Effects of VE Transition Techniques on Presence, Illusion of Virtual Body Ownership, Efficiency, and Naturalness

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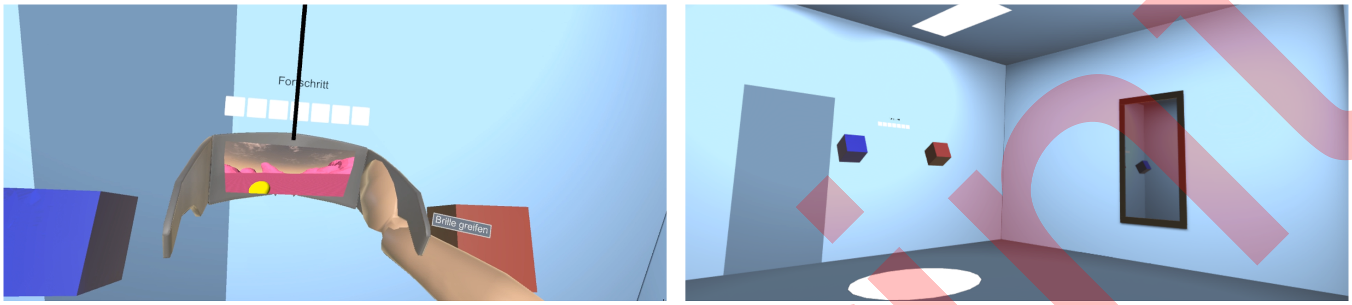

Figure 1: The VMD metaphor mimics a real world HMD that permits transitions between VEs (left). An acclimatization environment is a starting location for such transitions in which users are given time to accustom themselves to VR (right).

ABSTRACT

Several transition techniques (TTs) exist for Virtual Reality (VR) that allow users to travel to a new target location in the vicinity of their current position. To overcome a greater distance or even move to a different Virtual Environment (VE) other TTs are required that allow for an immediate, quick, and believable change of location. Such TTs are especially relevant for VR user studies and storytelling in VR, yet their effect on the experienced presence, illusion of virtual body ownership (IVBO), and naturalness as well as their efficiency is largely unexplored. In this paper we thus identify and compare three metaphors for transitioning between VEs with respect to those qualities: an in-VR head-mounted display metaphor, a turn around metaphor, and a simulated blink metaphor. Surprisingly, the results show that the tested metaphors did not affect the experienced presence and IVBO. This is especially important for researchers and game designers who want to build more natural VEs.

CCS CONCEPTS

• **Human-centered computing** → **HCI design and evaluation methods**; **Virtual reality**; **Interaction techniques**;

KEYWORDS

Transition Techniques, Interaction Design, Illusion of Virtual Body Ownership, Presence

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1 INTRODUCTION

Moving from the current location to a new one is an integral task in most Virtual Reality (VR) applications. It is commonly categorized as an aspect of spatial navigation, one of the three fundamental 3D interaction tasks [34]. Several well-understood locomotion techniques exist that allow users to continuously travel to a new target location in the vicinity of their current location, e.g., real-walking [13, 21], walking-in-place [44, 58], and redirected walking [12] as well as many controller-based and gesture-based locomotion methods [10, 15]. When it comes to overcoming greater distances or to transitioning to a different Virtual Environment (VE), other techniques are required that allow for a quick as well as believable change of location, called *transition technique*s (TTs) in the remainder of this paper. These often artificial, teleportation-based techniques are less-researched and their effect on the experienced presence, illusion of virtual body ownership (IVBO), and naturalness as well as their efficiency is largely unexplored [4, 11]. Naturalness in this specific context refers to a TT's intuitiveness as well as ease of use regarding its interaction technique and interface elements.

Still, TTs are highly relevant for VR user studies and storytelling in VR: In VR user studies, participants are commonly given time to accustom themselves to VR within an initial acclimatization environment, called *training room* [37], *VR acclimatization* [48, 49], *VR accustomization* [3], *embodiment phase* [47], *orientation phase* [2], or *familiarization phase* [43], before being exposed to certain stimuli (in another VE) that are to be evaluated. Using a virtual replica of the physical laboratory as acclimatization environment increases the users' sense of presence [62] and improves their distance estimation skills [61] as well as their spatial and situational awareness [65]. Thus, this procedure is particularly common for studies including virtual embodiment. In VR-storytelling, TTs are required as an equivalent to scene transitions in films [31, 38]. VR computer games, for instance, require such design elements to navigate the player between levels or to a *home* environment for system control, just as their non-VR counterparts. In both cases, a high presence, IVBO, naturalness, and efficiency as well as no occasion of simulator sickness is desired. In addition, it is especially important for VR user studies to know if the use of different TTs has the potential to confound the actual measurements.

Our contribution: Given the lack of user-centric, empirical, and comparative evaluation of TTs between VEs targeting head-mounted display (HMD) setups, this paper identifies three metaphors and compares them with regard to their effect on the experienced *presence*, *IVBO*, *efficiency*, and *naturalness*.

Simulated Blink (SB) fades a user's view to black, changes the location or environment, and fades in again.

Turn Around (TA) requires the user to turn around and changes the environment out of her field of view (see Figure 2).

Virtual-head Mounted Display (VMD) mimics the functionality of a real world HMD (see Figure 1 left).

The results presented in this paper show that the tested metaphors did not affect the experienced presence and IVBO and that the perceived naturalness can be increased by realizing TTs in a continuous and physical way.

The remainder of this paper is structured as follows: The next section presents an analysis of the state of research concerning VE TTs, presence in VR, and IVBO. Subsequently, the TT metaphors are presented conceptually, followed by an overview of their technical implementations. The applied methodology is then described together with a specification of the conducted user study procedure. Finally, the results of this evaluation are presented and discussed, followed by a conclusion and outlook.

2 RELATED WORK

LaViola et al. [34] categorize the task of travel to be an aspect of navigation that supports another task rather than being the user's primary goal in most VR applications. TTs are interaction techniques to fulfill travel tasks that are distinguished from other commonly used TTs in the distance to be travelled, which is high or undefined (if the target is another VE), and the degree to which the target is visible from the starting location. They are related to travel or rather TTs between physical and virtual locations, like [16]. However, transitioning from or to a physical location implies constraints that are out of this paper's scope.

