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Seamless Multi-Modal Transitions between Real and Virtual Environments Using a Physical Door Enhances Presence and User Engagement

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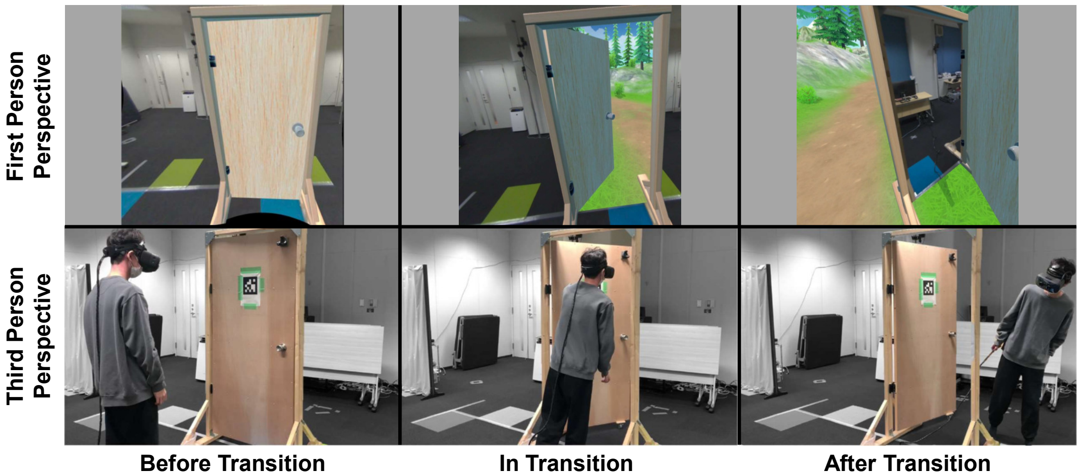

Figure 1: *The proposed system allows users to transition between real and virtual environments through a physical door.*

Abstract

Transition methods that seamlessly connect real environments (REs) and virtual environments (VEs) using head-mounted displays are known to enhance user experiences, particularly the sense of presence. However, transitions relying solely on visual cues often fall short in making the VE feel convincingly real. To address this limitation, we developed a multi-modal transition method that integrates a physical door, combining tactile (e.g., turning a doorknob), and auditory (e.g., hearing a squeaky sound) stimuli with video see-through augmented reality. This approach seamlessly bridges an RE and a VE, offering a richer, more immersive experience. To validate the effectiveness of our method, we constructed a VE allowing users to move between a real office environment and a forest VE. We hypothesized that our multi-modal transition would lead to a greater sense of self-experience, presence, relaxation, and a higher physical movement level than traditional transition methods like portal and fade methods. Our results demonstrated that the total IPQ (Igroup Presence Questionnaire) scores for the proposed method and the portal were significantly higher than those for the fade method. Moreover, users exhibited significantly greater travel distance and speed with our method compared to the fade transition. These findings suggest that our transition method enhances the sense of self-experience and presence and also encourages more physical movement than the portal and fade methods. This study contributes to the understanding of how multi-modal transition methods can effectively enhance user experiences in a VE and create more immersive virtual environments.

CCS Concepts

• ***Human-centered computing*** → *User interface design; Interaction design theory, concepts and paradigms; Mixed / augmented reality;*

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1. Introduction

With advancements in Virtual Reality (VR) and Head-Mounted Displays (HMDs), VR experiences have become increasingly realistic. However, most VR experiences using HMDs involve drastic changes in the visual experience within a short period of time. For example, users typically transition in the following order: real environments (REs), home screens, and then virtual environments (VEs). Initially, the user views the home screen, which is typically artificial and unrelated to either the RE or the VE. Next, the user selects options on the home screen, triggering a fade-out/in (fade) effect as they transition to the VE. Finally, the user engages with content in the VE. Consequently, users experience abrupt visual changes in two stages before fully entering the VE: from the RE to the home screen, and from the home screen to the VE.

The abrupt visual changes can degrade the user experience in VR [VF17, HL19]. These sudden changes make users more likely to recognize that "this is not reality, but merely a VR experience." As a result, it becomes particularly challenging to achieve a strong sense of presence, which is a key aspect of the user experience. Furthermore, this can limit various sensations perceived by users, such as fear or tension, when experiencing VR content.

To address this issue, transition methods that seamlessly connect REs and VEs have proven effective [AGF*]. One commonly used method is a portal, a window-like object that visually represents a transition point. As users pass through this portal, they are transported to a different environment. The portal enhances the sense of presence by requiring user interaction, with active movement serving as the trigger for the transition [HL19]. However, a visual portal alone may not be sufficient to enhance the sense of presence to the level where the VR experience feels truly real. Most transition methods, including portals, primarily rely on visual changes, which may not fully immerse. As a result, these methods might fall short in fully immersing the user. In contrast, the incorporation of multiple sensory modalities in VR experiences is well-known for improving various aspects of user experience, including the sense of presence [CVO].

