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Towards Seamless User Experiences in Driving Simulation Studies

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Abstract - *We present the results of a study where the physical transition into the driving simulator was masked by a virtual experience. Our main hypothesis was that participants should experience a higher sense of presence in the simulator when their entering the physical environment of the driving simulator is masked by a virtual experience that shows a transition from the real starting room to the car, combined with storytelling, but conceals the driving simulator itself. To confirm this hypothesis, we performed a comparative, between-subjects user study, in which two groups were examined while they used a driving simulator: one group experienced a virtual transition while walking to the simulator; the other group only walked to the driving simulator before starting the driving simulation. The user study evaluation showed that participants who experienced the virtual transition tended to feel a higher sense of presence. In addition, we found evidence in the behavior and subjective response that the virtual transition influenced the participants. However, there was no significant difference between the two groups in terms of their driving behavior. Ultimately, the results of this user study show that virtual transition technology has considerable potential for the user studies implemented in driving simulators.*

Keywords: *Virtual Reality (VR) Transition, Dynamic Driving Simulator, Presence, Storytelling, User Experience.*

Introduction

Driving simulations are integral to the automotive industry's development processes: they are being used in all phases of research and development. The simulator, see Fig. 1 for an example, offers a reliable evaluation standard by guaranteeing the reproducibility of a driving situation from one participant to another, without external dependencies on traffic conditions, weather, etc. [Cha15]. Critical situations can be easily created, observed and evaluated without placing the participants in actual danger. One of the principal criticisms of driving simulators is that a lack of realism can cause the participants to behave differently from how they would behave in real-world conditions [Cha15, Hel15, Col11].

Figure 1: Dynamic Driving Simulator

To provide meaningful results in a driving simulation studies a certain level of realism is required, which makes the participant feel immersed in the simulation and as if he or she is driving an actual vehicle. This sense of "being there" is what has been called "presence" in literature [Sla09, Sla03]. Presence refers to a person's feeling and behavior as if he or she were truly in the virtual world that is being presented [Sla09]. A participant's strong sense of presence can cause him or her to react realistically, it can encourage specific types of body language and physiological responses, as well as reactions identical to those in the real world [Llo13]. This is why an adequate sense of presence is an important factor in driving simulation studies.

The level of presence that can be reached in a driving simulator depends on a large number of factors. First of all, there are a number of technical factors such as the quality of the displayed visual environment, the auditory cues, the motion cues, the realism of the car's exterior and interior, the quality of steering and pedal feel, the vehicle dynamics, etc. Also the participant's characteristics plays a large role, as some people are more easily immersed in a virtual environment than others. Finally, there are also contextual factors, such as the way in which the participant is approached and briefed and how the study is performed. There is one important influencing factor that is often overlooked, that is how the participant physically reaches the driver seat. Many simulators do a rather poor job at hiding the fact that they are laboratory environments. For participants there is often no way of overlooking that fact, while they make their way over to the simulator, they are entering an environment that is nothing like an actual car on a real road, at which point they realize that their driving behavior would not have any real consequences.

In order to mitigate some of the negative effects of the above described factors and allow the participants to adopt to the simulated environment (and possibly help them forget they are in one), many simulator studies start with a familiarization phase, where the participant is asked to drive for a few minutes before the actual experiment starts. The data obtained in this phase is typically irrelevant for the experiment as its only purpose is to gradually increase the level of presence. As this does consume valuable simulator time, it is worthwhile to consider whether there are more efficient ways to increase the level of presence.

Related work

Different scientific fields have provided several different definitions of presence. In the context of electronic media, presence was basically regarded as telepresence [Har13]. In recent research, presence was defined as an illusion of being in another place [Sla09], but presence is not only an illusion of being in a place it is also the sensation of physically being a part of the story instead of witnessing images from a distance.[Llo13]. Mel Slater defined two categories of presence: place illusion and plausibility illusion [Sla03]. Presence has been typically measured by questionnaires, physiological and behavioral responses, and comparisons with the measurements obtained from real experiences [Cha15, Fri06, Sla03, Llo13, Men17, Har13, Mee02]. It has been claimed that a strong sense of presence can improve participants' cognitive performance and lead to realistic behavior in VR [Sla09].