The following terminology is used throughout this paper for classifying TTs and for discussing their relevant distinctions: Firstly, the *interaction type* of the technique characterizes the manner of triggering the navigation. It can be *physical*, i.e., "exploiting physical motion cues for navigation and translating natural movement to VR motion through some kind of body tracking", or it can be *artificial*, i.e., "utilizing input devices to direct VR motion and navigation" [4]. Secondly, the *motion type* of the technique describes the user's motions during the navigation. It can be *continuous*, "supporting smooth, uninterrupted movement in the virtual environment" or *non-continuous*, "providing instantaneous, non-continuous movement transitions" [4]. Finally, the *diegesis* of the interface elements utilized for the concrete realization of a TT metaphor, e.g., of the elements used to trigger the transition. They can be *diegetic*, i.e., part of the VE, or *non-diegetic*, like classical user interfaces in computer games [19]. With respect to HMD-VR applications, there is evidence that diegetic interfaces perform better than a non-diegetic ones, in terms of immersion, sense of presence, usability and cybersickness avoidance [51]. In addition, there is no need to use non-diegetic realizations for triggering actions, since using a button of a controller is a common diegetic realization for HMD-VR. HMD-VR setups normally display the position of the game controllers using 3D assets thus making them to a part of a VE. Hence, pressing a button in them is a diegetic realization for triggering actions. Altogether this explains why non-diegetic alternatives are rarely used in HMD-VR.

TTs between VEs utilized in research projects are oftentimes very simple, e.g., artificial, non-continuous, non-diegetic approaches like asking the user to close her eyes and loading a new scene [1, 29], or they are not concretely reported as part of the study design at all. Yet, there are some elaborated approaches: A physical, continuous, diegetic technique targeting CAVE setups is proposed by [32] that allows the user to grab and manipulate so-called *photoportals*, 2D windows showing a 3D view of another perspective of the VE. Users can "enter" a photoportal by putting their head into the portal thus using it to navigate within the VE. Static connections between head-high portals and remote locations within the VE constitute a similar technique that has been realized for CAVE setups [18] and HMD setups [14]. A different physical, non-continuous, diegetic approach targeting HMD setups is suggested by [31]. It allows users to teleport to remote locations by turning around by 180 degrees within a specific area.

A similar situation is found in the area of VR games. Most of them rely on artificial, non-continuous approaches, basing on a simulated blink metaphor for navigating the player between VEs or rather levels [27, 46]. Analogously, there are some elaborated approaches: *Budget Cuts* [42], *Accounting* [17], and *SuperHot VR* [63] utilize a physical, continuous, diegetic technique targeting HMD setups. In these games, grabable portals similar to the photoportals can be moved near the player's head to transition to a remote location or another VE. During this movement the portal is continuously enlarged (since it is getting nearer) until it fills the user's field of view completely.

In total, TTs for navigating between VEs are often artificial and teleportation-based. They are part of many VR research systems and computer games allowing the user to travel. As a central part of these applications, TTs also effect the overall VR experience. One fundamental aspect of this experience is the sensation of *presence*. Presence, *telepresence*, or *place illusion* is the qualia of having a sensation of being in a real place [53]. It distinguishes from *visual immersion*, an objective description of system properties [60] or rather of the sensorimotor contingencies that it supports [53], e.g., allowing the user to move her head to change the perspective onto an object or to walk to change location. Presence also distinguishes from *plausibility illusion* [53]. Plausibility illusion describes a user's illusion to perceive events happening in a VE as actually occurring events. These events are outside of the user's direct control but refer directly her. As an analysis of a TT's effect on the plausibility illusion requires the simulation of external events potentially confounding the targeted measurements, it is out this paper's scope.

High presence can be a goal in itself, especially in the field of VR storytelling [52]. It may also contribute to higher task performance [30], although it seems more evident that the achieved immersion is more important for this correlation [54]. When it comes to achieving or maintaining high presence, previous findings indicate that the interaction type, motion type, and diegesis of a TT is relevant [39]. Maintaining presence requires a *continuous* stream of stimuli and experiences [69]. Using TTs that interrupt this stream can lead to a break in presence and immersion which negatively affects the overall experience of the simulation. Moreover, presence will be increased if interactions involve whole-body movement [55]. Such a more *physical* form of interaction is also more engaging [31], i.e., the degree to which its execution is fascinating to a user, which is related to naturalness [9, 20]. Thus, naturalness is important for presence [36], indicating that *diegetic* interfaces are beneficial.

Naturalness, usability, and a user's performance depend on the degree to which an interaction technique matches the task context [9]. This includes a technique's concrete interactions and the relevant interface elements inside of a VE. For instance, a steering wheel might achieve a high degree of naturalism in case of a racing simulation, but cease to be effective for first-person shooter gamers. Hence, natural interaction techniques are most effective when they achieve a high level of fidelity and a familiar interface for users.

Finally, a poorly designed TT may introduce cybersickness [11, 36]. Early findings suggested that quick, non-continuous, teleportation-based TTs are correlated with increased user disorientation [8]. More recent implementations showcased their potential with only minor effects on space cognition and disorientation [5, 11].

Besides the characteristics of the interactions itself, the representation of the user in the VE is of central importance for the overall VR experience. Apart from not representing the user at all, the utilization of artificial virtual bodies as a proxy for the user's real physical body [26] is a commonly applied approach that creates the so-called IVBO [56]. The existence of a virtual body while interacting in VR is found to be related to a higher sense of presence, compared to interacting through a traditional user interface [57]. Other studies, however, do not suggest IVBO as a cause of presence [52] or do not find an increase in presence owed to IVBO [35].

Altogether, these findings with respect to presence, immersion and cybersickness theoretically suggest physical techniques to be better than artificial ones, continuous ones to be better than non-continuous ones, and diegetic ones to be better than non-diegetic ones. Concrete investigations targeting such correlations for TTs, however, are pending and thus raising the necessity of comparative, user-centric, empirical evaluations [4, 11]. This paper thus identifies and compares three TT metaphors with regard to their effect on the experienced presence. Due to the central role of IVBO for presence [67], the evaluation investigates the TTs' effects in two separate conditions, with a full and a minimal virtual body in a HMD setup. This is additionally important, since studies involving IVBO often use an initial acclimatization environment that should necessitate a TT to navigate the user into the actual stimulus environment [2, 3, 37, 43, 47–49]. In those cases, the impact of the chosen TT on the evaluated qualities is paramount. Additionally, the presented evaluation covers the techniques' efficiency and naturalness, to assess their suitability for VR storytelling.