Therefore, we propose a multi-modal transition system that directly connects REs to VEs through the use of a physical door in Video See-Through Augmented Reality (VST-AR) (see Figure 1). The physical door itself facilitates the multi-modal transition by incorporating two key features:

- It acts as a portal, requiring active user movement to initiate the transition.
- It provides a multi-sensory experience, offering tactile and auditory feedback in addition to visual cues as the door is physically opened and closed.

In this study, we developed a VR system that enables users to move seamlessly between an office RE and a forest VE. We hypothesized that our proposed method would offer a greater sense of self-experience, presence, relaxation, and physical movement compared to traditional methods like the portal and the fade. The experiment confirmed our hypothesis, showing that the proposed method significantly improved the sense of presence and relaxation while also increasing the amount of physical movement. This study contributes to the field by demonstrating the effectiveness of multi-modal transition methods in enhancing the overall user experience.

2. Related Work

2.1. Seamless Transition Between Real and Virtual Environments

Several methods exist for transitioning between VR experiences, AR experiences, and their combination within a single scenario [RHFD, PFKJA, BKP01, OTK*18, VF17, JWH18]. Billinghurst et al. developed the MagicBook transition method [BKP01], one of the earlier explorations in seamless transitions between REs and VEs. In this system, users view a physical book in an RE through a VST-HMD and experience AR content overlaid on the book. The transition occurs as users watch a video where the book appears to move closer, ultimately transporting them into the book's world. In this VE, users experience the first-person perspective of a character within the story. The high interactivity of this system significantly enhances user engagement.

Smooth Immersion is another system that transitions users from a VE simulating an RE to the desired VE [VF17]. However, the results showed no statistically significant differences in the participants' perception of the desired VE. In this system, virtual objects are generated in the simulated RE after the user wears the headset, which might have led participants to perceive the simulated RE as artificially created.

Okeda et al. proposed a transition method using 360-degree images for simulated REs [OTK*18]. When users wear an HMD in an RE, they see a simulated RE through a 360-degree image. This method allows users to smoothly transition from the simulated RE to the desired VE, successfully maintaining the belief that they are still in the RE. However, because a static 360-degree image is used, users cannot walk around or interact with objects in the simulated RE, which prevents them from fully perceiving the desired VE as real.

Limbo introduced a gradual transition from VEs to REs, utilizing VST-AR for simulated REs [JWH18]. Users can observe a gradual transition in real time with VST-AR. This study found that the gradual transition enhanced the sense of presence and body ownership more effectively than an instantaneous transition. However, this method does not support interactions such as touching or walking, limiting its ability to fully immerse users.

Some research focuses on transitioning from VEs back to REs [SMSMV21, HNTORD]. Soret et al. compared three conditions: direct transition using a 360-degree video, transition using a fade, and transition using a semi-transparent virtual door [SMSMV21]. The virtual door, which descends from the top of the VE and is opened by the user with a controller, was found to be superior in terms of user preference and ease of control. The smoothness of the transition and the sense of control, as users open the door and walk through it, contributed to this preference. Additionally, the virtual door transition caused less motion sickness compared to the other methods.

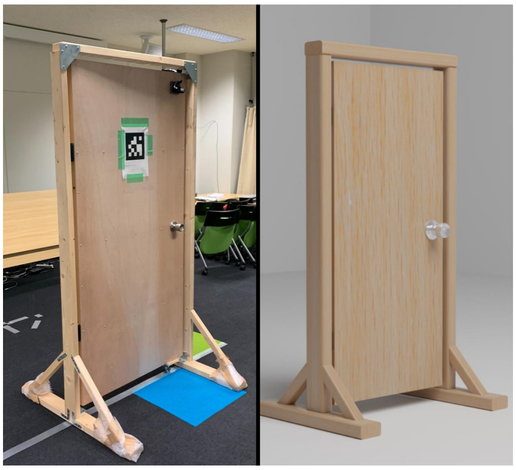

Figure 2: *(Left) Physical door. (Right) Virtual door by 3D model resembles the physical door.*

2.2. Impacts of Transition Methods on the Sense of Presence

Transition methods are effective in enhancing the sense of presence in VEs. Steinicke et al. investigated how the sense of presence in VEs varies depending on the transition methods used from REs [SBH*09]. In their experiment, users experienced flying while seated in a virtual airplane seat within a VE. The transition to the airplane seat was accomplished by using a wormhole as a portal from the VE that mimicked the RE. The results showed a significant increase in the sense of presence when the wormhole transition was used, compared to no transition at all.

Aoki et al. explored the use of a tablet to transition through a virtual door overlaid on an RE, allowing users to experience VR content within the door [ANTH17]. Their findings indicated that the sense of presence in the VE was enhanced when using the virtual door, compared to no transition. This improvement was attributed to AR maintaining the continuity between the RE and the VE, which is a key advantage of AR.

