Keep it simple? Evaluation of Transitions in Virtual Reality

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Figure 1: Some applications require switching between multiple environments. Here the user is using a *Portal* transition and is about to walk through the portal leading to the new environment (in the evaluation, a wireless headset was used).

ABSTRACT

The impact of different transitions between two virtual reality (VR) environments is still an open research question, and related work often serves only an isolated view on different techniques, i.e., with low ecological validity. The purpose of this study was to start closing this gap and evaluate the impact of six transitions while the user is solving a task that keeps them engaged. Therefore, we first propose a suitable and reproducible task design. Then we evaluate the six transitions in a user study. The results show that in contrast to prior work, the users preferred a short and efficient transition against a transition that was designed to achieve higher interactivity and continuity but was perceived as more cumbersome to use.

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CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; *Empirical studies in HCI*; Usability testing.

KEYWORDS

virtual reality, cross reality, transitions, task load, usability, task performance

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1 INTRODUCTION

One key aspect of virtual reality (VR) experiences is the transition between virtual environments. These transitions can range from diegetic, i.e., seamlessly fitting into an experience, to disruptive, i.e., being abrupt or strange, and potentially breaking the experience. The concept of transitions is well known and used by writers and filmmakers to provide continuity to the experience or break the continuity on purpose to underline a change of context. A common transition in VR is, for example, a portal where a user can see into the targeted environment and physically walk through the portal to reach the destination [6, 14]. To see how transitions benefit the overall user experience in various settings few studies were conducted. In these studies, the transitions are usually investigated in isolation without being embedded into an application or task. While many VR applications do not require direct interaction by the user, e.g., a virtual museum [23], still the transition is not the focus but a tool. Therefore, we want to evaluate if the findings of prior work do also apply when instead, the user is focused on something else, for instance, solving a task. The latter could be negatively influenced by a transition that draws attention or requires more engagement by the user. To research this, we first propose a task design that keeps the user engaged and isolates key performance measures. In this task, the user has to solve a cross-environment memory game, requiring frequent transitions between both environments. Then we apply this design in an exploratory user study to investigate potential effects on usability, preference, and task performance.

2 RELATED WORK

The concept of a transition between multiple virtual environments was introduced by Billinghurst et al. in 2001 [1], where users could read a Magic Book in augmented reality (AR) and then transition into the described book scene in VR. In 2011 Grasset et al. [8] conceptualized the transition interface in a multi-user environment to the "Transitional collaborative model". In this model, they separate a transition into three phases: the initiation, the transition, and the end phase. The transition starts with an initiation phase triggered by the user (e.g., a button press) or the system. Then the user is in the transition phase, a restricted mode where the view "moves" to the other environment. The last phase is the end phase, where the user reaches the target environment and can freely move and interact with the new environment.

Horst et al. [10] defined an outro-transition as a transition that guides the user from VR back to reality by removing the head-mounted display. They investigated eight transitions and how they are suitable as outro-transitions when initiated by the user or a presenter. Like Grasset et al. [8], they defined the three phases of a transition *Initiation*, *Interlude*, and *Exit*, with the extension that the *Interlude* can be optional, as some transitions may be instant. They found that the participants favored a short transition with little disturbance during usage. Two transitions were not favored, as their high interactivity was perceived as *"complicated"* and *"impractical"* by the participants. These transitions involved performing a wipe gesture or playing a minigame to perform the transition.

To evaluate which transition could be used in a VR experience, Husung & Langbehn [11] evaluated six different transitions. Each transition was inspired by transitions in film-making or existing VR experiences. In their study, the participants tried each transition across various environments and reported subjective measures like usability, preference, presence, or continuity. They found that the participants preferred transitions with higher continuity and presence. However, the participants were not assigned any task, so their results may lack ecological validity.

A similar study was performed by Pointecker et al. [17], who evaluated four transitions in terms of user experience, continuity, and simulator sickness between a VR and an AR environment and concluded a few design recommendations for transitions. The participants were assigned a task in their evaluation, but it was only there to give the user a reason to transition.