Charron et al. described different levels of presence: the maximal theoretical level, the real-life subjective level, and the subjective sense of presence in VR [Cha15]. The objective sense of presence can be calculated as a relation between a participant's presence in VR and the presence he or she actually felt as described in Eq.1 [Cha15]. The presence felt in reality is not necessarily equal to the absolute maximal theoretical level.

$$\text{Objective Presence} = \left(\frac{\text{Presence VR}}{\text{Presence Reality}}\right) \qquad (1)$$

Steinicke et al. [Ste09] separated the concept of presence into three components: subjective, behavioral and physiological presence. The subjective presence is the participants' self-reported sense of presence. The behavioral presence is the participants' behavior observed by the experimenter or system. The physiological presence is the participants' physiological reactions. Furthermore, Steinicke et al. proposed a procedure that can increase participants' sense of presence in VR [Ste09]. The researchers observed subjective, physiological, and behavioral reactions of the subjects during a fully immersive flight-phobia experiment. When participants were exposed to a transitional environment, consisting of a replica of the physical room where the experiment had started, before entering the virtual flight environment. The participants' subjective evaluations showed an increased sense of presence. In addition, participants were observed to move faster and more naturally, if they had entered the transitional environment before and walked there for five minutes. [Ste09].

A study from Men et al. provided further evidence that transitions are essential in VR settings and that effectively using them can control participants' sense of presence[Men17]. In their study, Men et al. explored whether transitions influenced the three factors: realness, involvement, and spatial presence. The experiment included four transition variations: simple cut, fade, fast movement, and vortex. The results showed that the simple cut transition supported the presence and the vortex transition broke the continuity of experience almost completely [Men17].

Meehan et al. performed physiological measurements of presence in a stressful virtual environment referred to as the Pit Room [Mee02]. The researchers hypothesized that higher sense of presence would evoke physiological responses similar to those produced in a comparable real situation. The researchers measured the participants' heart rate, skin temperature, skin conductance and used the self-report questionnaires. The heart rate was higher in the Pit Room in 90% of the cases and correlated with the participants' self-reported presence. The participants' skin temperatures were less indicative and had a slower response [Mee02].

Objectives of the present study

The goal of our research was to investigate the influence of a virtual transition on participants' sense of presence in a driving simulation. The virtual transition was achieved by visually augmenting the physical transition to the driving simulator with a virtual environment presented in a head mounted display (HMD). In this context, a virtual transition is used to mask the driving simulator's technical surrounding with a virtual environment. Ideally, the virtual transition makes participants forget completely that they are in a driving simulator, which should then lead to more realistic driving behavior during the driving experiment. The central question is whether a virtual transition can affect participants' sense of presence in the driving simulation.

In this study we examined to which extent subjective and objective measures varied between participants who had received a virtual transition while walking to the driving simulator compared to those obtained from participants who had a regular guiding to the simulator. Transition techniques are used throughout many media, such as films and computer games. In films, transitions are used between scenes to communicate a break in real-time actions and also to change time or place. Transition provides flexibility for time lines and locations within storytelling and are often used to control the sense of presence [Men17]. Another example of the usage of transition environments can be found in many theme parks, where the rides' queuing areas are decorated with thematic elements, sounds, lights and smells, which serve as a bridge to the ride experience. In the current study, we consider virtual transition environment that bridge the real world with the driving simulation environment by placing the user in an immersive virtual experience using an HMD. This approach required the creation of a virtual environment and a story that would harmoniously fit with the driving simulation environment that was experienced in the driving simulator. In addition, this solution had to be non-intrusive and support natural locomotion at long distances.

Hypothesis

The hypothesis of the experiment is that the participants exposed to the virtual transition environment would report a stronger sense of presence during the driving simulation than the group that goes to the simulator through the real hallways.

Research question

The research question is whether a virtual transition to the driving simulator can affect participants' sense of presence in the driving simulation?