Transitions that involve voluntary movements further enhance the sense of presence. Husung et al. compared six different transition methods, including a portal and an orb, in terms of presence, continuity, and user preference [HL19]. The orb was defined as a transition method where the destination space is displayed inside a sphere, and users transition by gripping the sphere with a controller and bringing it to their head. Their study found that the orb and the portal received the highest ratings. They concluded that interactive transition methods involving voluntary movements, which allow users to anticipate the transition destination, would further enhance the sense of presence.

Hoshikawa et al. investigated the effects of haptic feedback in door handles within the context of redirection and developed a device that simulates a doorknob [HFT*b, HFT*a]. Since their device was intended for redirection, it was designed by isolating the doorknob to avoid the limitations imposed by the rotation angle of a physical door. As a result, although users became more aware of the redirection due to the haptic feedback, an increase in the sense of presence was observed.

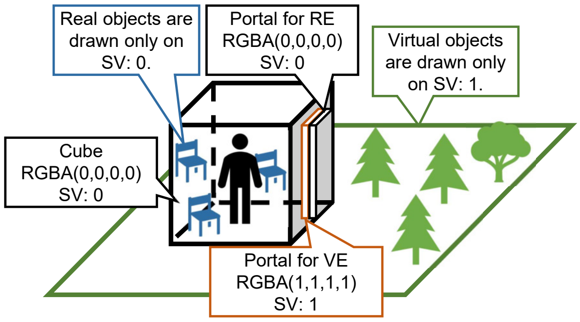

Figure 3: *The state before the transition.*

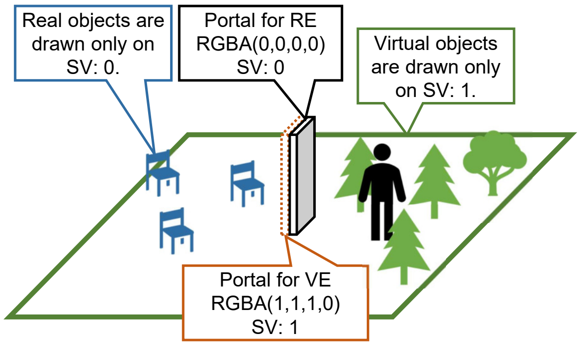

Figure 4: *The state after the transition.*

3. Methods

3.1. Implemention

The requirements for the proposed system are as follows:

1. Use VST-AR to present the RE.
2. Incorporate a physical door.
3. Overlay a 3D model that resembles the physical door and reflect the door's movements.
4. Enable the door to function as a portal for users to pass through.

To fulfill requirement (1), we utilized an HMD (Varjo XR-3) with VST-AR capabilities and the Unity game engine (Unity3D). VST-AR allows real-time display of the RE, including the physical door, as captured by a stereo camera.

For requirement (2), we constructed the physical door as a passive haptic device as shown in Fig. 2 (left). Since it is a genuine wooden door, it can provide multi-modal sensory feedback, such as the scent of the wood, the coldness of the doorknob and the creaking sound of the hinges when opened and closed. The physical door was designed based on the size of a general door (width: about 80 cm, height: about 190 cm).

To fulfill requirement (3), we created a 3D model of the physical door using Blender (Blender Foundation), as shown in Fig. 2 (right). An AR marker (Varjo Marker, Varjo Technologies) was used to calibrate the position of the virtual door relative to the physical door. By placing the AR marker on the physical door and capturing it with a stereo camera, we could accurately overlay the virtual onto the physical door. However, using the AR marker to track the door's rotation proved challenging. As it would require users

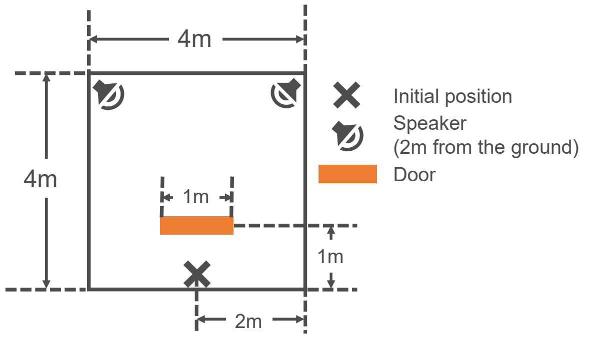

Figure 5: *Schematic diagram.*

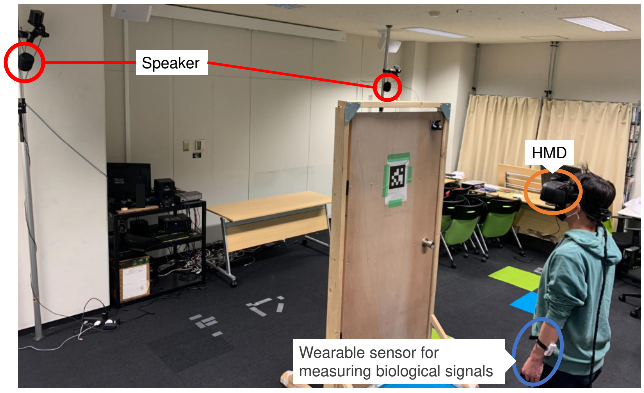

Figure 6: *Scene in the proposed method.*

to keep the marker in view while passing through the door, which is impractical. Therefore, a VIVE tracker was used to monitor the door's rotation angle. The VIVE tracker continuously tracked the opening and closing movements of the physical door. This data was reflected in the virtual door to ensure accurate synchronization between the physical and virtual environments.

