Does a Gradual Transition to the Virtual World increase Presence?

Frank Steinicke*, Gerd Bruder†, Klaus Hinrichs‡
Visualization and Computer Graphics (VisCG) Research Group
Department of Computer Science
University of Münster

Anthony Steed§
Virtual Environments and Computer Graphics (VECG) Group
Department of Computer Science
University College London

Alexander L. Gerlach¶
Clinical Psychological and Diagnostics
Psychology Department I
University of Münster

Abstract

In order to increase a user's sense of presence in an artificial environment some researchers propose a gradual transition from reality to the virtual world instead of immersing users into the virtual world directly. One approach is to start the VR experience in a virtual replica of the physical space to accustom users to the characteristics of VR, e. g., latency, reduced field of view or tracking errors, in a known environment. Although this procedure is already applied in VR demonstrations, until now it has not been verified whether the usage of such a *transitional environment* – as transition between real and virtual environment – increases someone's sense of presence.

We have observed subjective, physiological and behavioral reactions of subjects during a fully-immersive flight phobia experiment under two different conditions: the virtual flight environment was displayed immediately, or subjects visited a transitional environment before entering the virtual flight environment. We have quantified to what extent a gradual transition to the VE via a transitional environment increases the level of presence. We have found that subjective responses show significantly higher scores for the user's sense of presence, and that subjects' behavioral reactions change when a transitional environment is shown first. Considering physiological reactions, no significant difference could be found.

Keywords: Virtual reality, presence, transitional environment, virtual portals

1 Introduction

Virtual reality (VR) environments provide the most sophisticated technology for human-computer interfaces developed so far. Because VR systems are able to present information as seen from a user's perspective, they have great potential as an enabling technology for immersive exploration in many domains, for instance they enable architects and engineers to experience virtual models at true scale. Effectiveness of a VE is commonly defined in terms of enhancement of task performance, effectiveness for simulation or improvement of data comprehension. However, for a broad class of problems a common measure of the quality of effectiveness is the level of *presence* evoked in users.

Basically presence has been thought of as someone's "sense of being there" describing the phenomena that we feel and behave as if we are in a virtual world created by computer displays [17, 15]. When people enter the virtual world they experience a shift of their sense of place so that they feel to be themselves in the simulated environment, for example displayed on a head-mounted display (HMD), rather than in the physical place in which they actually are. Presence is a human reaction to a given level of immersion. Immersion refers to what is, in principle, a quantifiable description of a technology. It includes the extent to which the computer displays are extensive, surrounding, inclusive, vivid and matching. According to Slater, although presence and immersion are logically separable, empirically they are probably strongly related [16].

Indeed, presence is probably a unique affordance of a fully-immersive virtual reality system, but if presence is not required (actually, many 3D computer applications do not require presence), then there is no benefit in using an immersive system [18]. For example, if the focus of an application is on effective visualization of complex 3D objects, then a high-resolution desktop stereo display may be far more effective than a fully-immersive VE. On the other hand, if it is important that participants exhibit behaviors similar to those that would have been induced by comparable circumstances in everyday reality, then presence is essential. An ideal example from the broad class of problems is the use of immersive VEs for virtual therapy, for instance to treat various phobias (for example, [31, 8]).

It is a well-known fact that humans do not only have a feeling of being transported to the place depicted by a VE, but they also tend to act as if they were really there. In most fully-immersive VR systems, real-world information is blocked out, i. e., there is a separation between the user and her current situation. According to [18] users might feel a higher sense of presence in the VE if it is presented as persistent space that can be entered and exited, and moreover, if the traversal into the VE involves some notion of travel or detachment from the real world.

In order to improve a virtual reality experience it seems reasonable to provide users with a virtual replica of their real environment (usually the laboratory) such that they can accustom themselves to using an immersive VR system. After a certain time period, the user may enter the "actual" virtual environment, for example via a virtual door, and her presence may be increased due to this transition. Since it seems to be a promising approach to use a gradual transition between real and virtual world, this procedure is already applied in some VR demonstrations. However, until now it has not been verified whether the usage of such metaphors as introduced by a *transitional environment* increases the degree to which the user thinks that she is in a virtual and not a real environment.

In this paper we address the question whether a *transitional environment* increases the user's sense of presence or not. We have measured presence in a virtual flight phobia experiment performed in a fully-immersive head-mounted display environment. The experiment has been performed under two conditions: the virtual flight

*e-mail: fsteini@math.uni-muenster.de
†e-mail: g_brud01@math.uni-muenster.de
‡e-mail: khh@math.uni-muenster.de
§e-mail: A.Steed@cs.ucl.ac.uk
¶e-mail: agerlach@psy.uni-muenster.de

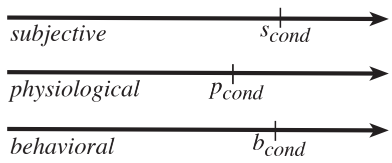


Figure 1: Sense of presence depicted as 3-tuple $(s_{cond}, p_{cond}, b_{cond})$ with subjective, physiological and behavioral component.

started immediately, or prior to the virtual flight subjects visited a transitional environment represented by a virtual replica of our laboratory.

