In Limbo: The Effect of Gradual Visual Transition between Real and Virtual on Virtual Body Ownership Illusion and Presence

Sungchul Jung*
University of Central Florida
SREAL Lab

Pamela J. Wisniewski†
University of Central Florida

Charles E. Hughes‡
University of Central Florida
SREAL Lab

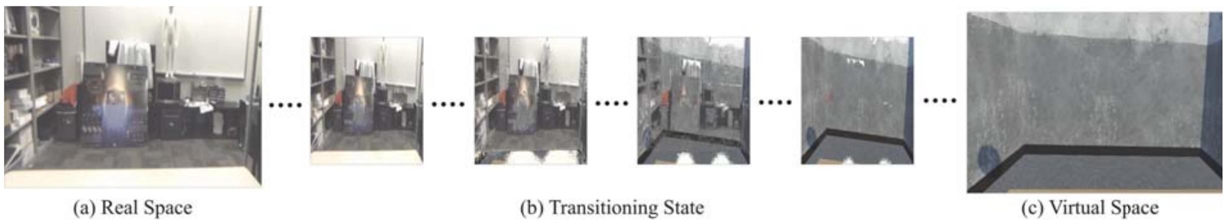


Figure 1: A series of view frames to show the gradual transition from real space to virtual space (a) A video see-through view of real room from a first-person perspective (b) Video data gradually disappeared according to time elapse until the virtual world completely appeared (c) A view of virtual room from a first-person perspective

ABSTRACT

We present a study of the relative effects of gradual versus instantaneous transition between one's own body and a virtual surrogate body, and between one's real-world environment and a virtual environment. The approach uses a stereo camera attached to an HMD to provide the illusions of virtual body ownership and spatial presence in VR. We conducted the study in a static environment which is similar to the traditional rubber hand experiment platform. Since our transition method is a blending scheme between real and virtual contexts, our study investigates the direct use of real-world information during the transition to increase the dominant visual illusion in a virtual space. We also investigate the use of a conceptual stage, called Limbo, which is a transition phase that evokes anticipation of the virtual world, providing a psychological link between the real and virtual before we enter a totally virtual space. Our study of the transition effect shows that the Limbo state has a significant influence in one's illusions of virtual body ownership (VBOI) and presence.

Keywords: Transition, Virtual Body Ownership, Presence, Perception, User Study.

Index Terms: I.3.7 [Computer Graphics]: Three Dimensional Graphics and Realism—Virtual Reality; H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities H.5.1 [Information Interfaces and Presentation]: User Interfaces—User-centered design

1 INTRODUCTION

With the rapid development of inexpensive and highly effective virtual reality technologies such as motion tracking, HMDs, and supportive tactile devices, it is now possible to provide immersive virtual reality experiences (IVE) at a low price. However, there still is a lack of convincing evidence about the effectiveness of VR experiences related to human mental models such as engagement, plausibility, place illusion and embodiment. Moreover, it is not always clear what are the most critical existing factors and which others might be missing.

In this paper, our research addresses one commonly missing element for enhancing virtual illusions and we show its practical effect on virtual body ownership (VBOI) or self-presence (SP), which is one's perception of a virtual body being one's own body [2, 9], and of spatial presence (P), which is one's perception of being in a setting other than where they currently are in the real world [17] . We approach this study by employing a variant of the traditional rubber hand experiment [3]. In contrast to the traditional VR research approach that focuses inside the VR space, we include elements from outside the VR space, as observed before the user enters the VR scenario completely. Here, we assume that human perception is sensitive to real-world information and this sensitivity affects our perception in the VR experience. For example, prior to wearing and during the donning of the HMD, we still visually perceive real-world information, including our body and the surrounding environment. However, after we have secured the HMD completely over our eyes, we feel as if we have been instantly transported to VR space, which is normally a disconnect because the virtual environment is visually different than the place where we were just located. Also, there is a disconnect when we have a virtual agent body that is different from our own body with mismatched real body information [20]. Thus, based on Gregory's top-down approach for a visual perception illusion model [5], we implemented a passive visual transition system with a gradual transition (GT) mode to adjust the human perspective gap between the two visual contexts (real and virtual) and compare it to a traditional instant transition (IT). With the GT, we refer to the transition as a Limbo stage according to a conceptual proposal by [19]. With this system, we conducted a study of the dominant illusions in VR such as virtual body ownership illusion and spatial presence. In this experiment, we hypothesize that a gradual transition will enhance the IVE experience, including VBOI (SP) and P, compared to a traditional VR setup with its instant transition. Our study suggests that GT leads to an enhanced immersive virtual environment design with strong statistical support for our hypotheses using subjective and objective measurements for a participant's behavior.