To satisfy requirement (4), we employed a stencil buffer (SV) for rendering. The initial state of the portal for drawing the door is shown in Fig. 4. The rendering protocol was as follows:

1. Draw a portal on the surface of the virtual door to allow the user to see virtual objects from the RE, with an RGBA value of $(1,1,1,1)$ and SV = 1.
2. Draw a portal on the back of the physical door to allow the user to see real objects from the VE, with an RGBA value of $(0,0,0,0)$ and SV = 0.
3. Draw a cube surrounding the user for VST-AR, only on pixels with SV $\neq$ 1, with an RGBA value of $(0,0,0,0)$.
4. Draw the virtual objects only on pixels with SV = 1.
5. When crossing the portal from the RE, disable the cube rendering and draw the virtual objects regardless of SV.
6. When crossing the portal from the VE, return to the initial state.

3.2. Experimental Design

We conducted a user study to evaluate the effectiveness of the proposed method by having participants transition from a real office environment to a forest VR environment. Participants experienced the transition using three different methods: our proposed method (door), the portal, and the fade transition. The key user experience metrics evaluated were the sense of self-experience, sense of presence, relaxation, travel distance, and travel speed. The independent variables in this study were the transition conditions, while the dependent variables were the user experience metrics. We hypothesized that these user experience metrics would be higher when using the door method compared to the portal and fade methods. This study employed a within-subjects design.

The sense of presence was assessed using the Igroup Presence Questionnaire (IPQ) [RS02]. The IPQ includes four indices: General (G), Spatial Presence (SP), Involvement (Inv), and Realism (Real). Participants responded to a seven-point Likert scale questionnaire for each index. The specific questions are listed in Table 1.

Changes in skin conductance were used to evaluate the effect of relaxation [Fuk18]. Lower skin conductance values indicate relaxation, while higher values indicate tension or excitement. To induce significant changes in stress before and after the transition, two methods were employed. First, participants completed a calculation task based on the Trier Social Stress Test [AKD*17], where they were asked to subtract two-digit numbers from four-digit numbers for five minutes. Second, the VE was designed to replicate nature, as previous studies have shown that natural VR experiences can induce relaxation effects [jJSM19].

The travel distance and speed were evaluated using the position information from the HMD. The travel distance is defined as the total distance covered from the start to the end of the experience. The speed is calculated as the average speed from the start to the end of the experience.

3.3. Environments

The schematic diagram of the experimental environment is shown in Fig. 5. The experimental space measured approximately 4 m × 4 m, with the virtual door and portal positioned 1 m in front of the starting point of the experiment. The VE included trees and other objects similar to those in a real forest to help users feel connected to nature. To reduce any sense of incongruity with the VR content, two wireless speakers were used to play sounds of wind and birds chirping. The speakers were placed 3 m in front of the physical door, 4 m apart, and 2 m above the floor, as shown in Fig. 5. Additionally, participants wore a wearable sensor (Shimmer technology Shimmer3 GSR+ Unit) capable of measuring skin conductance to verify the relaxation effect. The appearance of a participant during the experiment is shown in Fig. 6.

3.4. Conditions

Three conditions were set in this experiment: the door, portal, and fade (see Fig. 7). In the door condition, participants used VST-AR to pass through the physical door and transition from the RE and VE. In the portal condition, participants used VST-AR to transition from the RE to the VE, with the portal positioned in the same location as the physical door in the door condition. In the fade condition, participants transitioned from the home screen to the forest VE. This condition involved a common transition process in VR,

Table 1: *Questionnaire*

Q1.	Did you feel in control of the transition?
Q2.	Did you feel that the transition was smooth?
Q3.	Did the pre-transition environment feel realistic?
Q4.	Did you feel as though you actually reached the desired transition?
Q5.	Did the VE feel like an extension of the RE?
Q6.	Did you perceive a boundary between the VE and RE?
Q7.	Were you able to concentrate on this experiment?
Q8.	Did you find this transition method favorable?
Q9.	After returning to the RE, did you still feel like you were in the VE?
Q10.	After returning to the RE, did you still feel like you were walking in the forest?
Q11.	Did you feel a sense of calm as if you were in the forest?

