Using the Projection-based Vehicle in the Loop for the Investigation of in-Vehicle Information Systems: First Insights

Matthias Graichen[1], Lisa Graichen[2], Thomas Rottmann[1] and Verena Nitsch[1]
[1]*Human Factors Institute, Bundeswehr University Munich, Werner-Heisenberg-Weg 39, Neubiberg, Germany*
[2]*Department of Cognitive and Engineering Psychology, Chemnitz University of Technology, Chemnitz, Germany*

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Abstract: Most driving simulators cannot replicate real driving dynamics and thus fail to convey a realistic driving experience. To overcome this issue, the Vehicle in the loop (VIL) had been developed, which combines a virtual visual environment with the realistic kinaesthetic feedback of a vehicle while driving on a closed test track. Previous VIL setups used a head-mounted display (HMD) for displaying the virtual environment. This limits the driver's visual input to the virtual environment and makes it difficult to investigate potential research questions concerning driver interactions with in-vehicle information systems (IVIS). To address this issue, a new version of the VIL has been developed, which uses a projector for displaying the driving simulation on an inset in the windshield and two monitors mounted at the vehicle's sides. This work presents the first application of the Pro-VIL for investigating IVIS and their impact on driving performance in safety critical situations. For this purpose, we built a setup for comparing the user experience when using either a gesture- or touch-based interaction system, and the observation of driver attention. Results support the overall practicability of the setup, but also revealed new challenges for experimental research design and execution.

1 INTRODUCTION

Driving simulators are frequently used for analysing driving behaviour that is related to diverse endogenous and exogenous factors such as driving experience, states of fatigue, stress, or inattention, driving manoeuvres or complex traffic scenarios (e.g. Fisher, Rizzo, Caird, & Lee, 2011). Moreover, they are crucial to the investigation of driver adaptions to advanced driver assistance systems (ADAS), (partial) vehicle automation, or in-vehicle driver information systems (IVIS; Stevens, Brusque, & Krems, 2014; cf. recent research using driving simulators in Bengler, Drüke, Hoffmann, Manstetten, & Neukum, 2018). In comparison to observations in real traffic environments, virtual driving simulations are more cost-effective and allow for higher levels of standardisation and safe study execution (e.g. reaction on crossing pedestrians) with respect to both, participants and involved experimenters. Typically, static driving simulators (ranging from basic desktop simulators to more realistic vehicle mock-ups) and dynamic driving simulators (capable of simulating actual vehicle motions) are distinguished and their utilization would depend on research aims, availability and operational costs. When research aims focus on the usability of new HMI (human-machine interface) concepts, a simulator that simply provides the driver an appropriate driving environment (and thereby evoke the need for fulfilling the primary driving task) would suffice. In contrast, designing, parametrising, and validating technical aspects of new (safety-critical) driver assisting functions (e.g. lateral offset in emergency steering systems) often require testing processes that involve accurate and realistic vehicle dynamics. However, even dynamic driving simulators are not able to simulate vehicle motions completely as a driver would experience them under real environmental conditions (e.g. longer transitional forces cannot be displayed). As a result, a trade-off must be defined concerning the levels of experimental standardization and ecological validity, depending on the results' impact and consequences in terms of controllability and safety issues, e. g. conducting studies using a real test vehicle on a closed test track (Purucker, Schneider, Rüger, & Frey, 2018).

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To address these requirements of realistic vehicle dynamics, keeping high levels of experimental standardisation (accurately timed and replicable scenarios), and safe study execution, the Vehicle in the loop (VIL) was developed by Thomas Bock in cooperation with the AUDI AG (Bock, 2008), which combines the immersion of the driver in a virtual environment using a head-mounted display (HMD) with the experience of realistic dynamic forces of a real test vehicle on a test track (Berg, Nitsch, & Färber, 2016; Bock, 2012). However, using a HMD lowers an overall holistic driving experience as the driver is bound to the mere virtual environment, which limits potential research questions concerning driver interactions with any HMI within the vehicle. To overcome these issues, a new projection-based VIL (Pro-VIL) has been proposed (Riedl & Färber, 2015), but has not been evaluated in terms of applicability for the investigation of IVIS. In this work, we present the first-time application of the Pro-VIL aimed at evaluating both a gesture and a touch-based interaction (GBI, TBI) system regarding user experience, driver attention, and driving performance. We will first describe the general functioning of the (Pro-)VIL and the experimental setup, and will then present results concerning the driving experience and practicability of the setup for investigating IVIS. In addition, new directions for the further development of the VIL are discussed.