2 LIMBO: INSIDE TRANSITIONING

When we enter a computer-generated world using an HMD based VR system, we pass through three physical-mental transition stages (or changes in perceptual data): donning the VR devices (physical),

*e-mail: sungchul@cs.ucf.edu
†e-mail: pamwis@ucf.edu
‡e-mail: ceh@cs.ucf.edu

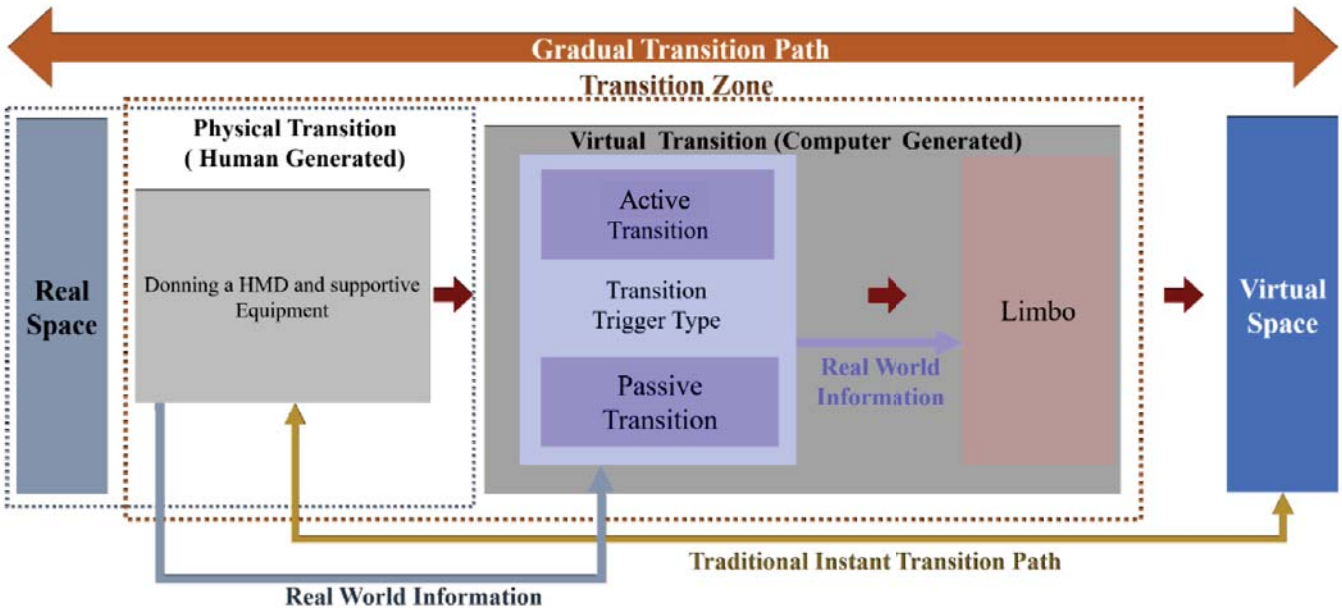


Figure 2: Transition Model for both gradual transition and traditional instant transition. The key concept for gradual transition to arouse Limbo is incorporating real-world information.

transitioning (mental) to VR while seeing the computer-generated world for the first time, before we completely entering VR space (physical/mental), which are similar to three of the five stages discussed in Sproll et al. [19]. In our paper, we focus on the transitioning stage that exists between two definite places (real and virtual), a stage where a user is conjecturing about the appearance of the emerging VR environment including their virtual body and adjusting to the mental gap between the distinctive spaces. This stage differs from transitional environments [21, 22] or preamble [18], since the user can not adjust regarding their own body because they were provided a purely virtual replica of their environment only, while we employed a real-world environment including real own body information. We call this space Limbo. To arouse the Limbo state, we stimulate the participant by visually transitioning to a virtual right hand with the same pose, from a first-person perspective, as the participant's real right hand. We include a haptic sensation by using an HTC Vive controller to gently tap the user's hand where the controller is accurately modeled in VR, so the tapping position, visual appearance and tactile feedback are the same for both the real and virtual hand.