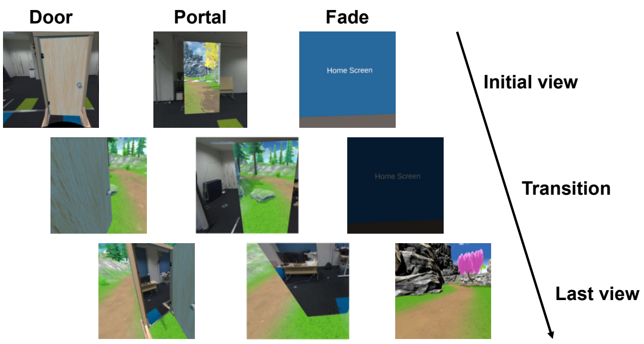

Figure 7: *Conditions.*

where the screen gradually darkens from the home screen before switching to the VE. Only in the fade condition, participants used the VIVE controller, initiating the transition by pressing the trigger button.

In all conditions, the timing of phases was controlled as follows:

- A familiarization experience was conducted for one minute.
- The pre-transition experience began 30 seconds after the start, prompting the transition.
- The post-transition experience ended one minute after the transition was completed.

3.5. Procedure

Each participant completed the task by following these nine steps. The order of the transition conditions was counterbalanced using a Latin square method.

1. Attached the HMD and wearable sensors, then familiarized themselves with the VR experience (one minute).
2. Performed the calculation task (five minutes).
3. Experienced the pre-transition phase (30 seconds).
4. Experienced the transition (duration not specified).
5. Experienced the post-transition phase (one minute).

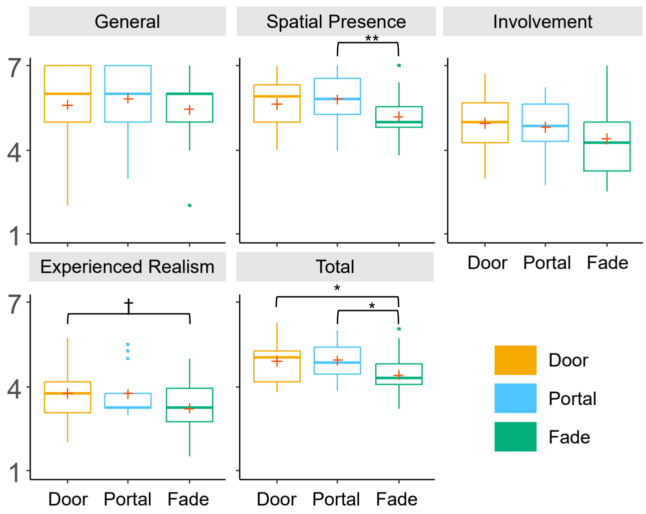

Figure 8: *Igroup Presence Questionnaire ($n = 18$). $\dagger : p < 0.1$, $* : p < 0.05$, $** : p < 0.01$.*

6. Completed the questionnaire.
7. Detached the devices and took a break (three minutes).
8. Repeated steps two through seven for each transition condition.
9. Completed the summary questionnaire.

3.5.1. Participants & Configurations

Eighteen graduate students, aged 23 to 26 years (11 males, seven females), participated in the experiment. All participants signed a consent form after receiving a full explanation of the study and agreeing to participate. The experiment was approved by the institutional review board at the first author's institution.

4. Results

Statistical analysis was performed using R software [R C23]. Paired t-tests were conducted for the IPQ, skin conductance, travel distance, and speed. For the other questionnaire results, Wilcoxon signed-rank tests were performed. Since both tests involve comparisons across three conditions, the Holm correction was applied. The significance level was set at $\alpha = 0.05$.

4.1. Questionnaire

The results of the IPQ are shown in Fig. 8. A paired t test with Holm correction revealed a significant difference ($t(17) = 3.56$, $p = 0.007$, $Cohen's\ d = 0.84$) in the SP of the IPQ between the portal ($M = 5.81$, $SD = 0.78$) and the fade ($M = 5.19$, $SD = 0.82$) conditions. However, no significant differences were observed between the door and the portal ($t(17) = 0.82$, $p = 0.424$), or between the door and the fade ($t(17) = 2.00$, $p = 0.124$).

In the Total score, significant differences ($t(17) = 2.70$, $p = 0.031$, $Cohen's\ d = 0.64$) were found between the door ($M = 4.91$, $SD = 0.74$) and the fade ($M = 4.42$, $SD = 0.76$), as well as between the portal ($M = 4.93$, $SD = 0.60$) and the fade ($t(17) = 3.25$, $p = 0.014$, $Cohen's\ d = 0.76$). For the Real score, a significant difference ($t(17) = 2.51$, $p = 0.068$, $Cohen's\ d = 0.59$) was observed between the door ($M = 3.76$, $SD = 1.10$) and the fade ($M = 3.22$, $SD = 0.90$). However, no significant differences were observed between the portal and the fade ($t(17) = 2.10$, $p = 0.102$) or between the door and the portal ($t(17) = 0.16$, $p = 0.873$).