Experiment description

We performed the experiment to investigate the effect of a virtual transition on the level of presence during the driving simulation. For the user study we choose a between-subjects design.

Participants

The participants were employees of different BMW departments. The majority were engineers and IT specialists.The total number of participants was 41 (28 males and 13 females) between 23 and 60 years of age. 19 participants had corrected vision (14 wore glasses; five wore contact lenses), 22 participants had previously participated in studies with driving simulators, 19 had never been involved in such studies. Eight participants did not have experience with VR, 33 had experience with VR. The average driving experience was 12 years.

The participants were randomly divided into two groups: the first group was exposed to the virtual transition (*VR group*) and comprised of 21 participants. The second group was not exposed to the virtual transition (*NotVR*) and comprised of 20 participants. We had to exclude 3 participants in total, due to simulator sickness, technical problems, or driving too fast. In conclusion, the usable data in each group consisted of the data of 19 participants. Both groups were equivalent in age, occupation, gender, driving experience and previous experience with simulators and VR.

Procedure

The overall experiment procedure for both groups was the same, except the steps related to the virtual transition. After arrival the participants were informed about the objectives of the user study, received safety instructions and signed an informed consent form. Next, the participants filled out the demographic data questionnaires, personal information data, and the pre-experiment Simulator Sickness Questionnaire (SSQ) [Ken93]. The participants where then equipped with a measurement wristband (E-4 Empatica [Emp17]), which measured heart rate and electrodermal activity. Then, the experimenter told the participants the scenario story. At this point, the virtual transition group put on the VR HMD as

Figure 2: Participant wearing VR HMD, Empatica and MSI computer placed in the suitcase

shown in Fig. 2. The participants of both groups walked to the simulator and entered the simulator dome. In the dome, the virtual transition group removed the VR HMD. Before entering the car mock-up inside the simulator dome, both groups received further safety instructions for evacuation in case of an emergency. After the experimenter repeated the driving instructions and driving regulations the participants entered the car, and the experimenter started the driving simulation.

The driving simulation was a dynamic simulation that used daylight driving conditions. The scenario was developed relative to the presence measurement methodology. During the driving simulation, the participants drove on a country road, which transitioned into an urban environment, followed by a highway. Every two minutes the participants were asked to rate their sense of presence on a scale from 1 to 10.

During the drive, the participants were exposed to four critical situations in order to observe their reactions to stress: 1) the lead vehicle braking unexpectedly on the country road 2) a pedestrian crossing unexpectedly the road in the city and 3) a phone call - represented by a loud ringing sound - on the highway, and 4) a lead vehicle unexpectedly cutting in on the highway. After each critical situation, the participants were asked to rate the criticality of the situation on a scale from one to three. After the simulation ended, the participants brought the vehicle to a full stop and waited until the experimenter retrieved them from the simulator mock-up. The duration of the driving simulation depended on the driving speed, on average 20 to 25 minutes.

The experimenter then guided the participants to the debriefing room, where they filled out the following post hoc questionnaires: the SSQ [Ken93], Slater-Usoh-Steed presence questionnaire (SUS) [Fri06], and the Igroup Presence Questionnaire (IPQ) [Igr16, Sch01]. Next, the VR group answered two interview questions and described the virtual environment by words and drawings

Dependent variables

During the experiment the following objective and subjective measures were used: subjective presence rating in form of immediate self-feedback assessment, physiological data (heart rate, electrodermal activity) to determine the participants' reactions to stressful situations on the road as well as vehicle-based measures of driving behavior and behavioral observation.

Before and after the experiment we used several questionnaires to measure presence. Personal data estimation (PED) was used before the experiment to collect demographical and background information on the participants. Motion sickness was measured using the Simulator Sickness Questionnaire SSQ [Ken93] before and after the experiment. Motion sickness is a potential indicator of physiological presence [Bar04]. The IPQ [Igr16, Sch01] measured the participants' self-reported presence after the experiment. The SUS questionnaire also measured the participants self-reported presence after the experiment [Bar04].