From a cognitive perspective subjects had to switch unconsciously between two hypotheses during the experiment [17]:

H1: "I am in the virtual environment" and

H2: "I am in the real environment".

Assuming that subjects have to assign numbers with respect to a Likert scale to express their confidence c_1 about hypothesis H1 and c_2 about H2, where 1 denotes less confidence and n denotes full confidence. The sense of presence evoked under a certain condition may be captured mathematically as $\frac{c_1}{c_2}$.

The main objective of this research is to show whether or not the sense of presence of a subject who has entered the virtual world via a transitional environment (*cond=TW*) is larger than a subject's sense of presence when she entered the virtual environment immediately from the real world (*cond=RW*). To measure presence we have analyzed different reactions of subjects with different levels of flight phobia during the virtual flight under both conditions. According to previous findings we break the concept of presence into three components: subjective, physiological and behavioral measures [15, 6, 21]. Then the sense of presence for a certain condition *cond* can be described by a triple $(s_{cond}, p_{cond}, b_{cond})$ (see Figure 1), where s_{cond} denotes the subjective, p_{cond} the physiological, and b_{cond} the behavioral component of a user's sense of presence.

According to this formal description the objective of our analyses is to examine the following hypotheses with conditions TW and RW:

HS: $s_{TW} > s_{RW}$,

HP: $p_{TW} > p_{RW}$, and

HB: $b_{TW} > b_{RW}$.

In other words: for which components of the sense of presence does a gradual transition to the virtual world via a transitional environment improve presence.

The remainder of the paper is structured as follows. In Section 2 we review projects related to our work. Section 3 describes the design and setup used in our experiment. Section 4 describes the results of the experiment, which are discussed in Section 5. The paper concludes in Section 6.

2 Related Work

There has been vigorous debate about how to best measure presence [3, 5, 2, 6, 12]. As mentioned in Section 1 we break the concept of presence into the three components: subjective, behavioral, and physiological presence [21, 28, 13]. Subjective presence denotes the degree of a subject's self-reported sense of "being there" in the virtual world and feeling that the world portrayed is more like a place visited and not just a series of pictures seen. Behavioral presence denotes to what extent a subject's behaving and acting in a virtual environment is consistent with human response in similar real world situations. Physiological presence denotes to what extent a subject's physiological response to a VE is consistent with a human's response to similar real world situations.

In the past different approaches have been presented and examined in how far they contribute to each of these factors. Presence can be supported by exclusion of real world cues since these might interfere or be inconsistent with the presented VE [18]. Furthermore, presence can be enhanced by incorporating a virtual representation of the user into the environment (a "virtual body") [20, 21], especially providing actual limb motion [27]. In addition, multimodal feedback in a VE increases the sense of presence, in particular if not only haptic and tactile feedback [10], but also audio and olfactory stimuli correspond to events in the VE [4]. Moreover, properties of the visual display have an impact on the user's sense of presence [30]. For instance, a wider field of view [1], realistic physical simulations [26], stereoscopic display [9], low latency [13, 2] and also dynamic shadows of objects in a virtual environment contribute to a user's sense of presence [7, 19]. When it comes to moving in the VE, real walking has been shown to be a more presence-enhancing locomotion technique than other navigation metaphors, i. e., walkers have a higher sense of presence than "flyers" or users navigating by walk-like gestures [21, 28].

The usage of a transitional environment between real and virtual world in order to increase the user's sense of presence or to improve the virtual experience in general is not a novel concept. Some projects have already used different concepts to provide a gradual transition from the real to the virtual world and in the opposite direction. For example, Slater et al. have performed an experiment called the "VirtualAnte" room, where subjects entered a virtual replica of the laboratory in which the experiment was taking place [18]. Subjects moved through a door to a new virtual location and carried out the main experimental task. When they returned, box-shaped objects had been added to the virtual lab, and in the meantime one object, i. e., a telephone, had been moved within the real laboratory. After subjects returned to the real laboratory by taking off their HMD, they had to reveal their degree of surprise that the additional colored boxes were not there, and that the phone had been moved. Indeed, re-orientation to the real world is fast, but there is also a break from the virtual model back to real world. Participants are often disoriented and surprised about the direction they are facing when they take off an HMD.

Slater et al. propose to use a virtual HMD within the virtual world, the donning of which transports users to a another virtual world [20]. After taking off the last HMD, the user is transferred to the VE from where she was transferred before. This procedure provides a *recursive* HMD-based virtual world. Transitional techniques might also be used in CAVE environments. For example, Steed et al. augmented a normal four-sided (three-walled) CAVE with a white curtain [22]. This curtain was used for projection, and the participants could see a virtual CAVE with avatars inside. As a participant walked through the curtain, an avatar appeared for her on the curtain.