3 TRANSITION TECHNIQUES

Three TT metaphors were selected to margin the design space of interaction type and motion type in terms of the theoretically best and theoretically worst characteristics with respect to presence, naturalness, and cybersickness. SB represents a commonly used TT metaphor that represents the lower margin, while TA and VDM represent the upper one. TA was chosen in addition to VMD due to its inclusion of whole-body movements. All three metaphors were chosen to be realized in a diegetic way due to the strong disadvantages and rare use of non-diegetic interface elements in HMD-VR.

3.1 Simulated Blink

A commonly used, artificial and non-continuous metaphor for achieving a transition between two VEs is by simulating a blink of an eye. This metaphor fades the user's view to black, changes the scene or teleports the player to a different location, and finally fades the view in again. Depending on the trigger method it can be diegetic or non-diegetic. For our comparison we used a button press to trigger the transition, making it diegetic.

3.2 Turn Around

The TA metaphor represents a physical and continuous transition. It is following the idea of [31]. This metaphor requires a user to turn around by 180 degrees after the intention to transition is given. The performance of the turn around is completely up to the user to allow for a high degree of self-control and simulator sickness avoidance. The environment behind the player is then replaced with the target VE (see Figure 2). As a result of this, the user sees the VE she is transitioning to, when she turns around. As soon as the first VE is outside of the user's view, it also gets exchanged with the new VE, thus completing the transition to the other environment. TA requires the user to physically perform the transition, turning it into a process that involves whole-body movement. Depending on the trigger method it can be diegetic or non-diegetic. For our comparison we used a button press to trigger the transition, making it diegetic. Despite implementing a mere button press to initiate the transition, the requirement to turn around makes it more complex in comparison to SB.

3.3 Virtual-head Mounted Display

A physical, continuous, and diegetic metaphor that mimics the functionality of a real world HMD, following the ideas of [17, 45, 59, 63] (see Figure 1 left). The VMD metaphor requires the user to grab a virtual HMD and to put it on using a gesture one would perform to wear normal glasses. By reversing this gesture, users can return to the initial VE. Just like real world HMDs, VMDs provide a live preview of the position where the user would enter the new VE after the transition. That way, users can already take a sneak peak of the navigation target and prepare for the transition by slowly putting on the VMD. During this process, the scenery gets continuously larger until it visually immerses the user into the target VE. Vice versa, by slowly removing the VMD, the visual immersion gets

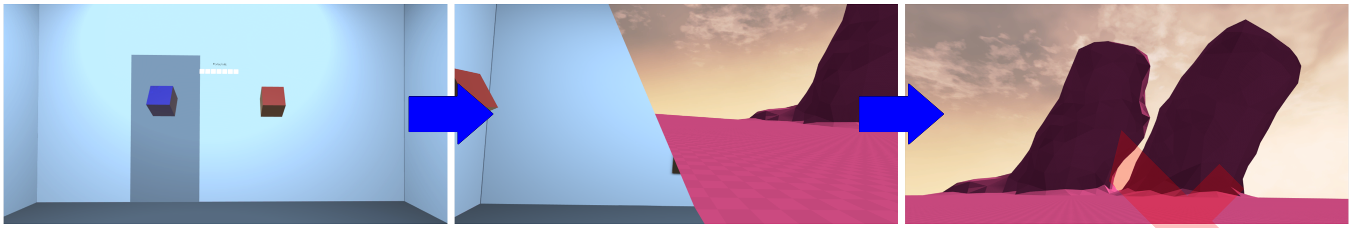

Figure 2: The TA metaphor requires users to physically turn around to change from one VE to another.

broken and the initial VE is revealed again. Thus, this metaphor combines a natural interaction with familiar and diegetic interface elements to match the task of immersing oneself in a different VE [9]. This, however, makes this metaphor more complex in contrast to a mere button press of SB.

4 DESIGN

In this paper, we compare the three TT metaphors *TA*, *VMD*, and *SB* with regard to their effect on the experienced presence, IVBO, naturalness as well as their efficiency.

4.1 Study

Due to the classification of the metaphors and indications discussed in section 2, suggesting that with respect to presence, IVBO, and naturalism, physical techniques theoretically should be better than artificial ones and continuous ones better than non-continuous ones, we assume the following hypotheses (H):

- H_{pre} VMD and TA elicit a higher self-reported presence
- H_{ivbo} VMD and TA elicit a higher self-reported IVBO
- H_{eff} VMD and TA are less efficient
- H_{nat} VMD and TA are more natural

To validate the four presented hypotheses, the study is designed to require users to transition between two individual VEs thus allowing them to evaluate the naturalness and efficiency of the three discussed TTs. Furthermore, to assess the TTs' effects on the experienced presence and IVBO, a simple task including a rudimentary interaction is required that simultaneously directs the users' attention to their virtual body parts. Due to the potentially central role of IVBO for presence, the evaluation investigates the TTs' effects with an between groups design by implementing a minimal virtual embodiment (**min-VB**), i.e., simply showing the devices' 3D assets, and a full virtual embodiment (**full-VB**), i.e., using an avatar as a proxy for a user's body, condition (see Figure 3). By providing these two conditions, an analysis of the moderating effects of IVBO is achieved. Internally, the groups follow a within subjects design as every group is required to use all of the TTs. The TTs appear in an randomized order to allow for an evaluation of the potential moderating effects.

4.2 System

A system design featuring two separate VEs is required for evaluating the three presented TTs. It should be simple to avoid confounds induced by distracting context. The first VE we chose represents the acclimatization environment found in many VR studies or alternatively the *home* environment found in many computer games

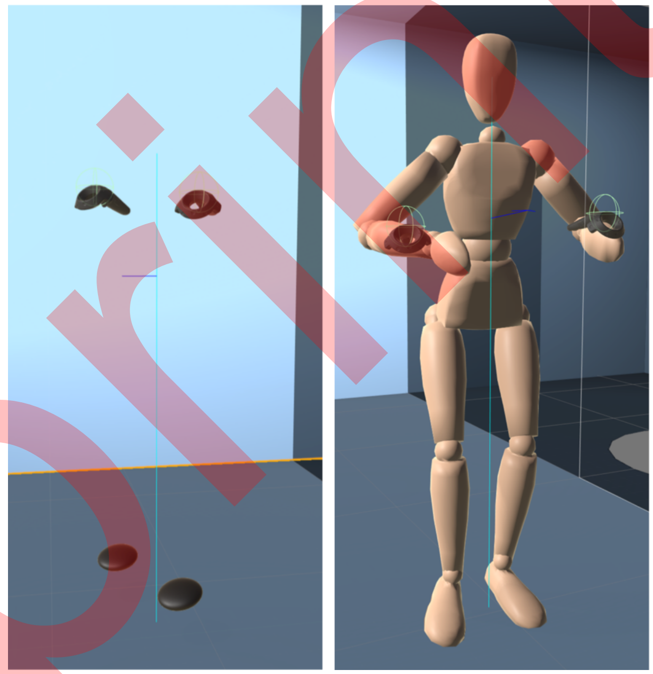

Figure 3: Realization of the two VB conditions. Min-VB (left) uses 3D assets of the controllers and clinched black cylinders for the feet tracker. Full-VB utilizes a wooden manikin as the avatar of the users.