We used the immediate self-feedback assessment during the driving simulation in order to obtain a development graph of the presence rating during the driving simulation. At given intervals, the participants were asked to evaluate their current sense of presence on a scale from one to 10. A score of one represented a low sense of presence, and a score of ten indicated a high sense of presence, equal to being in the real world. In addition, after a critical situation a second question was asked: "How critical was the situation?". The participants were asked to answer this question on a scale from 1 to 3, with the following meaning: 1: the situation was not critical; 2: the situation was critical, but I had the control over the situation; and 3: the situation was critical, I had no control over the situation.

The participants' answers were used to evaluate the connection between their physiological reactions, presence and perceived criticality of the driving events in the simulation. To evaluate the participants' perception of risk during the driving simulation, the participants' reactions to a phone call while driving on the highway were observed over the video camera and microphone placed in the driving simulator.

During the virtual transition, we observed the participants' behavior in order to evaluate their sense of safety and presence, particularly their gait, body gestures, and postures.

In terms of vehicle-based measures, the driving behavior of each participant was logged in a log file. The following elements were recorded: driving velocity, lane offset and brake reaction time. According to [Cha15], the driving velocity is related to the participants' risk perception, a lower presence causes lower risk perception and decreases the driving velocity. We assumed that the presence may also influence lane keeping accuracy, measured by the lane offset, and the brake reaction time in the critical situations.

The heart rate and the skin conductance values were collected with a measurement wristband (E-4 Empatica [Emp17]). The heart rate is associated with emotional experiences [Mee02], responses to novel situations and attention, which is related to presence [Bra06]. The skin conductance is an indicator of psychological, physiological stimulation and also of presence [Fri06].

After the experiment, we asked VR group participants two questions about the virtual transition environment, to determine how the participants perceived the virtual transition: "Did the virtual transition help you to enter the whole experimental story naturally?" and "What did you miss in the virtual transition environment?". To measure participants' presence in the virtual transition environment and the immersion of the transition environment, participants completed two tasks: they drew the sketch plan of the virtual transition environment and wrote six words that described this environment.

Implementation

To facilitate the virtual transition, we developed a virtual environment and a setup that would allow the participants to walk naturally to the driving simulator, from the entrance of the simulator room to the driving-simulator mock-up. To provide this natural movement, the simulator needed to be hidden entirely, both visually and audibly. To achieve a higher sense of presence, the participants must be involved from experiment beginning in the story, which should bridge the real environment and the driving simulation. This transition environment had to support the scenario of the driving simulation and the real circumstances. In addition, the participants' sense of presence should be measured during and after the driving simulation, as well as the other presence indicators.

The transition environment was developed for Dell Visor Windows Mixed Reality HMD with Inside-Out Tracking, high-resolution 1440x1440 liquid crystal displays, 105 degrees horizontal field of view and 90Hz display refresh rate [Mic17], using the MSI computer placed in the suitcase and headphones as shown in Fig. 2, to support natural locomotion in large scale rooms. This technique is considerably flexible and immersive and can entirely hide the physical environment.