1.1 Vehicle in the Loop

In a previous version of the VIL, the driver sees a complete virtual reality using a HMD but actually receives realistic kinaesthetic, vestibular and auditory feedback from the interaction with the real car while driving on a test track (Berg et al., 2016). The functional principle is shown in Figure 1. A virtual environment (1) is first constructed based on the available routes of the test track. While driving, the exact position and orientation of the vehicle (2) is located using differential GPS and an inertial measuring unit. An optical tracker (3) keeps track of the head movements of the driver (only in HMD-VIL). Then, the image generation (4) of the driving simulation is based on a sensor fusion of these signals and displays the exact section of the virtual environment the driver is currently looking at.

Various studies confirmed the validity of the HMD-VIL for the investigation of longitudinal driving behaviours (Karl, Berg, Rüger, & Färber, 2013) and steering responses in critical situations (Rüger & Färber, 2018; Rüger, Nitsch, & Färber, 2015; Sieber et al., 2013; Weber, Blum, Ernstberger, & Färber, 2015).

However, there are a number of drawbacks when using a HMD for displaying the virtual environment (Riedl & Färber, 2015). 1) The currently used HMD (NVIS nVisor ST50; for a comparison of evaluated VIL-HMDs see Berg, 2014) has a relatively narrow field of view (40° with a resolution of 1280x1024), which limits its applicability to scenarios which require a widely spread gaze behaviour as in turning manoeuvres or crossing situations when interacting with other traffic participants. 2) As there is neither a suitable display of the car body nor a view of the actual interior (including the driver's body), the

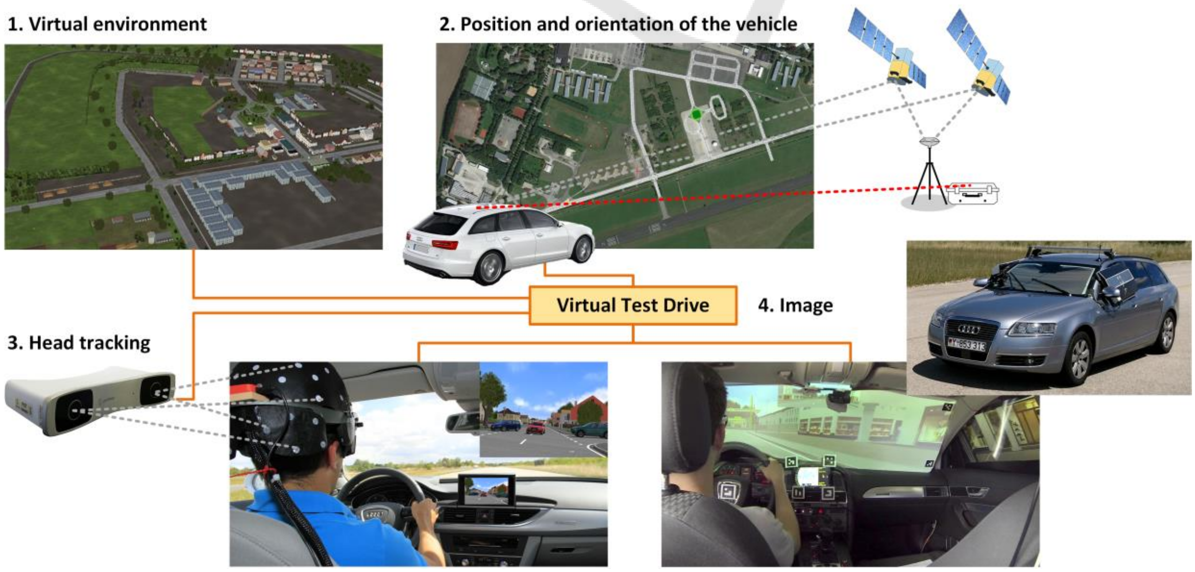

Figure 1: Functional principle of the VIL.

driver has the impression of flying over the street (Karl et al., 2013). 3) The currently used headset has no way of recording the gaze behaviour. 4) The HMD has a relatively high weight (1050 g), which makes it uncomfortable when wearing for a longer time.