(called *AE* in the remainder of this paper). It is designed to have simplified but still major similarities with the layout of the Real Room (RRm) where the experiment was conducted. For instance, the AE (see Figure 1 right) has the same size and major features (e.g. position of doors and windows) as the RRm. The RRm and the AE feature a mirror to allow the participants to inspect their virtual appearance and to induce IVBO.

The second VE represents the environment in which a stimuli to be measured would be applied in a VR study or alternatively a computer game level (called *SE* in the remainder of this paper). The SE is designed with a strong contrast to the AE to achieve an obvious difference between both VEs, thus increasing the experience of transitioning to a completely different VE. The SE is an open-world environment featuring pink terrain and some abstract mountains. These features provide users with a sense of direction and allow them to orientate themselves in the SE.

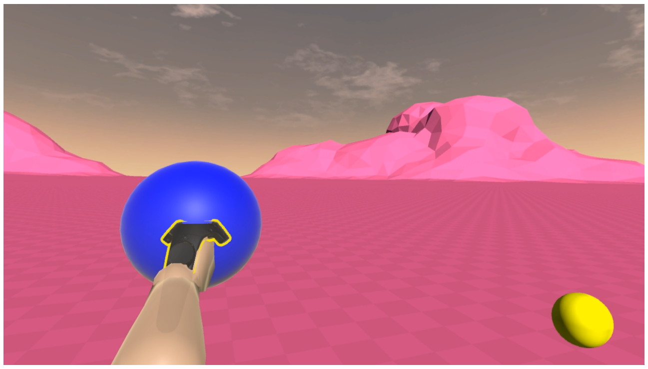

Figure 4: Yellow spheres that reveal their true color upon touch are spawned inside of the SE.

Finally, participants were given a game-like task that involved touching floating spheres in SE and memorizing one color (red or blue) to create an incentive to repetitively transition back and forth between the AE and SE. A color-selection console allowing for the input of either one of two colors is placed in the center of the AE (see Figure 2 left). The console features a progress bar that displays the number of times a user has to enter a color into the system to complete an experimental condition. Each time a user enters a color, a visual feedback indicating the correctness of the entered solution is provided and the progress bar is updated. As the correct color can only be determined by transitioning to the SE, an overall goal is created for the participants. Inside of the SE, three yellow spheres are randomly spawned within a radius of $1.5m$ after each transition. All spheres are programmed to change their color when touched with either the virtual hands or feet (see Figure 4). In addition, each sphere has a fixed height relative to the participant's body height to challenge the participants to perform some extensive movements, e.g., stretch out an arm or touch a sphere with a foot, and thus to redirect a user's attention towards the virtual body ($0.3m$ above the HMD, at the height of the upper body tracker, and $0.3m$ above ground level).

Min-VB is realized by virtually representing the position of the input devices, using 3D models of the controllers as well as clinched black cylinders for the additional trackers. Full-VB is realized using an avatar with the appearance of a wooden manikin called *Woody* [49]. Woody was chosen due to its gender-neutrality and its verified high IVBO rating [33]. Besides the HMD and the two controllers for each hand, three additional trackers are used to detect the user's upper body and feet position and orientation. Jointly, this information is utilized as input for an inverse kinematic algorithm that determines the overall avatar pose.

5 IMPLEMENTATION

The VR TT experiment system was developed with *unity* in the version 2017.3.1f1 [64] for PC using the *SteamVR Plugin* [66] in the version 1.2.2 to implement the controller-based interaction system and the overall player controller. The gameplay is rendered to the HTC Vive HMD [24]. The glasses used for the virtual HMD are part of the *Unity Standard Assets* and the virtual mirror is part of the *Vive Stereo Rendering Toolkit* [25].

Figure 5: Virtual bodies are implemented by tracking the positions and orientations of feet, back, head and hands.

The HTC Vive HMD (resolution: 2160×1200, 1080×1200 per eye; refresh rate: 90 Hz) was connected to the computer (CPU: Intel(R) Xeon(R) CPU E3-1230 v5 @ 3.40GHz, RAM: 16GB, Graphics card: MSI NVIDIA GeForce GTX 980 Ti) and the HTC Vive's tracking area had a size of $4.8m \times 4.5m$. The HMD and the controllers were cleaned after a participant has finished the experiment using a cleansing and disinfectant product.

The tracking of a user's body is achieved by using three additional Vive Trackers to determine the position of the upper body and the feet (see Figure 5). The upper body tracker is attached to a belt which is adjusted to position the device at the participant's back just above the hip bone. The two trackers for the feet are attached to a non-slip over shoe system which can be worn over the participants' shoes, keeping them in a fixed position right above the toes. The additional trackers are also worn by participants of the min-VB group to avoid causing a confound of the experiment.

5.1 Simulated Blink

SB and TA use the HTC Vive controllers' trigger buttons to initiate a transition. While being in the AE, the transition can only be initiated by standing on top of a transition platform placed adjacent to the color-selection console (see Figure 1 right). Also, while being in the SE, the transition can only be initiated after revealing all the three balls. This decision was made to prevent participants who use the controllers for the very first time to frequently transitioning back and forth as they subconsciously might use the trigger button to reveal the colors. The transition platform is used to reduce potential room-space-related issues, e.g., risk of a collision with the RRm's walls after the completion of some experimental task cycles, by positioning the player at a defined position inside of the RRm at the start of the experiment. SB is implemented by fading the players' view to black for 1*s*, subsequently teleporting them between the two VEs, and finally fading the view in again. The transition duration time was selected based on a quick internal evaluation that revealed 1*s* to be the most comfortable time. When returning back from the SE, the players find themselves back on the transition platform, thus allowing them to enter a color into the console without any additional movement.