For analyzing whether there is an impact on the user's sense of presence if a transitional environment is used, we conducted a virtual flight experiment. Similar virtual flight experiments are often used for fear of flying therapy. For instance, Hodges et al. have shown how VEs can be used to treat such phobias [8]. Fear of flying is just one example of a broad class of problems where a high sense of presence is important in order to cause the corresponding reactions of the subjects.

3 Experimental Design

In this section we describe the virtual flight experiment. In order to verify whether a transitional environment increases the subject's

(a) (b) (c)

Figure 2: (a) Photo of the laboratory environment, and images of (b) the transitional environment and (c) the transitional environment with a portal to the virtual plane, where the virtual flight experiment took place.

sense of presence we have conducted the experiment under two conditions. With the first condition (RW) subjects started in the virtual airplane when they turn on the HMD, so they started the virtual flight from the real world. With the second condition (TW) subjects were transferred to the virtual flight via a transitional environment. We wanted to analyze whether the gradual transition to the virtual world as used in condition TW increases the subject's sense of presence in comparison to the subject's sense of presence under condition RW.

3.1 Hardware Setup and Visualization Environment

Both experiments were carried out in a $10 \times 7m$ darkened tracked area of our laboratory. The subjects wore an HMD (eMagin 3DVisor Z800, 800×600@60 Hz, 40° diagonal field of view) for the stimulus presentation. On top of the HMD an infrared LED was fixed. We tracked the position of this LED within the room with an active optical tracking system (Precision Position Tracker of WorldViz), which provides sub-millimeter precision and sub-centimeter accuracy. The update rate was 60 Hz providing real-time positional data of the active markers. For three degrees of freedom orientation tracking we used an InertiaCube 2 (InterSense) with an update rate of 180 Hz. The InertiaCube was also fixed on top of the HMD. In the experiments we used a computer with Intel dual-core processors, 4 GB of main memory and an nVidia GeForce 8800 GTX for system control, rendering and logging purposes. To measure the physiological responses of the subjects we have equipped them with a VitaPort II, which is a clinical and research recording device made by Vitaport EDV Systeme GmbH.

The virtual scene (see Figures 2(b), 2(c), 3(a), 3(b), 3(c)) was rendered using OpenGL and our own software with which the system maintained a frame rate of 60 frames per second. As mentioned above we used two different virtual scenarios, i. e., a virtual airplane model (see Figures 3(a), 3(b), 3(c)) and the transitional environment - which was a virtual replica of our laboratory (see Figure 2). We used a virtual Airbus 340-300 airplane model that consisted of over 70,000 textured polygons. The transitional environment is built from over 20,000 polygons textured with over 100 real photographs. In order to improve the subject's sense of presence we display feet on the ground beneath the subjects that are oriented by the tracked head orientation. Although this is just a simple approximation, which is not in a subject's view most of the time, it gives her a self-centered frame of reference. We combined the visual scene with different sound effects, e. g., engine noise, which were transmitted to the subject's fully enclosed headphones. During the experiment the room was entirely darkened in order to reduce the subject's perception of the real world. In addition we attached a cloth to the subject's head. In order to prevent any cues about the real world no communication between experimenter and subject was performed during the virtual flight when the subject was in the airplane.

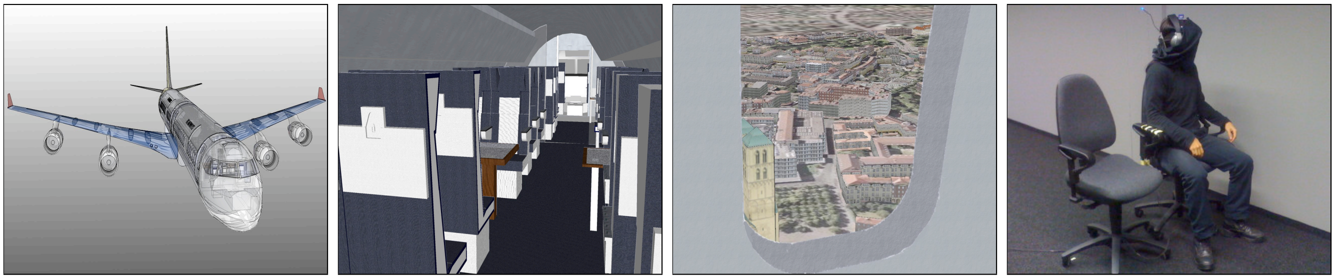
3.2 Participants

7 male and 3 female subjects (age 23-53, $\varnothing$: 32.6) participated in the experiment. Subjects came from backgrounds ranging from students to professionals with expertise in computer science, mathematics, psychology, geoinformatics, and physics. 3 subjects had no game experience, 4 subjects had some, and 3 subjects had much game experience. Two of the authors served as subjects; all other subjects were naive to the experimental conditions. Four of the subjects had experience with walking in VR environments using an HMD setup. Subjects were allowed to take breaks at any time. Some subjects obtained class credit for their participation. The total time per subject including pre-questionnaire, instructions, training, experiment, breaks, and debriefing took 2 hours. The entire experiment was performed within two days. We have used a within-subject design of the experiment. Half of the subjects have performed the experiment first with (see Section 3.4.2) and then without (see Section 3.4.1) transitional environment, whereas the other half performed the experiment in reverse order. We have changed the order for half of the subjects in order to reduce any unintentional effects on the results.