The results for the other questionnaire items are shown in Fig. 9. For Q1, which assessed control, significant differences were found between the door and the fade conditions ($Z = 2.59$, $p = 0.015$, $r = 0.78$), as well as between the portal and the fade conditions ($Z = 2.95$, $p = 0.006$, $r = 0.91$). No significant difference was observed between the door and the portal ($Z = 0.23$, $p = 0.960$).

For Q2, which assessed smoothness, significant differences were observed only between the portal and the fade ($Z = 2.72$, $p = 0.016$, $r = 0.85$). No significant differences were found between the door and the portal ($Z = 1.15$, $p = 0.296$), and between the door and the fade ($Z = 1.70$, $p = 0.193$).

For Q3, which assessed the perception of the VE, significant differences were confirmed between the door and the fade ($Z = 3.04$, $p = 0.003$, $r = 0.88$) and between the portal and the fade ($Z = 3.32$, $p < 0.001$, $r = 1.00$). No significant difference was observed between the door and the portal ($Z = 0.58$, $p = 0.643$).

For Q4, which assessed the feeling of actually visiting the VE, a significant difference was observed only between the door and the fade ($Z = 2.31$, $p = 0.067$, $r = 0.71$). No significant difference was found between the door and the portal ($Z = 0$, $p = 1.00$), and between the portal and the fade ($Z = 1.94$, $p = 0.115$).

For Q5, which assessed whether the VE felt like a part of the RE, significant differences were found between the door and the fade ($Z = 3.22$, $p = 0.001$, $r = 0.93$) and between the portal and the fade ($Z = 3.00$, $p = 0.003$, $r = 0.93$). No significant difference was observed between the door and the portal ($Z = 0.73$, $p = 0.534$).

For Q8, which assessed preference, significant differences were found between each pair of methods, in descending order: the door vs. the portal ($Z = 2.46$, $p = 0.015$, $r = 0.67$), the door vs. the fade ($Z = 3.17$, $p = 0.002$, $r = 0.85$), and the portal vs. the fade ($Z = 2.95$, $p = 0.005$, $r = 0.85$).

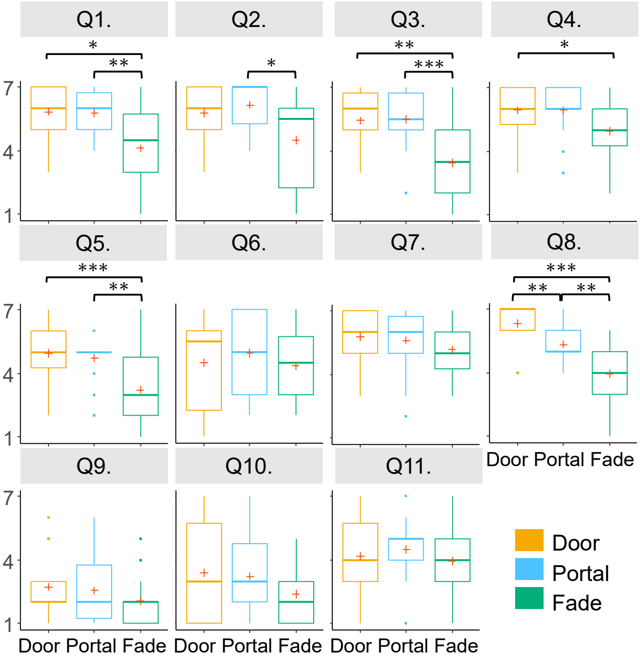

Figure 9: *Specific questionnaire on experiences and transitions ($n = 18$).* $*: p < 0.05$, $**: p < 0.01$, $***: p < 0.001$.

For the other questions, no significant differences were observed.

4.2. Skin Conductance

The changes in skin conductance are shown in Fig. 10. The skin conductance data for each participant was processed using a low-pass filter with a cut-off frequency of 5 Hz to remove motion-related artifacts. The baseline values of skin conductance were taken during the calculation task. The skin conductance values after baseline correction were obtained by subtracting the average baseline values from the average values recorded after each transition. As a result, no significant differences were found between conditions: the door ($M = 0$, $SD = 1.14$) vs. the portal ($t(17) = 1.13$, $p = 0.549$), the fade ($M = 0$, $SD = 1.14$) vs. the door ($t(17) = 2.32$, $p = 0.100$), the portal ($M = 0.09$, $SD = 0.85$) vs. the fade ($t(17) = 0.27$, $p = 0.790$). However, more than half of the participants showed an increase in skin conductance in each condition compared to the baseline values taken during the calculation task.

The skin conductance of a representative participant in the door condition is shown in Fig. 11. It can be seen that the skin conductance increased during the VR experience. The other participants also showed an increase in skin conductance during the VR experience.