In our experiment (see Figure 2), the transition begins while a participant is donning the VR equipment, a step which is generated by a human's physical actions. Once the HMD is in place, the transitioning to the virtual space may be triggered either actively through human behavior such as walking, gesturing, or pushing a button, or passively without the human's choice, depending on system design. The passive approach is adopted in the study reported in this paper. Regardless of the transition trigger mode, the user experiences a transition. However, the Limbo stage requires cues as we mentioned above to anticipate the VR environment while in transition to a completely computer-generated space. Similarly, we experience the de-transitioning in the inverse order while exiting the virtual world but that is not the focus here.

Generally in VR, the transition stage occurs without a critical impact on a user since rendering of the VR environment begins immediately after donning the HMD, while visually disconnecting from the real world. However, in our study we elongate the Limbo stage noticeably to give time for the user 's mind to adjust to the mismatched visual information between real and virtual spaces. As previously noted, we expect a higher sense of virtual illusion from the GT approach.

3 Related Work

3.1 VBOI and Spatial presence

As one of the dominant illusions, virtual body ownership (VBOI) shows a critical role in the VR environment when an user is controlling a virtual agent [15, 20, 25]. For a higher sense of VBOI, Argelaguet et al. have shown the influence of multiple factors including an avatar's resemblance to the human's appearance [1]. Also, Kilteni et al. summarized significant components for VBOI with positional congruence, synchronous visuotactile cues, synchronous visuomotor cues and anatomical plausibility [9].

3.2 Visual Perception

A psychologist, Gregory suggested a scheme, called ”ins-and-outs”, for representing a relationship between human perception and illusion [5,6]. His research argues that perceptual knowledge (awareness through senses) and conceptual knowledge (abstractions from prior experiences) are combined to produce a meaningful understanding of the current reality. Recently, Jung et al. showed a positive effect of visually personalized real body information as a supportive component to increase VBOI and spatial presence using a similar approach to Gregory's work. They adopted a virtual mirror reflection of the participant's own body, which elicits human perspective even though the displayed real body parts were not directly involved in the task [7, 8]. Similarly, Adalberto et al. focused on eliciting human perception toward object recognition by substituting a real object with a similar virtual object in a VR space [12].

3.3 Transition

A transition is a state change between a real and virtual world or a virtual and virtual world, and it is generally instantaneous. In our research, we focus on the real to virtual transition. As a first attempt to study a transition effect on spatial presence, Slater et al. created a replica in their laboratory of a real-world office, and a virtual space that mimicked that office [14, 16]. To investigate the transition effect for virtual illusion, Steinicke et al. adopted [16]'s scheme, designing a virtual space that mimics a real-world office in which a participant conducted their experiment. The participants experienced a transition while they move to a virtual space through a virtual portal [21, 22] by the action of walking. From the previous studies, they found the positive effect of the transition for presence. Similarly, Valkov and Flagge proposed a smooth transition concept to increase immersiveness. Using a similar approach to that employed by [21, 22], they started the study from a virtual replica of their real laboratory. While the participants were walking around in the virtual laboratory wearing an HMD, the laboratory began to change a bit at a time to the virtual world, passively, without the participant's intentional behavior [24]. Based on the findings, Liang et al. reported the effect of four type of virtual transition for presence when a participant moves to a virtual space using a portal from another virtual space [10]. Recently, Smolentsev et al, conducted research to investigate the effect of a preamble to increase the virtual illusion of low fidelity VR presented on a 2D screen. They provide evidence that the predefined virtual replica of their laboratory as a preamble increases spatial presence regarding the new virtual space more effectively than the instantaneous advent of the new virtual space [18], further evidence of the applicability of Gregory's ins-and-outs schema [5, 6] to VR. While this type of transition effect happened between virtual worlds, Jeffrey et al. presented their demo experience for the transition effect from the real to a virtual world using a stereo camera attached to an HMD [11]. In this paper, we adopted their device design to allow the transition effect between the real and virtual world. In contrast to others, we investigated the transition effect on the virtual body ownership illusion and spatial presence, when the transition happens between the real and virtual world and involves a user's body parts.