All subjects had to answer the flight anxiety situations questionnaire [14]. The questionnaire gives indications about a participant's level of fear of flying. Subjects had to rate their fear with respect to different flight situations, such as take-off, air turbulence or landing. Half of the subjects had no fear of flying at all, the others had slight symptoms of fear of flying. We neglected subjects with strong symptoms since their physiological measurements would have large amplitudes, and effects of the transitional environment would be hard to detect.

3.3 Measuring Methods

To determine the extent to which a subject feels present in the virtual environment we used the three common methods as described in Section 1. Subjective measures rely on the self-reports by the subject. Behavioral measures examine actions or manners exhibited by the subject as responses to objects or events in the VE. Physiological methods attempt to capture presence by measuring changes in the subject's skin temperature, skin conductance, breathing and heart rate etc. For instance, under certain circumstances one can educe more presence from an increasing heart rate in a stressful situation [13].



(a) (b) (c) (d)

Figure 3: Images from the virtual flight presence experiment showing the used airplane model from (a) outside and (b) inside. The view through a window form (c) a subject's perspective, who (d) sits on a physical mockup.

3.3.1 Subjective Measurements

Due to the subjective nature of presence, it is obvious to measure presence with respect to a subject's self-reported sense of presence. For this purpose, a few standard questionnaires are available [32, 29]. We used the Slater-Usoh-Steed (SUS) presence questionnaire, which has been developed over a number of years in several experiments at the University College London [29]. The questions are based on variations of three themes, i. e., sense of being in the VE, the extent to which the VE becomes the dominant reality, and the extent to which the VE is remembered as a place. Subjects had to rate each of six questions on a 1-to-7 Likert scale (where 1 means no presence, and 7 means high presence). As introduced in Section 1, s_{cond} refers to a user's self-reported sense of presence under condition *cond*.

3.3.2 Physiological Measurements

We examined two least intrusive measures of physiological responses. We measured changes in heart rate to determine the increase/decrease in the number of heartbeats per minute (BPM). We used an electrocardiogram (ECG) that measures electrical activity across skin associated with the electrical activity of the heart. In addition to the heart rate we measured the change in the conductivity of the subject's skin. With increasing stress, the sweat on the palm increases, and therefore the conductivity increases. As shown in previous experiments [12, 13], these two measures show best results in VR studies, and therefore we focused on them. In [27] an increasing heart rate in a stressful situation is interpreted as a signal for a subject's higher sense of presence. As introduced in Section 1, p_{cond} denotes the subject's physiological sense of presence under condition *cond*.

3.3.3 Behavioral Measurements

In addition to subjective and physiological questionnaires we measure responses that are produced by the subjects without conscious thought. For instance, subjects will probably grab the seat rest when we simulate air turbulence during the virtual flight, or they will duck down when they have to walk through a low virtual portal. During the experiment we tracked the user's head movements and we recorded the entire experiments on video for post analyses. We scored behaviors as responses to selected actions that we have introduced to the subjects on a 3 point Likert-scale, where 1 means no reaction, 2 denotes a slight reaction, and 3 means a strong reaction. Such stimuli include take-off, air turbulence, and landing, but also other reactions explained in Section 3.4.1 are evaluated. As introduced in Section 1, b_{cond} denotes the subject's behavioral sense of presence under condition *cond*.

Indeed, all considered measures vary from person to person. However, in our experiment we were interested if and how strong these measures vary if the subjects have visited a transitional environment before. Each subject has performed the experiment under both conditions, and we analyzed relative changes rather than absolute differences.

3.4 Procedure

The virtual flight environment was the same under both conditions no matter whether subjects entered the virtual airplane directly or after they moved through the transitional environment first. In order to enforce subjects to stay the same timespan ($\approx$ 10 minutes) in the VE, under this condition subjects had to walk 5 minutes in the airplane before the virtual flight began. With condition TW subjects had to walk 5 minutes in the transitional environment. In the following subsections we will explain both experimental conditions in more detail.