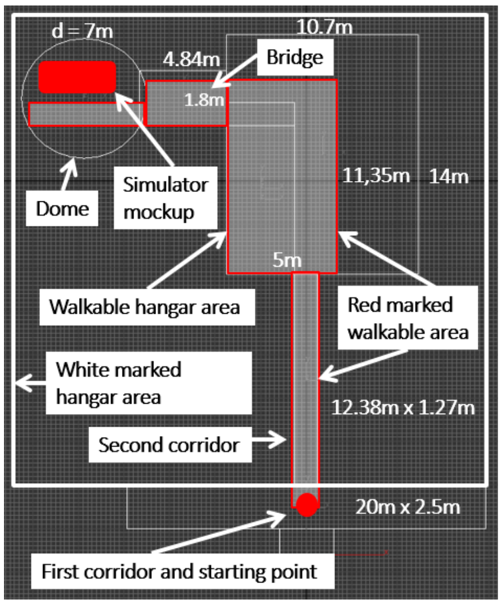


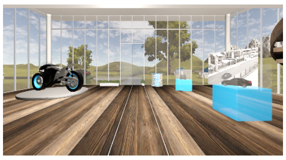
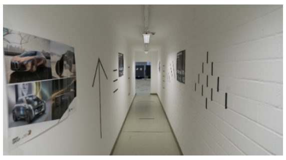
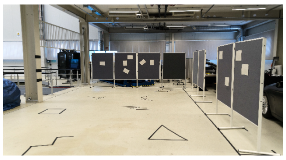
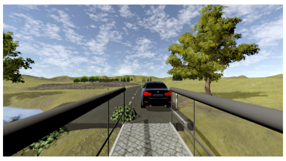
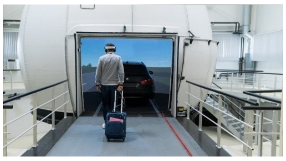
Figure 3: Real rooms plan in meters

We measured the real rooms as shown in Fig. 3, and modelled the virtual plan of the walkable space in 3D as a virtual building and outdoor environment, precisely matching the real rooms geometry and size.

The first room the participants see in the VR HMD was the physical replication of the real corridor where they physically are, and they stand in the front of the door in both worlds. After the door opens, the participants enter the building of the BMW Experience Centre, this building matches the real 12.38-m corridor as shown in the first row in Tab.1.

Where the real corridor ends and the simulator hangar begins, the participants exit the building in VR and see the surrounding landscape as shown in the middle row in Tab.1.

Table 1: Virtual environment with related real environment

Virtual	Real
	
	
	

After the participants crosses the hangar, they turn to 90 degrees in both worlds to go to the bridge and cross the real and virtual bridges and enter the dome as shown in last row in Tab.1. The landscape they see in the virtual world matches the landscape of the driving simulation projected in the simulator dome. Thus, when they remove the VR HMD, there is no break in perception.

The Dynamic Driving Simulator is based on a mock-up of a BMW vehicle placed in the dome (see Figure 1). The dome is connected with six degrees of freedom hexapod-based motion system (X, Y, Z, yaw, roll, and nod) and a moving 240 degree not stereoscopic projection system.

The VR transition Environment provides the interactive components. Initially, background instrumental music is playing when the participants enter the virtual BMW Experience Centre and outdoors the birds twitter on the trees, to cover the real-world noise and to better immerse. The male voice conveys the welcome message, gives instructions and makes aware of the driving task and the vehicle. In the driving simulation, the same voice talk to the participants to begin driving and asks questions about critical situations and the participants' sense of presence. When the participants arrive at a specific position, the screens appears, and the male voice provides information about objects in the room and asks the participants to evaluate the motorbike prototype shown in the virtual experience center or to choose the route to drive. The participants were asked to choose one of the offered options on the screens and to confirm the choice verbally. This interaction is an imitation of the voice command known as the "Wizard of Oz" interaction technique.

Results

The main goal of the experiment was to determine whether a virtual transition can increase a person's sense of presence in a driving simulation. A between-subjects design for the user study was selected, several indicators were evaluated: subjective feelings, physiological data, and driving behavior. Different statistical values and data analysis methods were used. To determine the validity of the results, each result was inspected with a statistical hypothesis test using the ANOVA test, F-test, T-test and the probability (p) value; if the p-value is less than 0.05 the results are statistically significant [Bor06, Max14].

Questionnaires

The IPQ analyzed the following presence factors: spatial presence, involvement, and realness [Bar04]. The evaluation of the IPQ answers showed that the spatial presence and involvement were equal in both groups. The difference between the two groups was in the realness perception: the VR group had a significantly higher sense of realness in the simulation ($p < 0.01$), indicating that the VR group perceived the driving simulation as more real than did the NotVR group; thus, it can be concluded that the VR group felt more present in the simulation.

The SUS questionnaire presented six items with a seven-point Likert scale. The mean values of both groups were not significantly different, but the average, min. and max. values were slightly higher for the VR group; this can be considered as a weak indicator of a higher sense of presence. The overall score (the number of high responses with scores six or seven [Fri06]), showed that the VR group score was higher (16% more instances of high response) than the score of NotVR group . This indicates that the VR group felt more present in the driving simulation than did the NotVR group.