5.2 Turn Around

For the TA technique, the AE and the SE are internally represented by means of two different layers that can be filtered out with transparent game objects. This permits to create the illusion that parts of a VE are missing. Two transparent filter cubes are used to either filter out parts of the AE to achieve a transition to the SE or, vice versa, to filter out parts of the SE to achieve a transition back to the AE. While the former cube is placed behind the user after the transition was initiated, the latter cube is spawned directly in the field of view to hide parts of the AE. After the user has turned around by 180 degrees and the previous VE is no longer in her field of view, it gets disabled. To increase the usability, the AE is rotated in such a way that the color-selection console is always positioned directly behind the user. That way, the user merely needs to turn around to complete the transition and to stand in front of the console thus allowing for an easy input of the determined color.

5.3 Virtual-head Mounted Display

The VMD's 3D asset can be grabbed by the user with one of the controllers (intersecting virtual controller and VMD asset, holding down the trigger button). VMD is implemented using a video texture that displays the view of a camera located at the user's spawn position inside of the SE. This texture is added to the inside of the VMD 3D asset. As soon as the grabbed VMD falls below a certain distance to the user's virtual head, the user gets teleported to the SE. Vice versa, as soon as she grabs the VMD asset from her virtual head, again exceeding the distance threshold, the player gets teleported back to the AE. For the purpose of achieving consistency between the two virtual environments and the other TTs, the user always returns to the position in the AE where the VMD was put on. Similarly, the transition returns the player to the last position inside of the SE before the VMD was removed. The VMD asset is connected to a spring-like force in the AE that achieves the functionality of a rubber band. That way, the glasses hang from the virtual ceiling and are always in easy reach for the users. Moreover, they swing back to their initial position after returning to the AE.

All realizations of the TT metaphors feature tooltips that are shown on the controllers to inform users about the possible interactions with the system.

6 MEASURES

All questionnaires used were translated to the common language of the study's location. The language proficiency of each participant was assessed to ensure that the questions were understood properly.

6.1 Simulator Sickness

The simulator sickness was measured for all participants before and after the experiment using the *simulator sickness questionnaire* (*SSQ*) [28]. This questionnaire was used to measure the overall quality of the VR simulation and to identify potential negative effects that could have affected the study's results.

6.2 Presence and Immersion

The study included the *immersive tendency questionnaire* (*ITQ*) [69] and the *presence questionnaire - version 3.0* (*PQ*) consisting of the 19 core items [68]. Also, a single-question mid-immersion oral presence assessment [6, 7] was conducted as presence is quickly lost after the end of the immersion. The questionnaires were used to evaluate immersive as well as believable aspects of the simulation and, more importantly, of the TTs. While the ITQ was only filled out before the start of the experiment, the PQ was completed after each experimental simulation session. The mid-immersion assessment was conducted after a participant's fourth transition to the SE.

6.3 Illusion of Virtual Body Ownership

The IVBO was measured using the *Alpha IVBO* questionnaire [50]. It was completed after each experimental simulation session to determine if the used TT affects the experienced IVBO.

6.4 Efficiency

The efficiency of the TTs, as a measure of the resources expended, was assessed by measuring a participant's *completion time* needed to complete an experimental condition. In addition, the *NASA-TLX* [23] was implemented to measures the users' perceived task load after the completion of each condition. To facilitate the evaluation process, the NASA-TLX was used in the modified *Raw NASA-TLX* (*RTLX*) [22] version, i.e., the RTLX eliminates the weighting process and only implements the six subscales [40].

6.5 Naturalness

The naturalness of the TTs was assessed by evaluating their intuitiveness, the most fundamental quality of natural user interfaces [20], as well as by asking for the users preference. Intuitiveness was assessed by implementing the *QUESI* [41] after the completion of each condition. At the end of the experiment, participants were asked to express their *preference* for one of the three TTs and to reason their selection.

7 PROCEDURE

The experiment consisted of eight stages:
(1.) *Introduction:* The participant is welcomed and receives a short introduction into the experimental design. The participant signs the informed consent form.
(2.) *Pre-questionnaire:* The participant fills out pre-questionnaire consisting of demography questionnaire, ITQ, and pre-test SSQ.
(3.) *Preparation:* The participant dons the tracking system, HMD and controllers. Subsequently, a brief explanation of the controls is given. The real world mirror is covered to avoid tracking issues.
(4.) *Acclimatization:* In the *full-VB* condition, Woody is adjusted to the participant's body height. Subsequently, the participant is

given the opportunity to explore the AE for 1 minute. In the *min-VB* condition, the participant is given the opportunity to explore the AE for 1 minute. Both conditions include a brief tutorial explaining the mechanic to reveal a sphere's color.
(5.) *Simulation:* The participant utilizes a TT to determine the correct color and enters the solution into the color-console. After the 4th transition to the SE, the mid-immersion presence gets assessed. (Repeated 7 times).
(6.) *Evaluation:* The participant fills out the post-questionnaire consisting of PQ, NASA-TLX, QUESI, and IVBO.
(7.) *Repetition:* Back to *Step 5* until all three TTs are completed. The TTs are presented in a randomized order.
(8.) *Conclusion:* The participant fills out the post-test SSQ and is asked which of the TTs would be the participant's choice for a frequent use in VR. Also, the participant is asked to provide an optional explanation for the choice.

8 PARTICIPANTS

In total, 49 participants (33 females, 16 males) were recruited from the undergraduate students who were enrolled at the University of Würzburg. They had a mean age of 21.18 ($SD_{age} = 1.98$) and were native speakers. 15 participants reported to be frequent computer game players and 40 participants reported to have used an HMD before. The participants first were sorted by their gaming experience to ensure an equal distribution of well experienced gamers among the two groups. Then, the participants were randomly assigned to either the full virtual embodiment *full-VB group* ($n = 23$, 7 females, 6 males; 7 regular computer game players) or the minimal embodiment *min-VB group* ($n = 26$, 16 females, 10 males; 8 regular computer game players).