4 EXPERIMENT

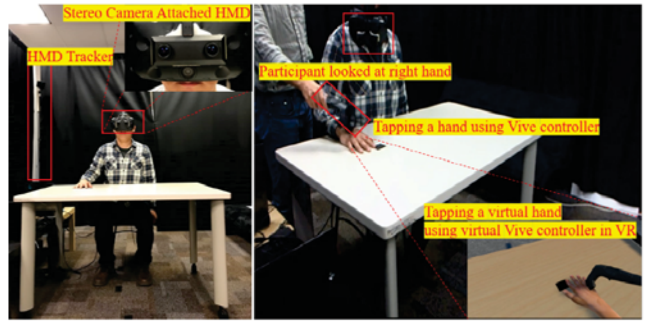
To investigate the effect of the gradual transition for virtual body ownership and spatial presence, we implemented a visual blending method using a stereo camera with a virtual body in VR. Before we conducted the experiment, we posed the following hypotheses regarding the dominant illusions:

- **VBOI** Using a gradual transition will provide a higher sense of virtual body ownership illusion than having an instant transition.
- **Spatial Presence** Using a gradual transition will provide a higher sense of spatial presence than having an instant transition.

We used multiple measurements including questionnaires with a 7-point Likert scale and observed behaviors in this study. Our experiment is a 2x1 Between subject design intended to show the effect of a gradual transition. Before recruiting the participants, we conducted an a priori power analysis to determine the required sample size using G*Power with a power of 0.80. This determined that we needed a minimum of 18 participants [4]. We recruited voluntary participants with normal to corrected-to-normal vision using on-campus fliers. Most participants had higher education backgrounds and were mainly in computer science. We conducted our experiment with 20 participants. We divided the participants into two groups, one for gradual transition as an experimental group with 10 participants (6 Male, 4 Female, Mean Age=29.5), and one for instant transition as a control group with 10 participants(8 Male, 2 Female, Mean Age=31.7). Our experiment was approved by our organization's Internal Review Board Office.

4.1 Experimental Platform

Based on a VR extended version [15] of a traditional rubber hand experiment [3], we designed our study with a gradual transition effect. In the real experiment space, we placed a desk and a chair with the HMD tracker behind the participant as seen in Figure 3(a). The participant wore a stereo camera attached HMD during this study while placing their right hand near a black-colored mark on a table. To collect the participant's objective response, we installed a web camera for recording their behaviors.



(a) Initial pose while the participant donning HMD

(b) Synchronization of tapping a real hand and a virtual hand

Figure 3: Experimental platform based on rubber hand study

In this study, a primary experimenter gave a tactile feedback by gently tapping a participant's hand and forearm using a Vive controller (Figure 3(b)). In the VR space, the participant has a virtual body seen from a first-person perspective that is in a pose similar to that of the participant who is placing their right hand near the black-colored tape on the table. Also, the participant sees the virtual surrogate of the Vive controller that is tapping the virtual hand. While a participant is located in VR space, we arouse their sensation with two kinds of threats: one is a virtual knife attempting to stab the right virtual hand, and the other is a virtual spider walking on the right virtual hand (Figure 4). In this study, we used a unisex style virtual hand that was the same for male and female participants.

(a) Attempt to stab right virtual hand with knife

(b) Loading a leg moving spider on a virtual hand

Figure 4: Virtual threats to arouse a participant illusion in VR space

4.1.1 Gradual Transition Implementation

We rendered a real-world environment using a stereo camera attached to the HMD to provide a video see-through platform for the participant to observe the real world. The stereo camera offers 45 frames per second(fps) with 1280 by 960 screen resolution for each eye. For a visually convincing transition effect, we blended a camera view plane between the real and virtual worlds while controlling HSL (hue, saturation, and luminance) model-based color components using a simple equation (Equation 1).

$$p = (ElapsedTime)/(FixedTimeDuration) \quad (1)$$

$$(h,s,l) = (Lerp(h,p)*e1, Lerp(s,p)*e2, Lerp(l,p)*e3) \quad (2)$$

According to the time elapsed, we calculated a percentage for the current value for each color component using linear interpolation