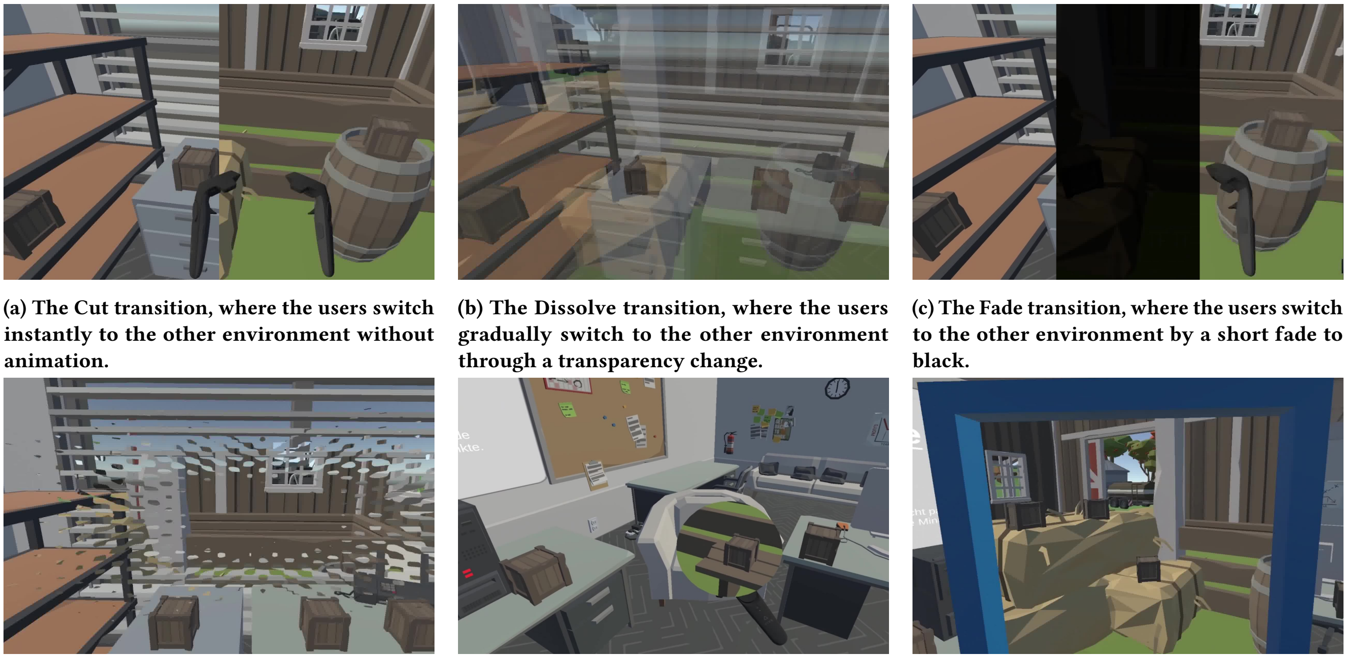
To investigate whether two different environments affect memory, Shin et al. [19] conducted a user study in which the participants started in one environment and were assigned a memory task. The participants were divided into four groups. The memory of the first group was instantly tested in the same environment, and the memory of the second group was tested 24h later in the same environment. Respectively, the third and fourth groups were tested instantly/after 24h in the other environment. They concluded that recalling was more efficient when done immediately after the memorization and if done in the same environment. While they did not evaluate different transitions, their task design seemed externally valid for experiences with multiple, different environments.

This prior work shows various transitions present in related work, but they were not embedded in a challenging task. Therefore, we want to evaluate the existing transitions with a task designed to keep the user engaged.

3 SELECTED TRANSITIONS

For this work, we re-implemented transitions from related work [11]. They consist of common transition designs from film-making, e.g., *Cut* [5] and *Dissolve* [5] and from existing VR applications, e.g., *Portal* [6, 14, 16, 17] and *Orb* [4, 7, 22]. In the following, we briefly describe each transition, its implementation, and potential benefits. Their final implementation is hinted at in Figure 2.

Cut: When the transition is initiated, the user teleports instantly to the target environment without visual or audio effects. Therefore, there is no noticeable transition phase for the user. According to Husung & Langbehn [11] this transition seems to break the continuity of the experience and was rated negatively by most participants. Based on these findings Pointecker et al. [17] even excluded *Cut* from their evaluation, as they were only interested in transitions that keep continuity. However, to see if this is still valid when the user is engaged in a task and does not purely focus on the transitions, we include this transition for our evaluation. **Dissolve:** After the initiation, the current environment dissolves into the target environment in the transition phase by blending the other environment over the current environment via transparency over 1.3*s*. This transition is inspired by film-making as it can bridge two environments and times [12], tending to be a better option than *Cut* in terms of continuity. **Fade:** With this transition, the screen fades to black, the user gets teleported to the other environment without noticing it, and the screen fades back to normal vision with a total duration of 1.3*s*. This transition is commonly used in films and VR experiences to separate two environments or storylines. **Morph:** An animated chequered mask blends the new environment over the current environment over 1.3*s*. Husung & Langbehn [11] called this transition "Transformation" and chose this transition as it uses VR-specific features and was inspired by the VR fun-house game [21]. **Portal:** In the initiation phase (see Section 2), the user can place a portal in the current environment and see the other environment through the portal [6, 14]. The user can now transition simply by walking through the portal, which closes behind