9 RESULTS

The results were analyzed by either computing *Wilks' Lambda repeated measurements ANOVA* and *paired t-tests* for comparisons of the measured effects inside of the within subjects design evaluations, i.e., full-VB and min-VB group, or computing *two sample t-tests* to compare the results between the full-VB and min-VB group. The effect size was determined by computing the *Cohen's D*. A correlation was analyzed by using *Pearson's product-moment correlation.*

9.1 Simulator Sickness

The total score of the SSQ was computed for the measurements that took place at the beginning ($M_{\text{full-VB}} = 13.98$, $SD_{\text{full-VB}} = 12.87$, $M_{\text{min-VB}} = 17.26$, $SD_{\text{min-VB}} = 14.96$) and the end ($M_{\text{full-VB}} = 17.07$, $SD_{\text{full-VB}} = 19.00$, $M_{\text{min-VB}} = 15.68$, $SD_{\text{min-VB}} = 16.22$) of the experiment. No significant difference was found between the two groups before ($t_{\text{pre}}(47) = 0.82$, $p_{\text{pre}} = 0.42$) and after ($t_{\text{post}}(47) = 0.28$, $p_{\text{post}} = 0.78$) the experiment. Also, no significant change in the SSQ total score between the two measurements was found in the two groups ($t_{\text{full-VB}}(22) = 0.75$, $p_{\text{full-VB}} = 0.46$, $t_{\text{min-VB}}(25) = 0.68$, $p_{\text{min-VB}} = 0.50$).

9.2 Presence

9.2.1 *Immersive Tendency.*
The participants showed a mean immersive tendency ($M_{\text{IT}} = 4.34$, $SD_{\text{IT}} = 0.53$) which was above the neutral mid-point (1 = low tendency, 7 = high tendency) on the ITQ. The participants who were randomly assigned to the full-VB group ($M_{\text{full-VB}} = 4.43$, $SD_{\text{full-VB}} = 0.56$) and to the the min-VB group ($M_{\text{min-VB}} = 4.26$, $SD_{\text{min-VB}} = 0.49$) were not significantly different ($t(47) = 1.08$, $p = 0.29$) in their immersive tendency.

Table 1: Mean Presence (PQ).

Group	M_{VMD}	SD_{VMD}	M_{SB}	SD_{SB}	M_{TA}	SD_{TA}	p
Full-VB	5.42	0.70	5.50	0.69	5.13	1.01	0.07
Min-VB	5.57	0.74	5.76	0.60	5.45	0.61	0.01*

Table 2: Mean Mid-Immersion Presence.

Group	M_{VMD}	SD_{VMD}	M_{SB}	SD_{SB}	M_{TA}	SD_{TA}	p
Full-VB	7.17	1.67	7.30	1.29	6.91	1.68	0.46
Min-VB	7.42	1.96	7.50	1.84	7.08	2.00	0.18

9.2.2 *Presence Questionnaire.*
The full-VB group and the min-VB group (see Table 1) gave an above neutral mid-point rating (1 = low presence, 7 = high presence) on the PQ for the VR TT system independent of the used TT. A significant difference was only found in the min-VB group ($F_{\text{full-VB}}(21) = 3.12$, $p_{\text{full-VB}} = 0.07$, $F_{\text{min-VB}}(24) = 5.36$, $p_{\text{min-VB}} = 0.01$) between SB and TA ($t(25) = 3.30$, $p = 0.003$, $cohensD = 0.65$). No significant difference was found in the min-VB group between VMD and SB ($t(25) = 1.53$, $p = 0.14$) as well as between VMD and TA ($t(25) = 0.95$, $p = 0.35$). Also, no significant difference was found between the two groups ($t_{\text{VMD}}(47) = 0.77$, $p_{\text{VMD}} = 0.45$, $t_{\text{SB}}(47) = 1.42$, $p_{\text{SB}} = 0.16$, $t_{\text{TA}}(47) = 1.37$, $p_{\text{TA}} = 0.16$).

9.2.3 *Mid-Immersion Presence.*
The full-VB group and the min-VB group (see Table 2) gave an above neutral mid-point rating (1 = low presence, 10 = high presence) on the mid-immersion presence assessment for the VR TT system independent of the used TT. No significant difference was found in both groups ($F_{\text{full-VB}}(21) = 0.80$, $p_{\text{full-VB}} = 0.46$, $F_{\text{min-VB}}(24) = 1.85$, $p_{\text{min-VB}} = 0.18$). Moreover, no significant difference was found between the two groups ($t_{\text{VMD}}(47) = 0.48$, $p_{\text{VMD}} = 0.63$, $t_{\text{SB}}(47) = 0.43$, $p_{\text{SB}} = 0.67$, $t_{\text{TA}}(47) = 0.31$, $p_{\text{TA}} = 0.76$).

Lastly, a significant correlations was between both presence assessment tools in the full-VB group (Pearson's cor: $t_{\text{VMD}}(21) = 3.17$, $p_{\text{VMD}} = 0.005$, $t_{\text{SB}}(21) = 2.19$, $p_{\text{SB}} = 0.04$, $t_{\text{TA}}(21) = 2.11$, $p_{\text{TA}} = 0.04$) and the min-VB group (Pearson's cor: $t_{\text{VMD}}(24) = 5.51$, $p_{\text{VMD}} < 0.001$, $t_{\text{SB}}(24) = 6.44$, $p_{\text{SB}} < 0.001$, $t_{\text{TA}}(24) = 5.06$, $p_{\text{TA}} < 0.001$).

9.3 IVBO

As Table 3 depicts, all three tested TTs had no effect on the participants' IVBO. The Alpha IVBO is a three factor questionnaire measuring a user's acceptance of the own virtual body (*acceptance*), the agency and visual representation of motion (*control*) and the perceived change of the own body (*change*). The implementation of Woody using inverse kinematic resulted in a rating above the neutral mid-point (1 = low effect, 7 = high effect) of the acceptance as well as control subscales and a below neutral mid-point rating

Table 3: Overview of the IVBO subscales.

Scale	M_{VMD}	SD_{VMD}	M_{SB}	SD_{SB}	M_{TA}	SD_{TA}	p
Full-VB							
Acceptance	4.23	1.12	4.23	0.85	4.16	0.78	0.88
Control	5.89	1.22	5.89	0.96	5.84	1.29	0.71
Change	2.33	1.18	2.46	1.26	2.32	1.26	0.89
Min-VB							
Acceptance	5.24	1.32	5.04	1.45	4.99	1.32	0.32
Control	6.07	0.84	6.25	0.69	5.99	0.91	0.34
Change	2.09	1.28	1.88	1.12	1.71	0.97	0.08

Table 4: Mean Completion Time in seconds.