Table 1: Questionnaire

Item	Question
P	To what extent did you feel like you were really inside the virtual room? To what extent did you feel surrounded by the virtual room? To what extent did you feel like you really visited the virtual room? To what extent did you feel that the virtual room seemed like the real-world? To what extent did you feel like you could reach out and touch the objects in the virtual room?
SP	To what extent was the avatar an extension of yourself? To what extent did you feel if something happened to the avatar it felt like it was happening to you? To what extent did you feel that the avatars body was your own body? To what extent did you feel that the avatar was you? How much did the avatars actions correspond with your actions?
VBOI	I felt as if the virtual representation of the hand was part of my body. I thought that the virtual representation of the hand could be harmed by the virtual danger. Sometimes I had the feeling that I was receiving the hits in the location of the virtual arm. During the experiment there were moments in which it seemed as if what I was feeling was caused by the black controller that I was seeing in the virtual space. During the experiment there were moments in which I felt as if the virtual arm was my own arm.

multiplied by constants *e1, e2, e3*, respectively. We iteratively calculated the color value until the percentage reached zero, which means a totally transparent video stream, so the participant sees only the virtual world behind the video data plane (Figure 1). We fixed the gradual transition effect to take 30 seconds in our experiment.

4.1.2 Measurements

According to Slater et al., using only a subjective measurement is not sufficient to assess dominant illusions in virtual environments [13]. Thus, we assessed virtual body ownership and spatial presence using subjective measurements based on questionnaires, and objective measurements based on each participant's behaviors. For the subjective measurements, we adopted pre-validated questionnaires called spatial-presence (P), and self-presence (SP) by Bailey et al. [2]. Even though they use the term self-presence instead of virtual body ownership, we determined the set of questions represents the body ownership property. For comparison purposes of self-presence, we adopted VBOI questionnaires from [15] and [1] with slight modifications based on our study context. Before analyzing the corrected data, we ran Cronbach's alpha test as a validation [23]. Lastly, we created a set of post questions for comparison purposes between the gradual transition effect and the instant transition effect. We provide our subjective measurement items for VBOI in Table 1. Objective responses were collected by recording all behaviors with a web camera.

4.1.3 Protocol

Before we conducted our study, each participant read an informed consent and filled in demographic data while in a waiting area. After completion of the demographics, the participant entered the experiment room, which is an isolated space to avoid distractions. We verbally provided overall instructions for the experiment and required actions to conduct the study before they actually participated. After the instruction, we asked the participants to close their eyes while sitting on a stool because we wanted to prevent any visual transition while the participants were donning the HMD. Up to this step, both GT and IT employ the same procedure.

After donning the HMD with their eyes closed, we asked participants to enter into an initial pose and to open their eyes, look around the environment, and look at their right hand. For a GT, we tapped the participant's real hand and forearm using the Vive controller for about 20 seconds as an arbitrarily chosen time duration, and asked them to look around the environment again, while the transitioning was taking place. After finishing the transition, we asked the participant to look at their hand (we did not mention real or virtual) while we kept providing the tactile feedback with the same tapping interval in the VR space. When we stopped tapping the arm and hand, we suddenly changed the black Vive controller to a knife. We held the knife in the air for five seconds and we then attempted to stab the participant's virtual hand, but we did not actually touch the participant's hand. After the event, we placed the knife on a virtual table, and a virtual spider suddenly showed up, moving its legs on the virtual hand with tactile feedback using the experimenter's fingers to give a sense that mimics the spider walking on the hand. We ran each event only one time, and for just over five seconds. After the second event, we asked the participant to look at the environment and ran the inverse transition effect to return to the real world. After the change to the real world, we asked the participant to close their eyes and take off the HMD.

For an IT, we conducted the same procedure as for GT except we rendered a black screen during the transition. The participant entered the virtual world instantly right after they donned the HMD and opened their eyes.

After finishing the experiment, each participant filled in a subjective questionnaire while in a waiting place. For a comparison between the two types of transitions, we asked participants to enter the study with the alternate study conditions again like a Within-subject test for post questionnaire only, so we did not correct data from the second study. After the second experience, the participant responded to a comparison question, which ended their involvement in the study.