3.4.1 Condition RW: Virtual Flight WITHOUT Transitional World

Before the virtual flight began, subjects had to walk to their assigned seat in a virtual airplane model (see Figure 3 (b)). Since we used two physical seats in the laboratory space, which were placed in correspondence to their virtual seat row, subjects perceived passive haptic feedback when they sat down. The accuracy between real and virtual seats was within centimeter range. After sitting down the virtual flight began. The flight took 3 minutes. Before, during and after the flight engine sounds indicated the state of the virtual flight acoustically. In the middle of the flight we used the hydrolytic feature of the chair to simulate an air turbulence. After the plane landed, subjects had to leave the plane via a virtual plank, which was presented by a physical plank providing passive haptic feedback. During the entire experiment noises transmitted via the headphones supported the notion of a flight. We used sound for background, instructions, take-off, and landing. No communication between subject and experimenter was performed during the entire experiment. Before the experiment subjects were instructed to take off the HMD after they have gone across the plank. A subject's view and the seat mock-up are shown in Figures 3(c) and 3(d), respectively.

3.4.2 Condition TW: Virtual Flight WITH Transitional Environment

The materials and methods for condition TW were similar to those for condition RW. The virtual flight was identical to the virtual flight presented under condition RW, except that subjects had to walk to their seat immediately without walking through the airplane. Since we wanted to ensure that for both conditions subjects stayed in the virtual world for the same period of time, they had to take their seat immediately, because they had walked already in the transitional environment.

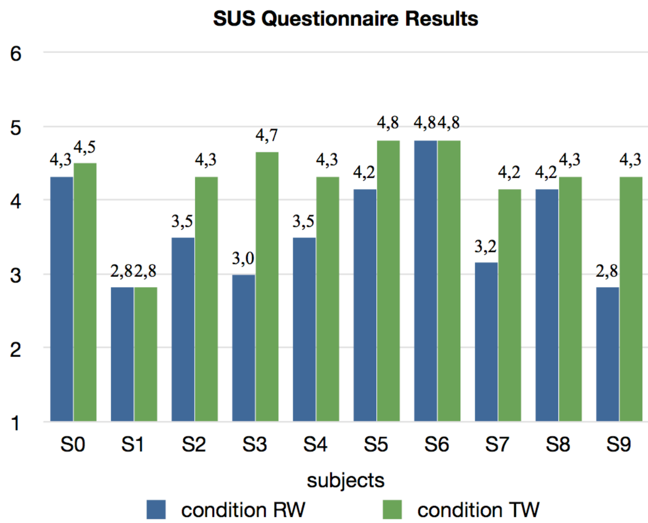


Figure 4: Results of the SUS questionnaires for individual subjects S0,...,S9 under conditions RW and TW. Subjects S0, S2, S4, S7 and S8 participated in the experiment first under condition TW and then under condition RW, the other subjects participated in the experiment under reversed conditions.

In contrast to starting the virtual flight experiment directly in the airplane, we used the virtual replica of the real environment for this condition. Hence, after having been equipped with the HMD, subjects saw a photorealistic model of the laboratory space used as transitional environment. In contrast to the situation in the virtual airplane, subjects could talk with the experimenter while they were walking through the transitional environment. We allowed this communication to indicate that they were not yet in the virtual world. Since the virtual model is a 1-to-1 copy of the real laboratory, subjects could walk around and touch objects like walls, doors, or cabinets. After approximately 4 minutes we told subjects that they had to press a particular button, which was mounted on one of the walls of the laboratory, in order to open a portal to the virtual world, i. e., the airplane. The portal was displayed on one virtual wall of the laboratory space (see Figure 2 (c)) which initially was coincident with the corresponding physical wall and thus would prevent a walk through. Therefore, we have applied redirected walking techniques, in particular motion compression approaches as explained in Section 3.4.3, that allow subjects to walk through the virtual portal without obstacles obscuring the path in the physical world.

After walking through the portal subjects have been transferred into the virtual airplane model. This transfer phase has been indicated via a 3 second animation sequence with compelling sounds. Afterwards, the part of the virtual flight under this experimental condition has been performed identical to the condition RW, i. e., when subjects started in the airplane directly. But instead of taking off the HMD after having crossed the plank, subjects were instructed that they had to follow the gangway until another portal occurs. They were told that they could return to the virtual laboratory by means of this portal, again by simply walking through it. Another animation sequence showed a flight back to the laboratory. After a subject has been transferred back to the transitional environment, i. e., the virtual replica of our laboratory, sound related to the virtual flight has been turned off and subjects could talk to the experimenter. Subjects had to press the button again in order to turn off the portal and to finish the experiment.

3.4.3 Virtual Portals

In order to transfer subjects from the transitional to the virtual environment such that they believe to be in a new environment, we required a plausible way of travel. Inspired from many series or movies, for instance, MGM's Stargate, but also 3D games such as the first-person action video game Portal [1], we have decided to use the concepts of virtual portals. The main idea of such a portal is that users can transfer themselves to another world or different locations in the same world, when they pass such a portal. For our experiment we wanted to provide a compelling visualization and appearance of the portals that indicated the way from the transitional environment to the virtual world and vice versa. Therefore, we visualized the portal on one of the walls of the transitional environment instead of visualizing them as floating objects within the room. As illustrated in Figure 2(c) the portal shows the virtual airplane model from a distance. We applied a shader enhancing the portal with a wave pattern and a bumpy appearance.