(a) The Cut transition, where the users switch instantly to the other environment without animation.

(b) The Dissolve transition, where the users gradually switch to the other environment through a transparency change.

(c) The Fade transition, where the users switch to the other environment by a short fade to black.

(d) The Morph transition, where the users switch to the other environment by an animated morphing effect around the user.

(e) With the Orb transition, the user can transition by moving an orb to their head with their controllers.

(f) With the Portal transition, the user can spawn a portal and walk through it to transition to the other environment.

Figure 2: The six selected transitions for this evaluation. They are re-implementations of the work by Husung & Langbehn [11].

the user. The *Portal* transition requires the most interactivity and movement of all transitions, resulting in a high user rating in prior [11] evaluation. Because a few participants stated in their study that they were afraid to stumble when walking through the oval-shaped portal, we changed the shape of the portal to rectangular. Further, we always place the portal in the center of the environment facing the user to allow for real walking locomotion in both environments.
Orb: A floating orb is spawned on initiation, which displays a preview of the other environment. By moving the orb closer to their face, the user transitions to the over environment. This transition was mainly inspired by the game Budget Cut [3] and offers high interactivity but less movement than *Portal.* The *Orb* received the highest user rating in the study from Husung & Langbehn [11]. In contrast to their implementation, we do not place the orb in the environment, but the user could spawn it via a button press, hovering over one of the controllers at any time. This makes the transition initiation independent of the user's current position.

4 MEMORY TASK

To investigate the transitions while the user is engaged in a task, we need to design a task that impacts the user's mental capacity, overarcs multiple contexts and requires the user to transition between two environments. To design such a task, we were inspired by Shin et al. [19] to implement a memory game in which the player must find two identical objects hidden under a set of boxes each turn and is only allowed to open two boxes at the same time. We place the boxes evenly across both environments to force the user to transition to another environment. Furthermore, we mimic a potential use case of these transitions in terms of transition frequency. For example, in an immersive analytic use case [17], the user spends roughly the same time in each environment and transitions now and then rather than often transitioning over a short period. We introduce two categories an object can fall into, to achieve this.

If an object is in the *Environment category*, its appearance corresponds with the environment in which it is hidden. For example, if the environment is an office, an object in this category could be a chair, a desk lamp, or a cup. The counterpart of an object in this category is also hidden under a box in the same environment. Therefore, if a user reveals an object of this category, they are told and know that the counterpart is hidden in the same environment, and no transition is needed. If there are two environments, it means two sets of objects are in the *Environment category*, one for each environment. If an object is in the *Cross category*, its appearance corresponds to no particular environment but is coherent with the other objects in the category. For example, suppose there is a farm environment and an office environment. In that case, the appearance of the objects in this category may be pirate-related objects, like a compass, a skull, or a treasure map. These objects are also hidden under boxes in the environments, but their counterpart is always hidden in another environment. Thus, if the user reveals an object of this category, they must transition to the other environment to find the counterpart. With this category, the memory game is not entirely separated between the environments, and a transition that helps create a mental bridge between the environments may help the user. To prevent the user from ignoring the objects of the *Cross category* until all pairs in the *Environment category* are found, we force the user to transition once an object of the *Cross category* is revealed as the first object in a turn by preventing other boxes in the current environment to be opened. Apart from this limitation, the user can transition to another environment at any time.

A simple gamification element is applied, where the user gained points for found pairs and lost points in case of a mismatch against better knowledge. This element is introduced to prevent simple try & error approaches and motivate the user to remember the objects correctly, thus, increasing the task difficulty and potential effects of the transitions on task performance and task load. We suggest using such a gamification element rather than applying time pressure to increase difficulty. as this could push the users to try & error approaches instead of using their memory. To minimize the effect of the user's random selection of the boxes, the object hidden under each box is defined when the user first opened it, keeping the order of discovery the same for each user.