With the emerging trend of virtual reality applications, new techniques are considered for replacing the previous headset, e.g. with the HTC Vive, which provides a lower weight (470 g), broader viewing angle and higher resolution (110°; 2160×1200), and can be upgraded to record gaze behaviour with the Pupil Labs eye-tracking add-on (https://pupil-labs.com/vr-ar). Nevertheless, the problem of a lacking interior view remains.

1.2 Projection-based VIL

To overcome the impression of flying on the street, a new setup has been proposed by Riedl and Färber (2015) using a short-distance projector, which is directly mounted under the vehicle's roof and projects the ego's front view on an inset fitted in front of the windshield (1280x800). For side views, two monitors (29 inches, 1920x1080) have been mounted at the outside of the left and right front doors (see Figure 1). The projector setup has been evaluated in terms of simulator sickness and ecological validity concerning the perception and production of longitudinal and lateral distances (Riedl & Färber, 2015), which has shown comparable results to those of the HMD-VIL. Without the HMD, the Pro-VIL provides an unimpaired driving experience with full visibility of the interior of the vehicles and hands, enabling driver interactions with passengers or interaction systems.

2 INVESTIGATION OF IVIS

The development process of new IVIS is not only guided by integrating new emerging technologies and design trends, but also by an overall user experience from a safety perspective. Thus, user efforts of using the system while driving should be minimized in order to reduce its risk of visually or cognitively distracting the driver (cf. Bayly, Young, & Regan, 2009; Liang & Lee, 2010). A possibility of using IVIS for even complex tasks (navigating through more than two menu levels) and without requiring the driver to visually search the controls is provided, e.g., by using gestural control. In Graichen, Graichen, and Krems (2018), the overall potential of GBI compared to TBI for reducing driver distraction has been shown, by significantly reducing the number and duration of gazes while interacting with the IVIS using a static driving simulator. To evaluate the potential of GBI to be also less cognitively distracting than TBI and thereby increasing the readiness of the driver to react timely and adequately in safety critical situations, this setup has been transferred to the Pro-VIL. Here, we describe first insights into participants' impression regarding this setup, and report results on simulator sickness before and after the study execution.

2.1 Vehicle Setup and Scenario

The experiment used the Wizard-of-Oz-Technique, thus all user inputs were actually carried out by the examiner on the rear seats. For displaying the IVIS screens, an additional monitor (Tontec, 7 inches, 1024x500) was mounted on the centre console, which also supposedly recognized touch inputs (see Figure 2). To demonstrate an apparent functioning gesture recognizing device, the Leap Motion was used.

To record the driver and interaction behaviour, two cameras were mounted on the rear mirror and the front passenger seat respectively. For eye-tracking the SMI ETG 2W device was used. Tracking markers were placed around the wind shield and monitor to capture gazes within these regions of interest.

Figure 2: Vehicle setup with wind shield projection, IVIS monitor, gesture recognition device (below the hand), gesture online-visualization, and eye-tracking markers.

2.2 Participants

An opportunity sample of 65 participants (16 female; mostly students), with a mean age of 26.14 (*Min* = 18, *Max* = 57, *SD* = 8.06). No restrictions were made regarding driving experience or visual aids. Only participants with a valid driving licence were selected.

2.3 Measurements

For the purpose of this work, only the questionnaire and results on simulator sickness (SSQ; Kennedy, Lane, Berbaum, & Lilienthal, 1993) and subjective driving experience will be described. A pre-post-test measurement was chosen to observe the development of sickness symptoms when sitting in the Pro-VIL for about 60 minutes. The SSQ measures 16 sickness symptoms, which can be assigned to three subscales: Nausea (SSQ-N), oculomotor disturbances (SSQ-O), and disorientation (SSQ-D), as well as to an overall score for total severity (SSQ-TS). During each trial, participants' comments were noted that gave indication to their personal driving experience.

Moreover, participants were encouraged to talk about the driving experience and overall impression on the Pro-VIL after each trial, and were again explicitly asked at the end of the session.

