Validation of Driving Simulation in a Virtual Reality Setting: The Effects of Age, Sex and Simulation Technology on Driving Behavior

Oliver Christ[1(✉)], Kaspar Kaufmann[1], Simon Wehrli[1], Emanuel Mistretta[2], Stefan Arisona[3], Thomas Wyssenbach[1], and Simon Schubiger[4]

[1] School of Applied Psychology, University of Applied Sciences and Arts Northwestern Switzerland, Riggenbachstrasse 16, 4600 Olten, Switzerland
{Oliver.Christ, Kaspar.Kaufmann, Simon.Wehrli, Thomas.Wyssenbach}@fhnw.ch
[2] etrex GmbH, Bruggerstrasse 69, 5400 Baden, Switzerland
emanuel.mistretta@etrex.ch
[3] Esri R&D Center Zurich AG, Förrlibuckstrasse 110, 8005 Zurich, Switzerland
[4] School of Engineering, University of Applied Sciences and Arts Northwestern Switzerland, Bahnhofstrasse 6, 5210 Windisch, Switzerland
Simon.Schubiger@fhnw.ch

Abstract. Rapid progress in virtual reality technology empowers immersive and naturalistic driving simulations also for low budget. The technology enables researcher with the means to test different variables in road traffic riskless and reproducible. In real traffic scenarios, differences in driving behavior and safety related-perception can be observed. The object of our study was to develop a low-budget driving simulation environment and to enable a riskless testing of future traffic scenarios.

Keywords: Pedestrian safety · Virtual driving simulation · Driving behaviour

1 Introduction

The implementation of innovative road traffic technologies should always implemented with much care. Field studies that try to measure the effect of innovative road traffic technologies on human behavior may lack on safety issues (e.g. see Tesla or Google). The following study wants to contribute to a riskless testing of future innovations. In Literature, driving simulators are widely discussed [1–5]. For our purpose, we investigated two different driving simulation techniques and tried to find evidence that shows similarities between real driving behavior and virtual driving behavior. This evidence would validate a saver application of virtual traffic innovations in future, if both, real driving and virtual driving behavior will show similarities. To reach this goal we first reviewed evidence of reaction times during real driving during day and night, behavior due to different simulation technique, perception tasks in different ages and sex

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differences in real car driving. We found that during driving at night the skill for object perception is reduced and the reaction time is higher than driving at day [2, 6–8]. Regarding the simulation technology, we found some evidence for more realistic behavior, when it comes to immersive VR than desktop VR [9–11]. The effect of age on driving behavior (e.g. braking response time) shows different results: Some studies showed slower responses from older participants [12–14]. Other studies showed no effect of age [15, 16]. A third result showed that in elderly population a reduction in recognition time was observable, but no change in the time to hit the brake [17]. The main difference regarding sex is that male car driver are more involved in car accidences due to speeding than female drivers [18–21]. After the conclusion of this review, we designed a low-budget driving simulator that enables the virtual testing of traffic situations in a realistic way. Then we developed a representative street scenario of the Swiss traffic system. This included the signs and the street system of the Swiss Traffic Norms and the typical design of the Swiss landscape (cities, etc.) After this, the selection criteria for participants and the assessment were developed. The participants were ask to drive through a virtual environment and press a button on the steering wheel when they see a pedestrian standing by a crosswalk. A navigation device helped them to find their way through the environment. After the study, we compared the results with the empirical findings from real driving scenarios.

2 Methods

2.1 Virtual Environment

The virtual environment for the driving experiments had to be convincing, sufficiently large, yet fully controllable for creating and testing multiple scenarios. We focused on three key aspects for creating a convincing environment: street layouts, lighting, and the overall look of the 3D scenery consisting of buildings, vegetation, pedestrians and other road side objects. In order to create a realistic street layout, the virtual environment is based on Open Street Map data from different Swiss towns. Using real world street network data ensures an accurate mix of road types, intersections and turns while avoiding the costly manual creation of an artificial street network. The Open Street Map data was then cleaned (e.g. removal of over/underpasses) and adapted (e.g. restricting the extent of the network) where necessary for the needs of the experiments. Using the standards of the “Verband der Strassen und Verkehrsfachleute VSS” (SN 640 020a; SN 640 070; SN 640 075) 3D geometry for roads, sidewalks and crosswalks were generated using Esri CityEngine. Esri CityEngine allows the automatic creation of high quality 3D sceneries consisting of roads, buildings, and vegetation based on attributed 2D geographic information such as Open Street Map and building footprints with minimal manual work. Additional 3D objects were modeled with 3DS Max. Street lamp distribution and generation was also done with CityEngine. We placed the street lamps with a 40 m distance in-between and the SITECO Streetlight 10 midi LED 5XA5823D1A08 (IES-File) light profile was employed for realistic illumination while rendering the 3D scene. This is the standard profile, which is used for crosswalks in Switzerland for two-lane roads. To cover the differences that variable light may have on our findings, we designed a day and a night version of the virtual environment. The two versions mainly differ in the ambient and direct lighting (sunlight) as well as the texturing of 3D objects such as illuminated windows during night. The participants' car was the only moving object in the virtual environment. Apart from the pedestrians - used as stimuli - no other people were placed in the scenery. Neither have there been any other cars. Real-time rendering and simulation of the virtual environment was entirely done with the Unreal game engine. Two routes with different conditions have been designed. Both routes exist as a day and a night version. Additionally, both routes had a virtual reality (VR) track, using a HTC Vive headset, and a standard computer screen (CS) track. While the VR setup provides a much more immersive experience – mainly by completely obscuring the physical world and enabling free viewpoint changes – The two different tracks of a route varied in light condition (night/day), display condition (VR/CS) and the position of the pedestrians. Consequently, we could guarantee that each light and display condition was used for every route. Each track contained 30 crosswalks. For 15 of them pedestrians have been positioned, demanding a reaction from the participant. The pedestrian was either standing in an open space or was partly covered by an object (e.g. tree, bicycle et cetera). The procedure of covering the pedestrians was randomized through software and it was unpredictable in which situation an occlusion would occur. The only control parameter was the number of pedestrians per track and on which crosswalks they were placed. Neither did we define if there is an occluding object nor what object it was. This ensured that every participant received another combination of situations. To prevent the participant's association of an object next to a crosswalk with the presence of a pedestrian, random object were also placed near crosswalks With this information, the navigation through the streets was normalized over all participants (all participants drove the same streets and distances).