As mentioned above, at the beginning of the experiment physical walls of the lab and virtual walls of the transitional environment were aligned in correspondence. Hence, a portal on the wall could not be passed without collision. Therefore, after the user has pressed the portal button in the transitional environment, we applied motion compression approaches based on the results of [24]. We scaled the movements with a factor of 1.4. Thus, one meter in the physical space is mapped to 1.4 meters in the transitional environment. According to Steinicke et al. [25, 23], such a manipulation can not be observed reliably by a walking user. Hence, when subjects moved to the virtual portal, they had only walked 60% of the required distance in the physical world and were still located almost in the center of the laboratory space. Now the user can pass the portal without hitting the physical wall. Thus we were able to display a portal on the virtual wall in the transitional environment through which subjects could enter the virtual world. When subjects re-entered the transitional environment after the experiment via the portal we applied the same concept again. Hence, subjects were transferred to the same position in the laboratory where they left the transitional environment before.

4 Results

4.1 Results for Subjective Measurements

Subjective evaluation of the virtual flight condition without transitional environment shows that subjects had only a slight self-reported sense of presence s_{RW}. This is indicated by the average score of 3.63 ($\sigma = 0.70$) of the SUS questionnaires; no high rates, i. e., 6 or 7, were chosen by the subjects. The absence of vestibular stimuli during the flight, which could be experienced in a flight simulator, may be one reason for the low level of presence. Furthermore, other aspects that have not been incorporated in this study such as limb motions or additional passengers could have affected a subject's sense of presence. However, as mentioned in Section 1 we were not focused on the absolute sense of presence, but on the sense of presence in comparison to the condition where subjects were in the transitional environment first. Thus we want to examine whether the scores for the SUS questionnaires for condition RW differ significantly from condition TW.

In comparison to the first condition, subjective evaluation of the virtual flight with the transitional environment condition shows that subjects still had a slight, but increased sense of presence s_{TW}. This is underlined by the average score of 4.31 ($\sigma = 0.57$) of the SUS questionnaires; 3 subjects answered three questions with 6. The virtual flight parts were identical for both conditions, but subjects had to walk through a transitional environment before and after the

[1]The single player game Portal, in which a player must solve physical challenges by opening portals to maneuver objects and herself through space, was released by Valve Corporation in 2007.

flight for condition TW. The results of the SUS questionnaires displayed in Figure 4 show that the self-reported sense of presence has remained constant or has increased for *all* subjects. When the results are pooled the subject's sense of presence increased by 19% under condition TW. On average each subject increases her SUS scores by 0.68 ($\sigma = 0.59$). The SUS scores for subjects, which have participated in the experiment under condition TW first, show a higher sense of presence for both condition RW (3.74 vs. 3.52) and condition TW (4.32 vs. 4.28). We have performed a Wilcoxon rank-sum test in order to verify hypothesis HS (see Section 1). The test shows that the increase of the SUS scores from 3.63 to 4.31 is statistically significant ($\rho < 0.005$) and hypothesis HS: $s_{TW} > s_{RW}$ holds therefore.

4.2 Results for Physiological Measurements

During the experiment under condition RW the physiological component of the subject's sense of presence p_{RW} showed an increase of skin conductance (SC) and heart rate (HR) (cf. Table 1).

Condition	Measure	
	Mean SC (in μSiemens)	Mean HR (in BPM)
RW	46.0240	106.0600
TW	43.2295	105.0610
Δ (RW-TW)	−2.7947	−0.9973

Table 1: Results of the physiological measurements.

This was expected since subjects were forced to walk during our experiment, and transpiration as well as heart rate increases during such activities. The mean skin conductance of the subjects was 46.02 Micro-Siemens (μSiemens). The average of the maximum skin conductance of each subject was 68.71μSiemens. The mean heart rate of all subjects was 106.06 BPM. The maximum heart rates were reached at the moment of the air turbulence and when a subject had to walk across the plank. The average of the heart rates of each subject was 126.29.

Analogue to the condition RW, the physiological component of a subject's sense of presence p_{TW} increased. Measurements of the subjects under condition TW showed an increase of skin conductance and heart rate during the experiment. The mean skin conductance of the subjects was 43.23μSiemens. The average of the maximum skin conductance of each subject was 72.21μSiemens. This is 2.79μSiemens less than the subject's mean skin conductance under condition RW. The mean heart rate of all subjects was 105.06 BPM. The average of the maximum heart rates of each subject was 128.79. Hence, the mean heart rate during the experiment decreased by 0.997 BPM under condition TW. Both measures show small decreases of physiological values when considering the entire interval. The average of the maximum values for skin conductance and heart rate show a slight increase. Both decrease of the average values as well as increase of the average maximum values are not significant, many factors may have influenced the results. Therefore, we have not considered the physiological measures for further analyses, and hypothesis HP: $p_{TW} > p_{RW}$ (see Section 1) could not be verified.