2.4 Research Design and Procedure

A two-way (2x2) within-subjects design was chosen, with the interaction type (GBI vs. TBI) being the first factor, and the level of interaction (simple vs. complex tasks) the second factor. All five trials were based on the same urban scenario requiring one turning manoeuvre and one U-turn, but differed regarding the surrounding traffic. Each trial involved three interaction tasks with the IVIS, with two of them being directly followed by various safety critical situations (e.g. unpredictable crossings or merging or vehicles). Overall, participants drove more than 11.5 km with the Pro-VIL. The experiment took each participant about 1.5 h.

Upon arrival, participants completed questionnaires pertaining to demographics, experience on GBI systems, and a pre-test of the SSQ. Then, they were introduced to the vehicle and the functional principle of the VIL. Afterwards, the participants were trained to control the IVIS with both possible input modes of GBI and TBI, including a demonstration of the gesture recognition performance using an online-visualization on the display (Figure 2). After that, participants drove one training scenario to familiarize themselves with the vehicle and the VIL. Then, they drove five trials in total, including the first trial without any safety critical situation to capture a baseline of individual driving performance regarding lane keeping and preferences on time headway in car-following. Before each trial, the eye-tracking system was calibrated. Within the four test trials, the trained interaction tasks with the IVIS (e.g. zoom into navigation map, or call traffic information) were instructed by the examiner at fixed scenario positions. After each trial, participants were debriefed, completed questionnaires pertaining to different aspects of user experience with both interaction systems. At the end of the session, participants completed the post-test SSQ and were interviewed on their impressions of the Pro-VIL. Overall, the experiment took about 90 minutes.

3 EVALUATION OF DRIVING EXPERIENCE

In the following sections, the results on simulator sickness, qualitative data pertaining to driving experience and immersion effects as well as experiences from the perspective of the study execution are described.

3.1 Driving Experiences

When explaining the functional principle of the VIL to the participants, several expressed worry due to the lack of visual feedback on their real position on the test track, and asked about the reliability and precision of the system. Noticeably, most participants showed a cautious driving style (low speed and acceleration) in the practicing trial, but drove increasingly more confidently within the baseline trial. However, the real driving speed was often underestimated, which led to a higher radius in turning manoeuvres. Some participants commented on the different resolutions between the projection and monitor displays. Overall, most participants enjoyed the driving experience and were often completely taken by the test environment (e.g. reducing speed at a radar trap, emergency brakings in safety critical situations, and addressing aggressive comments, hand gestures and even using the car horn to the virtual causer of the accident). However, after failing in safety critical situations, participants often became silent and later expressed negative feelings.

3.2 Simulator Sickness

During the trials, one participant requested to pause due to light sickness symptoms, and one participant reported severe symptoms about one hour after completing the study (the participant already knew about his sensibility from previous studies with the HMD-VIL). Some participants reported light headaches after the test phase. Two participants reported sickness symptoms prior to the test phase

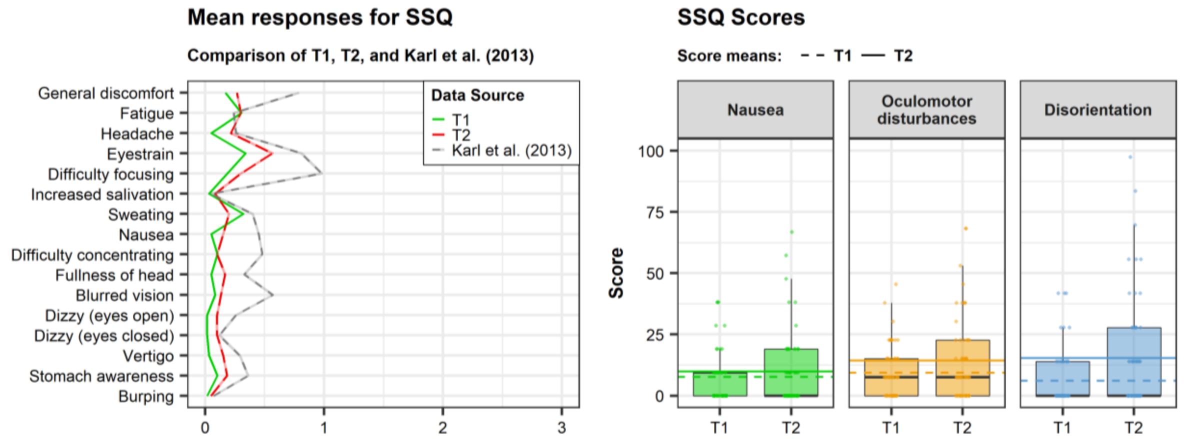

Figure 3: Average SSQ symptom profiles (left) and distributions of scores (right).