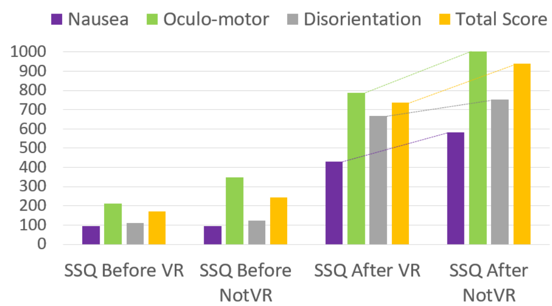


Figure 4: SSQ Sub-score and Total-score results

The SSQ was completed before and after the experiment and showed that the motion-sickness symptoms increased significantly in both groups after the experiment ($p<0.002$), which was expected. The NotVR group's motion sickness symptoms were more pronounced, especially the oculomotor ones, and their total score symptoms were more evident than those of the VR group as shown in Fig. 4. This could be regarded as weak evidence that the NotVR group experienced a lesser degree of presence. From a different point of view, motion sickness potentially distracts participants and thereby decreases their level of presence [Fri06].

Behavioral observation

As described in the previous chapters, we observed and documented the participants' behavior. The observed behavior in reaction to the phone call showed that both groups had different reactions: the VR group ignored the phone call more often than did the NotVR group. This suggests that participants in the VR group had a higher level of presence, which caused them to make more realistic risk assessments. This could have been influenced by the virtual transition. In the NotVR group, the dominant reactions were to search with the eyes for possibilities to pick up the phone and pushing the call response button on the steering wheel. In the VR group, the dominant reactions were also the searching for possibilities to pick up the phone on the steering wheel and the verbal response. In the VR group, more of the participants reacted to the call verbally, when compared with the NotVR group. A possible explanation is that the VR group already experienced the verbal interaction in the virtual transition, and this interaction influenced their behavior.

Looking at driving behavior, we observed that the two groups' driving velocity was for all road types not significantly different ($0.3<p<0.8$). The VR group tended to be slightly slower (on avg. 1 km/h) on the country road and in the city. On the highway, the VR group was faster (avg. 3 km/h) than the NotVR group.

The velocities in the driving simulator were compared with the participants' self-estimated velocities. They indicated higher velocities in the questionnaire than they actually drove in the simulator. There was no difference between the two groups. The maximal deviation between the self-estimated velocity and the velocity in simulation was on the highway (up to 27km/h, p=0.01). This difference indicates that a more careful driving style was used in the simulation, most likely because of the novelty of the experience [Cha15].

The timing and force of the brake reactions were examined as well. The time between the beginning of each event and the moment when the participants started to brake was evaluated for critical events. In event one on the country road (E1) the average brake-reaction speed of the NotVR group was faster than that of the VR group for 0.5s. In event two in the city (E2) the VR group was faster, with an average of 0.4s. In event four (E4) on the highway the NotVR group was significantly faster for 0.9s (p=0.03).

The times from the beginning of each event until the maximal brake force was achieved was evaluated. The VR group produced its maximal brake force faster than did the NotVR group. This result implies that the VR group pressed the brake pedal with more force, which can be interpreted as a sign of stress caused by these participants' higher sense of presence. The average brake force was equal between the groups.

The lane offset was calculated for the entire driving simulation route. The NotVR group tended to drive closer to the left side of the lane, and the VR group preferred the right side. This was especially noticeable at the start of the driving simulation, on the country road as shown in Fig. 5. The right side of the lane is located farther from the oncoming traffic and could be considered as safer. The findings for the lane offset indicate that the VR group felt less confident at the start and that they assessed the risk better than

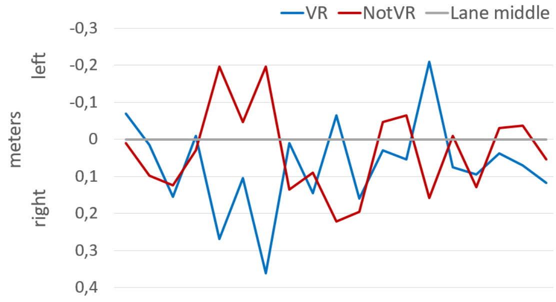


Figure 5: Lane offset results

the NotVR group did, which implies that the VR transition influenced the participants' perception.