To evaluate the objective measures, we also define two phases the user can be in while solving the memory game. When no pair is known to the user, they are in the so-called *Exploration Phase* (EP). While in the EP, the user is gathering information about the memory. Thus, some measures of the task performance, e.g., error rate, are not recorded. However, if needed, some measures on how the user is gathering the information, e.g., the order of boxes opened, could be recorded here, but this is not part of our evaluation. If the user knows at least one pair, the user is in the *Searching Phase* (SP). In the SP, we assume that the user is currently trying to find the known pair using their memory. In this phase, we record task performance in the form of an error rate but not any measurements about how the user gathers information about the memory.

5 EVALUATION

We used a 1x6 within-subject study design, the one factor being the transition method. After a short introduction, each participant signed a consent form and answered a few demographic questions. Then they were introduced to the VR hardware and assigned their first condition. The conditions were balanced using Latin-square. The participants were shown a short video introducing the memory task in the first assigned condition. Further, a short clip was shown in each condition, describing the current transition. Then the participants had a short trial phase. In the first condition, the participants had to find one pair of the *Cross category* (see Section 4) to get familiar with the memory task. In the following conditions, they were only asked to use the current transition four times, as they were already familiar with the memory task. The experimenter then started a new memory game when the participants had no further questions The participants were reminded that there was no time pressure and were asked to solve one complete memory as the main task. After finishing the memory task, the participants completed questionnaires regarding the currently used transition. Then the next condition was started with the trial phase. After the participants finished all six conditions, they completed a final questionnaire. The whole procedure took around 90 minutes per participant and was approved by the ethics council of our institution.

(a) The office environment

(b) The farm environment

Figure 3: Overview of both environments the user was in to solve the memory game, and between they could freely transition. Under the brown boxes, the different objects were hidden.

24 Participants took part in the study and received 10€ each for participating. Their age ranged from 20 to 41 years with $M = 25.71, SD = 4.667$. 8 (33.3%) participants identified as female, 15 (62.5%) as male, and 1 (4.2%) as diverse. 18 (75%) stated to have prior experience with VR and 14 (58.3%) with 3D video games. 2 (8.3%) participants stated to be left-handed.

5.1 Apparatus & Virtual Environment

The study took place in an empty room with a desk and seat for the participant to answer the questionnaires on a laptop. For conducting the actual task, we provided a play space of $\sim 4m$x$4m$. In this study, we designed two environments to fit entirely in the play space. The first environment was a farm with objects of the *Environment category*, like a box of apples, a wheelbarrow, and a pumpkin. The second environment was an office with objects of the *Environment category*, like a desk lamp, a chair, or a folder. As objects for the *Cross category*, we chose a variety of pirate-related objects like a skull, a compass, or a treasure map. Six objects of the *Environment category* and four of the *Cross category* were hidden in each environment. This results in ten boxes per environment and ten pairs in total. We placed the boxes in a way that they were evenly placed in a radius of $\sim 1.5m$. Figure 3 shows both of the environments used in the study, along with the boxes. We used an HTC Vive Pro with the wireless adapter and the standard HTC VIVE controllers. The study was implemented with Unity 2021.3 and XR Interaction Toolkit 2.0.4. For the environments and the objects, we used assets from Synty Studios[1].

5.2 Measures

As subjective measures, we used the SUS questionnaire [2] to measure **usability**, the Flow Short Scale (FSS) [18] for **flow**, the technique-related presence questions from Husung & Langbehn [11] for **presence** and the NASA-TLX [9] for **task load**. Flow describes the effortless absorption in activities, where the subject is highly motivated by and committed to their task without obvious external rewards [15]. We measured flow instead of continuity, as continuity considers the transitions in isolation and not embedded in a task. In contrast, flow takes the concept of continuity and embeds it into a task scenario. Further, we asked the participant to rate each transition right after the corresponding condition, state their most and least liked transition in the final questionnaire, and leave comments on what they did or did not like. We used the Fast Motion Sickness Scale (FMS) [13] to control for induced simulator sickness.

As objective measures, we recorded the task performance in the form of the **error rate**. The error rate is the ratio of turns where the user failed to find the correct pair against better knowledge of all turns where they previously uncovered the correct locations of the pair. As suggested in Section 4, the error rate was only measured while the participant was in the SP.