4.3 Results for Behavioral Measurements

Considering the subjects' behaviors we have examined the videos, which we have captured during the experiment, in a post-session a few days later. Since subjects had to walk before and after the flight, we reviewed their way of walking as well as their behavior in certain stressful situations, i. e., take-off, air turbulence, landing, and walk across the plank. We have measured their speed, but also considered other noticeable problems while they were walking, such as unnatural walking, walking with arms reached out, stumbling and

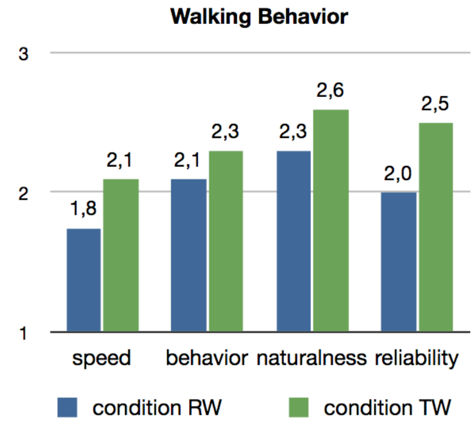


Figure 5: Pooled results for the walking behavior for conditions RW and TW.

so on. This approach provides a measure for the behavioral sense of presence b_{RW}. One author of the paper had to view different video sequences of the experiment two days after the experiment took place. This observer did not know whether the shown sequence was from the experiment under condition RW or condition TW, i. e., whether the shown subjects had been in the transitional environment first or if they had started in the airplane directly. We have left the observer unaware about this information to reduce any unintentional effects to the results. The observer had to classify the way of walking by means of considering walking speed, behavior, naturalness, and reliability (see Figure 5). For example, the observer revealed the relation between walking and viewing direction as one metric for the walking reliability. Looking into the direction of walk indicates that subjects feel insecure, whereas a free look-around is revealing that subjects feel safe. Each aspect had to be classified according to three levels such as very slow - slow - normal, or unnatural - almost natural - natural. The evaluation of the ways of walking of the different subjects shows that subjects partly feel uncomfortable and insecure, while walking in the HMD environment. The observer classified the walking speed with this condition with 1.75 ($\sigma = 0.72$) on average, which corresponds to very slow to slow walking. The pattern of walking was evaluated as 2.1 ($\sigma = 0.74$), where 1 corresponds to walking with caution, and 3 corresponds to safe walking. The observer evaluated the overall impression of the walking with 2.4 ($\sigma = 0.69$) on average, which corresponds to almost natural walking. Two subjects reached out their arms almost constantly. When considering the viewing direction the observer noticed that subjects looked most of the time into the walking direction. He classified this by 2.0 ($\sigma = 0.66$), where 1 corresponds to always looking at heading direction and 3 corresponds to free look-around. Hence, even after approximately 5 minutes walking in an airplane and a 3 minutes flight, subjects still moved very slowly and unnatural. Only 5 subjects have reacted to the air turbulence simulation by means of amazement and grabbing the seat. 7 subjects crossed the plank very carefully, whereas 3 subjects seem to be unimpressed. 4 subjects tried to talk to the experimenter during the experiment, although we told them that talking to the experimenter is not possible while they are in the virtual airplane.

Analog to the results for condition RW, we reviewed the subjects' behaviors on the captured videos for condition TW. The evaluation of the way of walking for the different subjects shows that subjects feel more comfortable and safe while walking in the HMD environment, if they have entered via a transitional environment. The observer classified the walking speed in this condition with 2.1 ($\sigma = 0.74$) on average, which corresponds to slow walking. The pattern of walking was evaluated as 2.3 ($\sigma = 0.67$), where 1 corresponds to walking with caution, and 3 corresponds to safe walking. The overall impression of the walking to the observer was 2.6 ($\sigma = 0.52$) on average, which corresponds to an impression between almost natural walking and natural walking. When considering the viewing direction, in contrast to condition RW subjects stared less into the walking direction. The observer classified this by 2.5 ($\sigma = 0.71$), which corresponds to a rather free look-around during walking. Hence, after approximately 5 minutes walking in the transitional environment, subjects appear to move faster and more natural in comparison to the situation when they start the VR experience directly in the target virtual world. Two more participants, i. e., 7 subjects, have reacted to the air turbulence simulation by means of amazement and grabbing the seat. 8 subjects crossed the plank very carefully, whereas only 2 subjects seem to be unimpressed. 3 subjects tried to talk to the experimenter while in the virtual airplane. This number has decreased although in this condition subjects were allowed to talk to the experimenter during the time when they were in the transitional environment. 6 subjects started to talk to the experimenter when they re-entered the transitional environment after the virtual flight. When entering the VE through the virtual portal, all subjects walked carefully and decreased speed. 4 reached out their arms when walking through the portal. At the second portal back to the transitional environment, 6 subjects ducked in order to avoid collision with the virtual portal. In summary, from an external perspective subjects move more comfortable and safe through the VE. We have performed a Wilcoxon rank-sum test to verify hypothesis HB (see Section 1). The test shows statistically significant improvements for the walking speed ($\rho < 0.05$), behavior ($\rho < 0.1$), naturalness ($\rho < 0.1$) and reliability ($\rho < 0.01$), and thus hypothesis HB: $b_{TW} > b_{RW}$ holds.

