09 km/h	0.528 s	20.15°
Age group	Nausea	Oculomotor symptoms	Simulation fidelity	Overall system usability
Adults (19–33)	0.412	0.484	0.570	0.554
Elderlies (67-70)	0.500	0.491	0.450	0.436

When results are converted into numerical values, our analysis show that driving behavior in the VR environment is in line with experimental observations [7]. In particular, young adults are more prone at showing a risky behavior by driving at higher speed and having a lower time gap compared to elderly (see Table 2). However, the lower driving accuracy by elderly could also be related to their difficulties in adapting with the VR system as shown in the results from the questionnaire.

Concerning user experience, the results achieved through the usability and sickness measures show, from a qualitative point of view, the satisfactory usability of the VR system (especially considering the very low budget) and the influence of participants' age. However, the low scores obtained also show that there is still a long way to go until VR systems could actually reproduce driving behavior with fidelity.

4 Conclusions

In this paper some preliminary studies on the use of VR low-cost commercial technologies to observe driving behavior have been presented. A VR driving simulator has been developed and tested using subjects belonging to different age groups. Results show that driving behavior difference among age groups was comparable between the virtual environment and reality. Although a more complete analysis is necessary to exclude, for example, if this is due to the digital literacy of younger generations (and to understand the digital-divide more in general), results are also promising as they show that simple low-cost solution could be used to study traffic safety, thus paving the path to developing countries with limited financial resources.

Acknowledgement

The authors wish to thank the wonderful secretary-team of the Nishinari laboratory (Erika Shiihara, Yuko Tsumori and En Fujimoto) not only for their administrative support but also for the perfect translation of the questionnaires into Japanese language. We also want to thank the students who helped organizing the experiments. This work was supported by JST-Mirai Program Grant Number JPMJMI17D4, Japan and partially by FONDAZIONE CARIPLO (Italy) "LONGEVICITY-Social Inclusion for a Elderly through Walkability", Rif. 2017-0938 and the JSPS grant FY2019 /L19513.

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