During the driving simulation, participants' sense of presence was evaluated by asking the same presence question every two minutes. There was no significant difference between the groups, except for the variance in the values between the two groups. In the NotVR group, the answer values among the participants were significantly more scattered (p=0.04) as shown in Fig.6. The participants reported a higher sense of presence on the highway and a lower one in the city. Apparently, the presence rating was influenced by the participants' perception of the graphics and motion specifics of each road type.

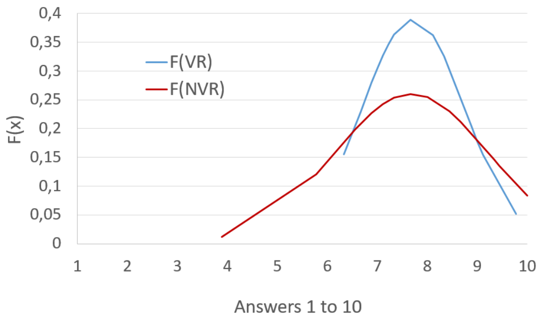


Figure 6: Presence questions results probability mass function

The critical events on the road were evaluated on a scale with three grades of criticality. The NotVR group had evaluated all of the events more critically than did the VR group. According to the measurements, the participants who drove faster evaluated the situations as more critical. The NotVR group was slightly faster in the city and on the country road. This result indicates that these participants made lower risk estimations during the driving simulation. According to the recorded driving speed in the city and on the country road, the NotVR group had a shorter time to react and become more frightened in the critical situations, leading to rate them as more critical.

Physiological observations

We also measured physiological responses of participants to stressful situations, which some researchers have proposed as objective measurements of presence [Mee02]. For all events, the

NotVR group had higher heart rates than did the VR group; 10% of the participants in both groups had a higher pulse than the standard resting heart rate (max. 90 bpm [Sha17, Bra06]). In E4, the NotVR group's average heart rate significantly rose to 125 bpm (p=0.04). This result showed that the participants perceived the events on the road as critical [Bra06, Mee03, Mee02]. The heart-rate values correlated with the ratings of the critical situations, confirming that the NotVR group was more frightened in critical situations.

The skin electrodermal activity (EDA) was not significantly different between the two groups. However, the VR group tended to produce higher EDA values in all events than did the NotVR group. This higher EDA indicated higher stress level and sense of presence [Mee03, Mee02]; moreover, the EDA values at the start of the experiment, in the meeting room, were much higher than those produced during the driving simulation. This inconsistency in the EDA values makes this data difficult to evaluate.

VR transition evaluation

At the end of the experiment, the VR group participants were asked whether the virtual transition aided their immersion in the experiment story, and all of them answered that it helped them enter the story naturally. The participants trusted the virtual environment. The majority of the participants noted that removing the VR HMDs was disruptive. In addition, they noted that the characteristics of the VR transition's computer graphics provided more fidelity in comparison to the graphics in the driving simulation.

The observed behavior of the participants' walking through the transition environment reflected their feedback. All of them walked a long distance confidently and at a regular speed; they looked around and stepped to the left and right casually.

In addition, the participants' sense of presence in the VR transition was evaluated because, if the environment of the VR transition was not immersive and if the participants did not feel present in it, then the VR transition could not improve their sense of presence in the driving simulation. For this evaluation, the VR group completed two creative tasks. The first task was to describe with six words the virtual world they experienced while wearing the HMD; this task was established to refresh the participants' memory and to determine how they perceived this environment. The most common words were "realistic, futuristic, enjoyable, clean, lonely, synthetic, exciting", and "spacious", as well as their synonyms. The second task was to draw a floor plan of the virtual world experienced while wearing the HMD. The more precise and detailed the plan is, the more spatially present the participant felt in the virtual world[Bar04].