5 Discussion

The experiment indicates that the usage of a transitional environment has the potential to increase the user's sense of presence. Self-reported comments show that subjects of this experiment get more immersed into the virtual flight experiment under the condition TW, i. e., when they have entered the airplane via a transitional environment. As mentioned above the strongest impact of the usage of a transitional environment could be manifested by the subjective measurements. Self-reported comments of subjects indicate that they prefer the usage of a transitional environment. For instance, one subject remarked:

> *"After walking and flying through the wormhole, I really got the feeling of being transferred to another world."*

This was a typical comment of subjects. The metaphor of a wormhole supports their notion of being transferred to another world. Some subjects noticed that acoustics were very important when they left the transitional environment and entered the virtual one. In the transitional environment we neglected acoustics, whereas in the virtual world airplane engine sounds were displayed.

Subjects move more safely and naturally through the airplane model, when they entered via a transitional environment. This is also indicated by the observer's evaluation of the captured videos. Most subjects moved more safely and faster when they had visited the transitional environment prior to the virtual flight. According to the evaluation of the observer no subject moved more slowly or unsafely after they had walked in the transitional environment. Again, subjective comments underline these results. Two subjects remarked that it was definitely easier for them to orient themselves, and that they found it easier to estimate distances in the VE. In general, subjects have remarked that estimation and performance of motions have improved after they had visited the transitional environment. One subject observed:

> *"It was definitely easier for me to judge my movements and to orient in the airplane, when I was in the virtual laboratory before."*

This is also underlined by the increased speeds of the subjects under condition TW, i. e., when they had visited the transitional environment first.

A significant difference in the physiological measurements was not found by our analyses. Probably, there were many factors contributing to changes in heart rate and skin conductance which were difficult to control such as individual walking speeds. One possibility to diminish unintended side-effects when evaluating physiological measurements is to avoid physical activities of the subjects such as walking. Furthermore, a larger number of subjects is required to derive significant results.

We were surprised about the positive feedback about the application of virtual portals. The post-questionnaire has shown that subjects really preferred the usage of portals, which transferred them to the virtual world.

6 Conclusion and Future Work

In this paper we have analyzed the usage of transitional environments via which users could enter a virtual airplane in which the main experiment took place. In the experiment we focused on the question whether the usage of transitional environments affects the user' sense of presence in the virtual environment or not. We have considered three common metrics, i. e., subjective, behavioral and physiological measurement, to analyze presence under two different experimental conditions: virtual airplane experiment with and without transitional environment.

An impact on the physiological measurements could not be verified by our study, but we have found effects on the behavioral and subjective measurements. In particular, subjective evaluation of the participants shows a significant increase of the subject's sense of presence. The behavioral measurements indicate that subjects move more safely and naturally when they have accustomed themselves to the VR system setup in a familiar environment first.

Many factors may have a certain impact on the results of the presented experiment like visual representation or multi-modality, and therefore further experiments need to be conducted. Furthermore, in future experiments we will consider whether the usage of a transitional environment improves distance estimation or user movement in general. Interrante et al. [11] have shown that distance estimation in virtual environments which are known from the real world is better than distance estimation in unknown environments. Perhaps such skills could be transferred to the virtual world, when users enter a transitional environment first; a transitional environment is a known environment, since it is a replica of the real world where the user starts the VR experience.

Due to many comments of the subjects about the benefits of virtual portals and wormholes, respectively, and their compelling sensation, we will examine these concepts for helping the user to get around in a virtual environment. We will develop and integrate further approaches, which allow users to change their position and orientation in a large-scale VE.

As opposed to using virtual transitional environments, one could also consider a physical mock-up as real transitional environment. For instance, the laboratory could be decorated as a waiting room at the gate before the user starts the virtual flight. It has to be examined in how far this approach, which is already applied in theme parks, further contributes to the user's sense of presence.

To summarize the results, we suggest using transitional environments since they have great potential to increase at least the user's self-reported sense of presence, while portals to the virtual world can further improve the VR experience.

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