4.3. Travel Distance and Speed

The total travel distance and the average travel speed are shown in Fig. 12, 13. Significant differences in the travel distances were observed between each combination of the door ($M = 15.3$, $SD = 6.39$), the portal ($M = 11.4$, $SD = 4.57$), and the fade ($M = 9.86$, $SD = 4.52$). The differences, in descending order, were as follows:

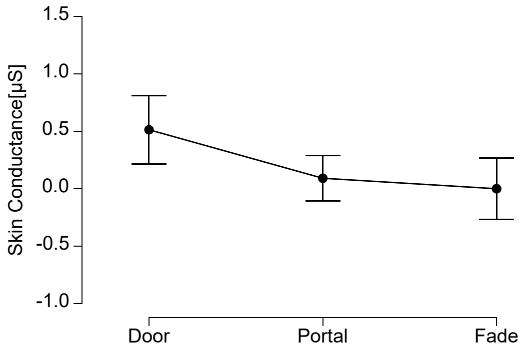

Figure 10: *Skin conductance. Difference between the calculation task and in the VE after each transition ($n = 18$). Representative values indicate the means and error bars indicate the standard error (SE).*

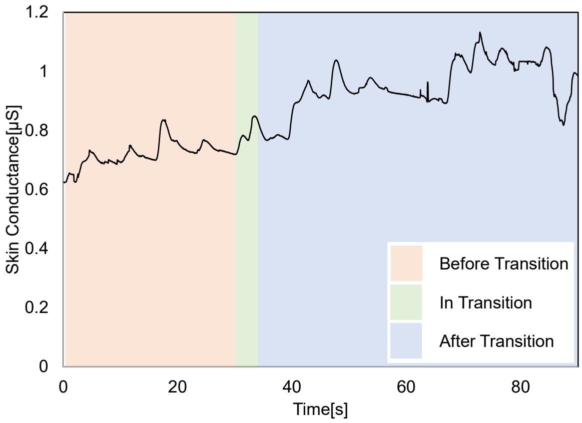

Figure 11: *Change in skin conductance in transition status under the door condition in a specific participant.*

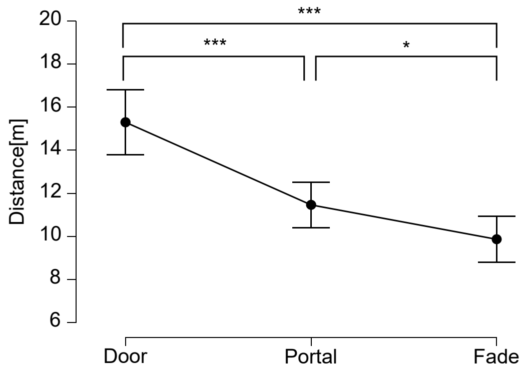

Figure 12: *Total of travel distance in the VE ($n = 18$). Representative values indicate the means and error bars indicate the SE.* $* : p < 0.05$, $*** : p < 0.001$

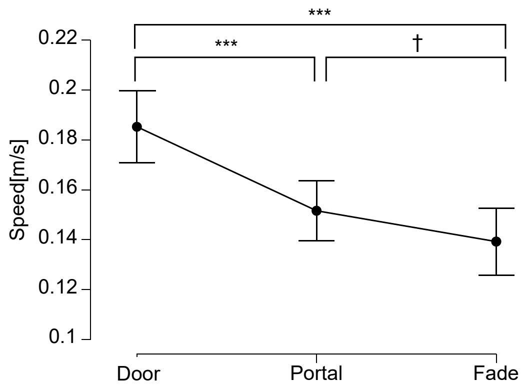

Figure 13: *Total of travel speed in the VE ($n = 18$). Representative values indicate the means and error bars indicate the SE.* $\dagger : p < 0.1$, $*** : p < 0.001$

the door vs. the portal ($t(17) = 5.44$, $p < 0.001$, $Cohen's\ d = 1.28$), the door vs. the fade ($t(17) = 7.38$, $p < 0.001$, $Cohen's\ d = 1.74$), and the portal vs. the fade ($t(17) = 2.34$, $p = 0.032$, $Cohen's\ d = 0.55$).

Similarly, significant differences in travel speeds were found between each combination of the door ($M = 0.19$, $SD = 0.06$), the portal ($M = 0.15$, $SD = 0.05$), and the fade ($M = 0.14$, $SD = 0.06$). The differences, in descending order, were as follows: the door vs. the portal ($t(17) = 7.90$, $p < 0.001$, $Cohen's\ d = 1.86$), the door vs. the fade ($t(17) = 5.60$, $p < 0.001$, $Cohen's\ d = 1.32$), and the portal vs. the fade ($t(17) = 1.78$, $p = 0.093$, $Cohen's\ d = 0.42$).

5. Discussion

5.1. Sense of Self-Experience and Presence as the Questionnaire

No significant differences were found between the door and the portal across all the IPQ indices. However, the significant difference observed between the portal and the fade in the SP index may be attributed to the portal's ability to allow easier observation between the RE and the VE, making it feel more connected to both environments. This may have helped maintain the sense of being in the RE within the VE.

For the Real index, the significant difference between the door and the fade may be due to the door's placement, spanning both the RE and the VE, which allowed participants to interact with the same door in the same way in both environments.