2.2 Hardware

For the simulation itself, we used a Medion «Erazer» X5336 G desktop computer with an Intel i7-6700k, 4.0 GHz processor, 32 GB RAM, and a NVIDIA GTX 1080 FE graphic card. The steering wheel was a Thrustmaster T150 RS and the pedals a Thrustmaster T3PA – Pro Pedalset. The participants have been seated on a PlaySeat gaming chair. For the computer screen (CS) simulation we have been using a Samsung 5 Series LED-TV with a screen size of 32″ and a resolution of 1920 × 1080 pixel. The VR-Headset was a HTC Vive consisting of two OLED displays with a resolution of 2160 × 1200 pixels that was also tracking the head motions. For this study, we define reaction time as the time elapsed from the moment the stimulus (pedestrian) becomes visible until the participant produces a reaction. When the participant approaches in the car a crosswalk with a pedestrian standing aside, the participant had to press a button as soon as the pedestrian was perceived. The pressed button is registered by the simulation as the participant's reaction to the visual stimulus. To compute the first possible moment a pedestrian appears in the field of view of the participant, a raycast method was applied. For the measurement, a timer was started by the ray intersection and stopped by the button press of the participant. If the participant failed to press the button, the timer automatically expired when the crosswalk was passed. To avoid driving mistakes affecting the simulation, the collision with obstacles was deactivated. This setup enabled comparing the effects of the mean individual reaction times in the different driving conditions in a standardized way.

2.3 Participants, Experimental Design and Procedure

40 (18 women and 22 men) invited participant joined the experiment, while 32 participants completed the study. We tried to keep the distribution of the sexes as similar as possible to the distribution we find in the swiss road traffic. All of the participants carried a valid driver license. We utilized a multivariate, multifactorial, within-subjects design. As independent variables, we used different visuals (CS vs. VR), light (night or day), route, age and sex. The dependent variables include reaction time and average speed. The task was to drive a certain route in the virtual environment, guided by the head up display in the car. The participant also had to press a button at the steering wheel, when a person standing beside a crosswalk came into view. No additional reaction (e.g. braking before the crosswalk when seeing a person) had to be accomplished. Furthermore, to reduce possible confusion, the speed limit for all routes was set to 50 km/h. All trials were done at the Virtual Technologies and Innovation Lab of the School of Applied Psychology.

3 Results

The results showed a significant main effect of the simulation method ($F(1, 124) = 424.688$, $p = .000$) and the light conditions on the reaction times ($F(1, 124) = 6.168$, $p = .014$). No interaction was found. The reaction time was lower in VR than in the CS condition (see Table 1).

Table 1. Mean reaction times in sec. in different conditions

Display	Day/night	Mean	SD
Monitor (CS)	Night	10.89	1.28
	Day	10.40	1.24
HMD (VR)	Night	6.33	1.0
	Day	5.71	1.48

No effect in of age was observable, but male driver drove faster ($p < .05$) in the virtual environment than female driver (see Table 2).

Table 2. Mean reaction times in sec. in different sex groups

Display	N	Mean	SD
Men	18	42.47	3.33
Woman	14	37.69	4.80

4 Discussion

This study aimed to find evidence that shows similarities between real driving behavior and virtual driving behavior. We could show that similar to the real world [18–21] male driver also tend to drive faster in the virtual world (eventually with more risk) than female driver. This is independent from simulation technique. The simulation technique itself has an effect of reaction time as it was found in [9–11] when it comes to recognition of pedestrians. In VR condition the driver were about 4 s faster than in the SC condition. We also found the same ratio of slow to fast reaction when you drive a real car at night or at day in the virtual setting [2, 6–8], with higher effects in the VR condition. When it comes to age, as previously reported [15, 16], no effects were found. Overall, we could show that a virtual driving simulation environment is able to evoke naturalistic driving phenomena (that can be observed from real driving scenarios). This could be a useful tool in the future for safer testing new traffic related innovations.

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