Group	M_{VMD}	SD_{VMD}	M_{SB}	SD_{SB}	M_{TA}	SD_{TA}	p
Full-VB	131.94	31.42	123.74	24.60	139.54	29.81	0.16
Min-VB	131.02	30.15	114.50	21.40	134.66	28.44	0.02*

Table 5: Mean NASA-TLX score.

Condition	M_{VMD}	SD_{VMD}	M_{SB}	SD_{SB}	M_{TA}	SD_{TA}	p
Full-VB	27.50	17.76	19.38	10.07	28.19	15.21	0.007*
Min-VB	21.92	15.05	16.63	9.80	21.47	14.00	0.02*

of the change subcomponent. Similarly, the min-VB condition resulted in a rating above the neutral mid-point of the acceptance as well as control subscales and a below neutral mid-point rating of the change subcomponent. The acceptance subcategory was rated significantly higher in the min-VB group than in the full-VB group ($t_{\text{VMD}}(47) = 2.88$, $p_{\text{VMD}} = 0.006$, $cohensD_{\text{VMD}} = 0.82$, $t_{\text{SB}}(47) = 2.33$, $p_{\text{SB}} = 0.02$, $cohensD_{\text{SB}} = 0.67$, $t_{\text{TA}}(47) = 2.63$, $p_{\text{TA}} = 0.01$, $cohensD_{\text{TA}} = 0.85$) for all of the used TTs.

9.4 Efficiency

9.4.1 Completion Time. As Table 4 displays, a significant difference in the total completion time for an experimental condition was only found in the min-VB group ($F_{\text{full-VB}}(21) = 2.03$, $p_{\text{full-VB}} = 0.16$, $F_{\text{min-VB}}(24) = 4.61$, $p_{\text{min-VB}} = 0.02$). A further analysis of the results revealed a significant difference between VMD and SB ($t(25) = 2.30$, $p = 0.03$, $cohensD = 0.45$) as well as SB and TA ($t(25) = 3.00$, $p = 0.006$, $cohensD = 0.59$) but not between VMD and TA ($t(25) = 0.56$, $p = 0.58$). No significant difference was found for each of the used TTs between the two groups ($t_{VMD}(47) = 0.10$, $p_{VMD} = 0.92$, $t_{SB}(47) = 1.41$, $p_{SB} = 0.17$, $t_{TA}(47) = 0.59$, $p_{TA} = 0.56$).

9.4.2 NASA-TLX. For evaluating the NASA-TLX and comparing the perceived task load of the three tested TTs, the mean score across all six subscales of the assessment tool was computed. As Table 5 displays, a significant difference in the perceived task load was found between the TTs in both groups ($F_{\text{full-VB}}(21) = 6.34$, $p_{\text{full-VB}} = 0.007$, $F_{\text{min-VB}}(24) = 4.80$, $p_{\text{min-VB}} = 0.02$). Further analyses revealed a significant difference in the full-VB group between VMD and SB ($t(22) = 2.97$, $p = 0.007$, $cohensD = 0.62$) as well as SB and TA ($t(22) = 2.55$, $p = 0.02$, $cohensD = 0.53$) but not between VMD and TA ($t(22) = 0.17$, $p = 0.87$). The min-VB group showed a significant difference between VMD and SB ($t(25) = 2.67$, $p = 0.01$, $cohensD = 0.52$) as well as SB and TA ($t(25) = 2.70$, $p = 0.01$, $cohensD = 0.53$) but not between VMD and TA ($t(25) = 0.22$, $p = 0.82$). No significant difference was found between the two groups for any of the tested TTs ($t_{\text{VMD}}(47) = 1.19$, $p_{\text{VMD}} = 0.24$, $t_{\text{SB}}(47) = 0.97$, $p_{\text{SB}} = 0.34$, $t_{\text{TA}}(47) = 1.61$, $p_{\text{TA}} = 0.11$).

Table 6: Mean QUESI rating.

Group	M_{VMD}	SD_{VMD}	M_{SB}	SD_{SB}	M_{TA}	SD_{TA}	p
Full-VB	4.05	0.79	4.37	0.63	3.99	0.86	< 0.001*
Min-VB	4.20	0.64	4.48	0.57	4.12	0.49	0.01*

9.5 Naturalness

9.5.1 Preference. At the end of the experiment, the participants were asked to choose their preferred TT: 18 participants chose VMD (full-VB = 9, min-VB = 9), 20 participants voted for SB (full-VB = 9, min-VB = 11) and 11 participants selected TA (full-VB = 5, min-VB = 6). The participants were also given the opportunity to provide an explanation for their choice. They praised the high naturalness, believability and degree of self-control of VMD, the simplicity and efficiency of SB, and the high physical involvement in the transition process as well as naturalness of TA. However, they also reasoned a selection of SB with a high degree of familiarity which made this TT seem natural to them.

9.5.2 Intuitive Use. All three TTs scored above the neutral mid-point (1 = negative perception, 5 = positive perception) on the QUESI questionnaire (see Table 6). A significant difference in the perceived intuitive use was found between the TTs in both groups ($F_{\text{VBO}}(21) = 11.23$, $p_{\text{VBO}} < 0.001$, $F_{\text{min-VB}}(24) = 5.19$, $p_{\text{min-VB}} = 0.01$). Further analyses revealed a significant difference in the full-VB group between VMD and SB ($t(22) = 3.17$, $p = 0.004$, $cohensD = 0.66$) as well as SB and TA ($t(22) = 3.39$, $p = 0.003$, $cohensD = 0.71$) but not between VMD and TA ($t(22) = 0.37$, $p = 0.72$). The min-VB group showed a significant difference between VMD and SB ($t(25) = 2.44$, $p = 0.02$, $cohensD = 0.48$) as well as SB and TA ($t(25) = 3.07$, $p = 0.005$, $cohensD = 0.60$) but not between VMD and TA ($t(25) = 0.66$, $p = 0.52$). No significant difference was found between the two groups for any of the tested TTs ($t_{\text{VMD}}(47) = 0.73$, $p_{\text{VMD}} = 0.47$, $t_{\text{SB}}(47) = 0.62$, $p_{\text{SB}} = 0.54$, $t_{\text{TA}}(47) = 0.64$, $p_{\text{TA}} = 0.52$).

10 DISCUSSION

The study was designed to identify and compare potential effects of TTs on the experienced presence and IVBO that not only would affect the overall experience of VR applications but also potentially confound user studies.