and were therefore excluded in the following analysis. Two missing item values were identified in the SSQ pre-test and imputed by predictive mean matching using the R package 'mice' (Van Buuren & Groothuis-Oudshoorn, 2011). Figure 3 (left) provides an overview of the average values for each symptom, compared to SSQ results for driving in complex worlds taken from Karl et al. (2013).

The SSQ scores were computed according to Kennedy et al. (1993). Reliability analysis for subscales and the overall score showed low Cronbach's α values in T1 (ranging from .41 to .52) and acceptable values ranging from .68 to .76 at T2. As depicted in Figure 3 (right), symptoms for SSQ-D were more severe than SSQ-N and SSQ-O in both, pre- and post-surveys. To compare each of the scores at T1 and T2 a paired Wilcoxon signed-rank was conducted. Scores for SSQ-N differed not significantly between T2 (M = 9.86; SD = 14.69) than on T1 (M = 7.6; SD = 10.14), r = -0.15. Scores for SSQ-O were significantly higher on T2 (M = 14.28; SD = 16.58) and T1 (M = 9.38; SD = 10.38), p = 0.024, r = -0.29. Scores for SSQ-D were significantly higher on T2 (M = 15.31; SD = 22.45) than on T1 (M = 6.13; SD = 11.34), p = .003, r = -.39. The score for SSQ-TS was significantly higher on T2 (M = 147.53; SD = 182.03) than on T1 (M = 86.44; SD = 99.24), p = .01, r = -.33.

3.3 Technical Issues and Procedure

Two study assistants are necessary to ensure a safe and reliable study execution, as the handling of the Pro-VIL and the used vehicle setup required sustained attention to detail and the accurate order of working steps. One technical issue of the presented study concerns the power management of the vehicle, which provided enough power to drive just about two sessions. It was recommended to recharge the vehicle in short intervals without driving.

Another issue was the complex study procedure, including operating on the rear seat with two computers simultaneously: One for the virtual environment and monitoring the webcams (mounted on the vehicle to ensure safe driving on the test track), and another computer for timely controlling the IVIS corresponding to the driver inputs, monitoring the performance of the eye-tracking system, and recording the vehicle data.

4 DISCUSSION

At first, participants expressed doubt regarding the reliability of the VIL system, but then showed signs of high immersion effects (e.g. strong behavioural reactions against accident causers) and remarked that they enjoyed the driving experience. Though some scores for SSQ symptoms were significantly higher after the study, results are lower compared to the HMD-VIL shown in Karl et al. (2013), and even lower than those shown in Riedl and Färber (2015) using the Pro-VIL without side monitors. Some symptoms might be attributed to different resolutions between the projector and the monitor, which could be overcome by lowering the resolution of the side monitors. By now, there are new short distance projectors available, which are also capable of a higher resolution. But still, there would remain some blurring in the projector image, as the pixels are more stretched in the lower areas due to the sloping inset in the windshield. A new projector (1920x1080) was mounted after the study, which increases the pixel density from 1.024 to 1.536 horizontally, and from

2.286 to 3.086 vertically. Overall, a new ‘front view to side view ratio’ of 0.4 in horizontal density and 0.8 in vertical density could be achieved. The potential effects of the new projector on driver experience and simulator sickness will be examined in the future.

As the vehicle did not allow for longer session times without frequent recharging at the time of the study, the power management was completely redesigned afterwards to increase the operating time, which is now at approximately 7 hours (without any other instrumentation or study equipment).

Overall, the Pro-VIL was successfully applied in the domain of investigating IVIS and their effects on the driving performance in safety critical situations. The additional setup of the Pro-VIL for investigating the effect of GBI and TBI was well accepted and all participants were able to handle the driving task and secondary tasks with the IVIS, which allows for analyses of realistic driving behavior.

Future plans involve a multi driver simulation, combing both, the HMD and the Pro-VIL.

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