For the Total index, significant differences were confirmed both between the door and the portal, and between the portal and the fade. This suggests that VST-AR enables a transition from the RE to the VE that feels closer to the RE than conventional methods [VF17, OTK*18].

For Q1, which assessed control, significant differences were found between the door, the portal, and the fade, confirming the effectiveness of transitions involving voluntary movements. For Q2, which assessed smoothness, a significant difference was confirmed between the portal and the fade, indicating that the portal system provides a smoother transition experience than the fade. However, no significant differences were found between the door and the fade, possibly due to discomfort with the behavior of the virtual door, as some participants reported. For Q3, which assessed the perception of the VE, both the door and the portal showed significant differences compared to the fade, indicating that VST-AR can make the pre-transition environment feel like an RE. For Q4, which assessed the feeling of actually visiting the VE, the significant difference between the door and the fade may be attributed to the interactivity of the physical door. The process of touching, pushing open, and passing through the physical door likely contributed to a stronger sense of having reached the transition destination.

For Q5, which assessed whether the VE felt like a part of the RE, the significant difference observed between the door and the fade may be due to the tactile interaction with the physical door, making the RE feel like an extension of the VE. The portal also showed a significant difference compared to the fade, indicating that using the portal system from the RE makes the VE feel like a part of the RE. For Q6, which assessed the boundary between the RE and the VE, no significant differences were found. This is the opposite of Q5, and it is assumed that participants accepted the VE as a part of the RE, leading to no significant difference. For Q7, which assessed focus on the VE, no significant differences were observed either. It is possible that the participants felt that the VE was a part of the RE, which may have reduced their focus on the VE.

For Q8, which assessed preference, the door received the highest ratings. Participants' comments obtained for the door included: "The transition made me strongly aware of going to the virtual world," "I felt the boundary with the real world more strongly because of the door," and "I felt as if reality was extended when accompanied by actions I normally do in my daily life." These factors likely contributed to its high ratings.

The results of the IPQ and specific questions Q4 and Q5 showed significant differences between the door and the portal compared to the fade. Participants' comments indicate that the door achieved high interactivity, suggesting that the proposed method provides a strong sense of self-experience and presence.

5.2. Relaxation Effect as the Skin Conductance

No significant differences were found in skin conductance across the conditions. This suggests that the transition method did not significantly affect the relaxation effect in the VR forest. However, many participants showed an increase in skin conductance compared to its baseline value, indicating that they might have been excited by the VR experience itself.

5.3. Travel Distance and Speed

Significant differences were found between the door, the portal, and the fade in terms of total travel distance and average travel speed. In particular, the door showed significant differences compared to both the portal and the fade. Some participants mentioned that they were interested in the physical door and walked around it, contributing to this result. This suggests that the door effectively increases user engagement in the VE. Additionally, the presence of the physical door may have made it easier for participants to gauge distances in the VE, allowing them to move freely without fear of colliding with walls or desks. In contrast, in the fade condition, participants may have been more cautious about moving, as they could not see the RE and were concentrated about potential collisions.

6. Conclusion

In this study, we developed a multi-modal transition method that connects the RE and the VE using VST-AR and a physical door. Our approach addresses the problem of drastic visual changes between the REs and VEs. The results of the user study demonstrated that the total IPQ and Spatial Presence (SP) values for the proposed method were significantly higher than those for the conventional fade method. Furthermore, the travel distance and speed associated with the proposed method were significantly greater than those observed with the portal and fade methods. These findings suggest that the proposed method provides a higher sense of self-experience and presence, as well as increased movement and speed, compared to the fade method. This study contributes to the field by demonstrating the effectiveness of multi-modal transition methods in enhancing the overall user experience.

This method relies on the use of a physical door as a key component, but there are several limitations to its effectiveness. First, it remains unclear which aspects of the stimuli provided by the door contribute most to enhancing the user experience. Even a door that only resembles a real one without allowing active opening and closing might have produced sufficient effects. In addition, the presence of other users sharing the space [WTYC], or the imposition of a clear task [FBWZ], may lead to different results. Next, we did not investigate how much each sensory modality—such as touch and sound—individually contributes to the user experience. Understanding the individual influence of each modality is important for improving the overall transition method using a physical door. Lastly, since the door is a physical installation, VR content must be designed around the device, creating a spatial constraint. An approach like that of Hoshikawa et al. could partially solve this limitation [HFT*a].

In the future, we plan to implement additional techniques to further enhance user experience. For example, rendering visual effects around the door related to the VE may help users remember their destination. Moreover, providing multi-modal stimulation through the door, such as auditory cues, vibrations, or thermal feedback, could further immerse users and reinforce the perception of the VE. Furthermore, we expect that the proposed method will be particularly effective for transitioning to environments that closely resemble REs, such as 360-degree images of tourist destinations. Conversely, we would also like to investigate the extent to which the proposed method can make science fiction virtual environments, which are far removed from reality, feel more realistic to users.

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