10.1 Presence

The analysis of the experienced presence only revealed a significant difference in the min-VB group between SB and TA when measured using the PQ. In contrast, the mid-immersion presence assessment revealed no significant difference. Presence is quickly lost when the visual immersion has ended. Also, users quickly recover from a break in place illusion [53]. Thus, the mid-immersion presence assessment right after a transition potentially is more accurate than the PQ filled in at the end of an experimental cycle. Consequently, the three tested TTs have only a limited moderating effect on the experienced presence. Hence, all of them are interchangable in VR applications without breaking a user's presence. A potential explanation for this finding could be the fact that transitions are used in all visual media, such as movies, animations and computer games. Hence, a change of environment potentially is a habituated occurrence that is not perceived as a disturbance.

No significant difference was found between the full-VB group and the min-VB group in the experienced presence independent of the used assessment tool. This can by explained by the fact that the participants of both groups were (partly) visually represented by the virtual replicas of the controllers that induced a certain level of IVBO. Thus, it is possible to assume that aspects of IVBO relevant for presence were similarly induced by the min-VB as well as by the full-VB conditions. This can be a valuable insight for designers of immersive VR applications as creating believable avatars is currently still a complex and expensive process.

The study also demonstrated by analyzing the results of the PQ and the mid-immersion presence assessment that both approaches yield a valid indication of presence. Hence, by merely implementing the mid-immersion single question presence assessment, a study can be streamlined and still provide insights into the tested system's presence.

H_{pre} The results of the study led to the rejection of H_{pre} as all three TTs showed a similar effect on the self-reported presence.

10.2 IVBO

The results revealed no significant difference in the perceived acceptance, control, and change related to IVBO caused by the utilization of the three tested TTs. Therefore, it can be assumed that all of the three techniques are causing no interference with the IVBO. Hence, they can be used in user studies to allow participants to change between to independent VEs.

However, the study revealed a significantly higher acceptance rating in the min-VB condition. This could be an effect of the experimental design. Instead of mainly focussing on their virtual embodiments, participants were challenged to transition between two different VE to determine a color. Despite the chosen simple task including a rudimentary interaction, the experimental procedure accidentally yielded game flow. This game flow could have redirected a participant's awareness from her virtual body to the activities required to complete the task. The result also aligns with the finding [35] that game flow resulting from a game's gameplay can result in a player's loss of awareness for herself and for her virtual body, respectively. This could also have happened with any other task that provides a clear goal and immediate feedback. Implementing such a task, however, was necessary. It gave the participants an incentive to repetitively transition between the two VEs, provided them with immediate feedback, and hid the core research goal. In the end, the conclusions drawn from this study are still very relevant as they indicate a TT's effects when used in a game-like or task-oriented context.

H_{ivbo} As a result, the study also led to the rejection of H_{ivbo} as the self-reported IVBO was not affected by the tested TTs.

10.3 Efficiency

The efficiency evaluation consisted of the measured completion time and perceived task load. It revealed that VMD and TA are, as expected, slower and cause a higher task load. This can be explained by the additional actions a user has to perform to achieve a transition using VMD and TA. SB, in contrast to the other two tested TTs, merely requires a user to press a button to complete a transition. The other two TTs require a user to perform the gesture of putting on glasses or to physically turn around by 180 degrees, respectively.

Still, despite the significant difference, all TTs yielded low task load ratings that indicate their efficiency for achieving a transition from one VE to another. This outcome is important for game designers who like to realize transitions in a more natural and engaging way.

H_{eff} The study's results confirm H_{eff}. SB achieved a significantly lower total task load and significantly faster completion time.

10.4 Naturalness

Finally, the naturalness evaluation consisted of the users' preference and perceived intuitive use. The evaluation revealed that SB yielded a significantly higher intuitive use rating. On the one hand, this can be again explained by the realization of this TT, i.e., using a mere button press to complete a transition. On the other hand, it is explainable by the common occurrence of SB in many media forms. SB represents a traditional TT which is commonly used and hence was potentially well internalized by the participants. Thus, the intuitive use rating could have been influenced by previous experiences that included a SB to change from one VE to another.

The study also revealed that SB is the preferred TT, closely followed by VMD. SB was rated easy to use and very efficient thus confirming its frequent implementation. VMD was rated to provide a high degree of self-control and to be natural as well as believable. A potential benefit for users who experience VR for the first time, e.g., during a user-centered experiment or a therapy application. TA, as a whole-body movement, physical and continuous technique, was rated as very dynamic and natural. This validates the indications drawn from previous research. The two tested physical and continuous TT metaphors were perceived as natural and partly as plausible. In the end, this is another important insight for game designers who like to implement natural interaction techniques.

H_{nat} The results confirm H_{nat}. VMD received almost similar preference ratings and was named the most natural TT that provides a high degree of self-control. TA, despite being the least preferred TT, was also rated dynamic and natural.

11 CONCLUSION AND FUTURE WORK

This paper analyzed the effects of techniques permitting a transition between different VEs on the experienced presence, IVBO, efficiency, and naturalness. For this purpose, three TT metaphors were identified: (1) *SB* achieves a transition by fading the user's view to black, changing the user's location, and fading the view in again, (2) *TA* requires a user to physically turn around to navigate to a different VE, and (3) *VMD* mimics the functionality of a real world HMD. They were selected to margin the design space of interaction type and motion type in terms of the theoretically best and theoretically worst characteristics with respect to the evaluated qualities.

The present study led to a twofold contribution: (1) In contrast to the theoretical conclusions drawn from literature, we provide evidence that the three tested TTs did not affect the experienced presence or IVBO in the frame of a game-like implementation. (2) We confirmed the frequent implementation of SB as it yielded a significantly higher intuitive use rating and was the most preferred TT. At the same time, we provided insights that the two continuous and physical TTs were perceived as natural and, in the case of VMD, as believable in contrast to SB. This is an important result for the scientific and game design community. Our results show that all of the tested TTs can safely be implemented without reducing the perceived presence and IVBO.

Future research aims at identifying a TT's effect on the perceived plausibility illusion which was out of scope for this paper. While not affecting presence and IVBO, TTs might have an effect on the perceived plausibility. Additionally, we like to explore the efficiency and acceptance of the three TT metaphors for achieving a nested VR experience, i.e., to utilize them for a vertical transition into different VE layers. Finally, we like to use our categorization of TTs and the insights gained from the present study to present a comprehensive taxonomy.

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