All of the plans were drawn correctly and with a good level of detail, indicating that the participants felt spatially present in the VR transition and paid attention to the details in the virtual environment.

Conclusion and Discussion

The goal of this study was to examine how a virtual transition can affect a person's sense of presence in driving simulation. The central question was whether hiding the physical surroundings of a driving simulator with a virtual environment can improve participants' sense of presence in the driving simulation itself. Our user study investigated whether different presence indicators varied between the participants that experienced the virtual transition before they entered the driving simulator and the participants that did not, as well as how significant the variance was.

The evaluation of the IPQ and SUS showed differences in the sense of presence: the VR group perceived the driving-simulation environment as more reliable, and the total score of the SUS showed a significantly higher sense of presence in the VR group. In the driving behavior and the immediate self-feedback assessment of the presence feeling during the driving simulation, the results did not show significant differences between the two groups. One of the reasons might be that the Dynamic Driving Simulator is a high-fidelity simulator, leading to the NotVR group's reporting a very high sense of presence during the driving simulation. Some of the participants claimed that their sense of presence depended on the road types, because of some graphics and the motion-cueing specifics of the driving simulator. The VR group always compared the driving-simulation environment with the environment that they had seen in the VR HMD, this pointed to the discrepancy in perception of environments caused by the taking off the VR HMD in the front of the simulator mock-up. It should be noted that the participants were in VR transition environment around three minutes, and driving simulation took 20-25 min.

This study has provided evidence that can be interpreted as the influence of the VR transition on participants. At the driving start, the VR group kept more to the right side of the lane because doing so was safer. When the two groups are compared, more of the participants in the VR group responded to the phone call orally, and their reaction was most likely encouraged by their previous experience in the VR transition. In addition, the post hoc questionnaires confirmed that the VR group tended to feel more present in the driving simulation than did the NotVR group.

To answer the question, whether the VR transition affected the driving behavior on the basis of the data gained from the experiment, multiple circumstances have to be considered. The average driving experience of the participants was 12 years. Some of the participants were experts in the field of VR or driving simulators, these participants were focused on how individual components of the simulator worked. In addition, the Dynamic Driving Simulator is a high-fidelity simulator and is based on a real BMW car. Another possible explanation of the results is that the participants were in the VR transition environment only for a short time. On the one hand, the transition might have been too short to produce significant effects; on the other hand, the main task of a virtual transition is to cover the technical surroundings of the simulator and support the story of the driving simulator experiment itself.

The task of hiding the physical environment of the simulator was successfully achieved. Interestingly, all participants in the VR group, on their way back after the driving simulation experience, did not recognize the physical rooms and were especially surprised by the narrow corridor at the start. These participants had not perceived the long (12m) narrow

(1.2m) corridor even though they touched the physical walls at the start of the experiment. When entering the hangar in reality and the outdoor environment in the VR, some of the participants reported post hoc that they had felt the wind moving the trees (which had wind animations in the VR). Some of the participants' self-reported comments indicated that they would prefer to use a transitional environment.

However, one significant drawback of the user study was that the participants had to remove the VR HMD in simulator dome before entering the simulator mock-up. These participants mentioned this experience, and it might have disrupted their sense of presence. In the future, the best approach to avoid this disruption may be to have the participants remove the VR HMD in the simulator mock-up or to have them drive in the simulator wearing the VR HMD.

In conclusion, the virtual transition presented in this work slightly increased the participants' sense of presence in the driving simulation. Several improvement possibilities have been identified and need to be explored. It will be interesting to see not only how virtual transitions will develop further but also how they can be used to increase the realism of the driving behavior in the driving simulators.

The virtual transition technique has considerable potential and allows natural walking in large environments, and it is highly immersive because of real-time rendering, inside-out tracking, high frame rate, and a high display resolution. In regards to all the driving simulation study steps: the preliminary conversation, the safety instructions, and the guidance to the simulator can be combined into one scenario and performed while users are wearing the HMD. In future studies, the time the participants stay in the virtual transition should probably be increased and include more types of interactions and additional tasks.

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