5 Analysis

5.1 Questionnaire

Before we analyzed the collected subjective data, we assessed construct validity of multiple items in the same categories using Cronbach's alpha, and all four items were satisfied with $\alpha > 0.7$. To analyze the subjective measurements, Mann-Whitney test was used for all items, since our data did not show a normal distribution with the Anderson-Darling method, which means they were non-parametric data. We observed the explicit outcome that GT (Blue bar) is more influential on VBOI and presence as seen in Figure 5. We provide the interquartile range box with outlier and median symbol in all box-plot graphs along with median confidence interval box at the 95% level with the white colored dotted box inside each bar. Along with the graph, we found a significant difference for all dependent variables: spatial-presence ($p<0.006$), self-presence ($p<0.012$) and VBOI ($p<0.001$) respectively. Interestingly, both self-presence and VBOI showed a positive impact when a Pearson's product-moment correlation was run to assess the relationship between them as one construct. Since the test shows $r(18) = .40$, $p<0.005$, which is a moderately positive correlation, and Cronbach's alpha confirmed a strong relation of $\alpha > 0.92$, we assume we can treat these as one dependent variable in this study. Through our open question, only one participant reported any discomfort and that was in the GT condition. We provide numerical results in table 2. We calculated P value at the 5% significance level for all classes.

We also collected qualitative feedback from participants to triangulate our quantitative results from the post comparison question, seen in the pie chart (Figure 6).

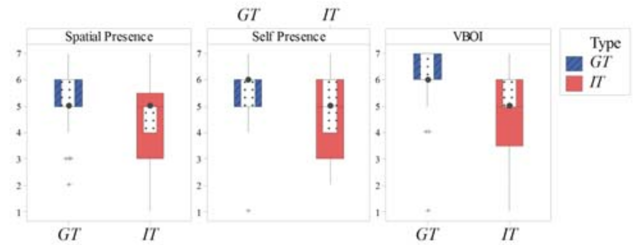


Figure 5: Subjective Result. Gradual transition shows a significant difference for spatial presence and virtual body ownership illusion

Table 2: Descriptive Statistics with mean value(SD) and median

Item	P-Value	GT $\mu(\sigma)$, Mdn	IT $\mu(\sigma)$,Mdn
Spatial Presence, α=0.92	***P*<0.006**	**5.32(1.19), 5**	4.42(1.70), 5
Self Presence, α=0.89	***P*<0.012**	**5.62(1.18), 6**	4.7(1.75), 5
VBOI, α=0.78	***P*<0.001**	**6.12(1.14), 6**	5(1.81), 5.5

Regarding system preferences, it seems there was not a significant difference, though 10 participants (50%) voted for gradual transition. However, even though there was no reported difference between the transition methods, 10 participants (50%), felt more spatial presence in the gradual transition scenario, and 12 participants (60%) voted for gradual transition regarding a higher sense of VBOI.

5.2 Behaviors

To analyze a participant's behavior, we reviewed recorded videos from this study. Because of a recording error, we dropped one data entry from the instant transition, so we observed 10 recordings for gradual transition while we observed only 9 recordings for instant transition. Since emotion is ambiguous to classify accurately, we simply coded the behavior based on three categories: audible noise, physical body movement, and no observed reaction. For example, if a participant made any verbal or non-verbal noise after the event was triggered, we coded it as a response. Similarly, if a participant showed body movement even slightly after the threat happened, we coded it as their response. We present the graph with accumulated number of behaviors in each category (Figure 7).

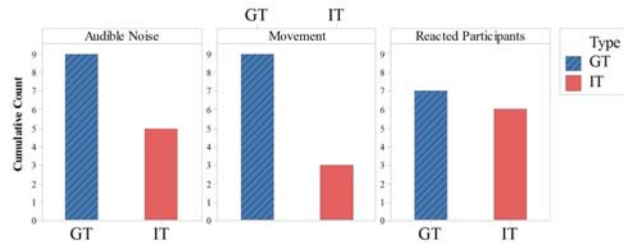


Figure 7: Behavior Result. Gradual transition case shows higher number of behavioral reactions compared to Instant transition case

From the recording results, we found there were a greater number of audible noises and body movements aroused with gradual transition, though the number of participants who reacted at some point was similar for GT and IT. Because both conditions are enough to arouse a sensation, participants exhibited behavioral responses in all cases since we provided the known critical elements for the sensation, such as visuotactile, resemblance, and positional congruence for both conditions. However, we conclude that gradual transition gave a stronger illusion than instant transition. We will explain this conclusion in detail in the discussion section.

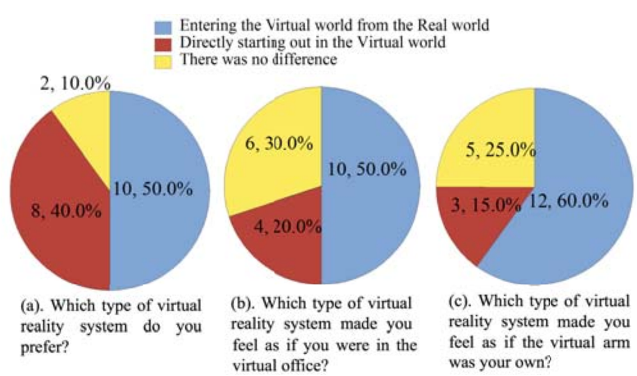


Figure 6: Post Result. We represented the result with a pair (number of votes, percentage). When asked directly, more participants preferred the gradual transition overall, stating that it made them feel as if they were in the virtual office (spatial presence) and as if the virtual arm was their own (VBOI).

6 Discussion and Limitation

In this paper, we conducted a virtual hand study focused on the effects of a gradual transition on virtual body ownership illusion and spatial presence, using multiple measurements questionnaires and recorded behaviors. From the result, we found a statistically positive effect of the GT for VBOI and spatial presence explicitly in comparison to IT. We also confirmed that self-presence and VBOI were similar constructs with correlation analysis and Cronbach's alpha, allowing us to combine these constructs into one. Thus, our results support our research hypothesis that gradual transition will provide more VBOI and spatial presence in comparison to traditional instant transition. Along with these results, we are confident that our implementation provided a useful Limbo status during which the participants could adjust to the conflicting information between the real and virtual worlds. One more noticeable feature of this study was the Vive controller, since we gave a continuous tactile feedback using the controller, and the participant felt the same tapping feedback while they saw the same shape of the controller in both the real and virtual spaces, a connection that might have worked as a mental-physical link or cue between the distinct spaces. Interestingly, the question "Sometimes I had the feeling that I was receiving the hits in the location of the virtual arm." shows a significant difference between GT and IT with ($p<0.021$) and GT achieving a higher mean value, even though we tapped on the identical location with the same regular time interval in both cases.

In contrast with the positive effect, we found that there is no difference regarding system preference as seen in the first chart based on a post questionnaire. From these results, we guess that our gradual transition system is not effective as a convenient interface to entering virtual space, perhaps because the video see-through might arouse some confusion because of its relatively low frame rate and narrow field of view. In addition, HSL color component based gradual transition is quite sensitive to light conditions in the real world, so this might not be applicable to the transitions required in all VR applications. Finally, we had some trouble rendering the virtual hand in the exact location of the participant's real hand, so we asked our participants to look at the environment instead of looking at their right hand during the gradual transition.

However, we still conjecture that the real-world information from the gradual transition would greatly help to give a more dominant illusion even though our statistical results were limited, since these did show a strongly positive effect on preference compared to the traditional instant transition method.

7 Conclusion and Future Work

In this paper, we described our experimental platform to represent the effects of gradual transition on virtual body ownership illusion and spatial presence based on a modified traditional virtual hand experiment. From the results, we found a positive effect of the gradual visual transition from real to virtual with statistical support in both subjective and objective measurements. With the result of this study, we could argue that adopting real-world information could elicit positive human perception and increase dominant illusions compared to the traditional instant transition. Thus, we would recommend the adoption of a Limbo transition stage employing real-world information when researchers or developers design VR environment using virtual agents. As future work, we are extending this study to include a personalized body, with a highly detailed and accurate virtual hand and surround environment, during the transition to the virtual environment. That study will involve an even mix of male and female participants, something we unfortunately did not adequately achieve in the reported study. Gender differences, if they exist, might be more substantial and informative when personal characteristics are accurately captured, modeled and rendered.

Acknowledgments

The material in this paper is based upon work supported in part by the University of Central Florida (UCF) Dissertation Completion Fellowship Program, the UCF TeachLivE Laboratory, and the UCF Synthetic Reality Laboratory. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the University of Central Florida.

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