5.3 Analysis

We perform an exploratory analysis of the measures that were collected. Therefore, we use a one-way ANOVA with repeated measures to identify the potential effects of the transitions on the measures. If the measures are ordinal, the non-parametric Friedman test is used instead of an ANOVA. If an ANOVA or a Friedman test is significant ($p <= 0.05$), pairwise t-tests or Wilcoxon tests with Bonferroni corrections are applied as post hoc tests. This section only reports the significant p-values for the post hoc tests. Please refer to the supplemental material for a detailed report of the post hoc tests. Figure 4 shows the descriptive statistics of our results.

The Friedman test for the SUS-Score shows a significant difference among all six conditions with $\chi^2(5) = 23.152, p < 0.001, n = 24$. The follow-up pairwise comparisons reveal that *Cut* (M=91.7 SD=19.59) & *Orb* (M=65.3 SD=25.78) with $p < 0.001$ and *Cut* (M=91.7 SD=19.59) & *Portal* (M=77.1 SD=20.37) with $p = 0.018$ were significant. Further, the Friedman test for the FSS-Score is significant with $\chi^2(5) = 12.618, p < 0.027, n = 24$, but with no significant post hoc tests. For the preference, the Friedman test also yields a significant difference with $\chi^2(5) = 14.184, p < 0.014, n = 24$, and a significant post hoc test for *Cut* (M=8.2 SD=1.52) & *Orb* (M=5.9 SD=2.19) with $p = 0.027$. However, the Friedman test for the NASA-TLX results in no significant difference among the six conditions with $\chi^2(5) = 6.998, p = 0.221, n = 24$; thus, no post hoc tests are applied. For presence, the results are again significantly different with $\chi^2(5) = 20.682, p < 0.001, n = 24$ and the post hoc test for *Cut* (M=5.02 SD=1.40) & *Dissolve* (M=3.73 SD=1.47) with $p = 0.018$, *Cut* (M=5.02 SD=1.40) & *Fade* (M=3.85 SD=1.26) with $p = 0.045$ and *Cut* (M=5.02 SD=1.47) & *Orb* (M=3.38 SD=1.53) with $p = 0.001$. The Friedman test for the FMS is not significant with $\chi^2(5) = 1.544, p = 0.908, n = 24$. Further, the Chi-Square Distribution test for the most liked transition is significant $\chi^2(5, 24) = 12.500, p = 0.029$ with *Cut* ($N = 9$) and Morph ($N = 6$) being rated the top two transitions. For the least liked transition, the Chi-Square Distribution test is not significant with $\chi^2(5, 24) = 7.000, p = 0.235$ with *Orb* ($N = 7$) rated the worst and *Fade & Portal* ($N = 5$) being the second least favorites. The ANOVA for the error rate yields no significant difference with $F(5, 115) = 0.363, p = 0.873$.

6 DISCUSSION

Based on the analysis results, we can conclude that the introduction of a task seems to affect how a transition is perceived and adopted by the user. A surprising result is that the participants rated the usability of *Orb* and *Portal* significantly lower than the usability of *Cut*. These results differ from those from prior work [11], where *Morph* had the lowest usability and significant differences between *Cut* and *Orb* & *Portal*. Further, the participants rated *Cut* the highest in the evaluation and *Orb* & *Portal* under the worst three, again contrary to the results from Husung & Langbehn [11], where the preference for *Cut* was rated the lowest. However, the authors already assumed this could change if these transitions were used often or over a longer period. This is also backed by the attributes of each transition we extracted from the participant's comments. Four people explicitly stated that *Cut* is *"fast"* and/or *"efficient"*. In contrast, 7 participants stated for the orb transition and 6 for the portal transition, that they are *"unnecessarily complex"*, *"cumbersome"*, and *"slow"* to use. This is in line with the findings from Horst et al. [10], which indicate that high interactivity negatively influences the preference if it is unnecessarily complex in the current context. While the subjective results indicate a higher efficiency of *Cut* against *Orb* & *Portal*, we find no significant differences in the error rate, indicating that the efficiency of the transition had no impact on the memory of the participant. Further, the transitions seemed not to affect the overall task load and flow.

Similar to usability, the presence measure differs from those from Husung & Langbehn [11]. Their participants rated the presence of *Orb* and *Portal* significantly higher than the other four transitions, and *Cut* was rated the second lowest. Our participants, on the contrary, rated *Cut* the highest regarding presence, and *Orb* and *Portal* received an average rating. It seems counter-intuitive that the

[1] https://www.syntystudios.com/

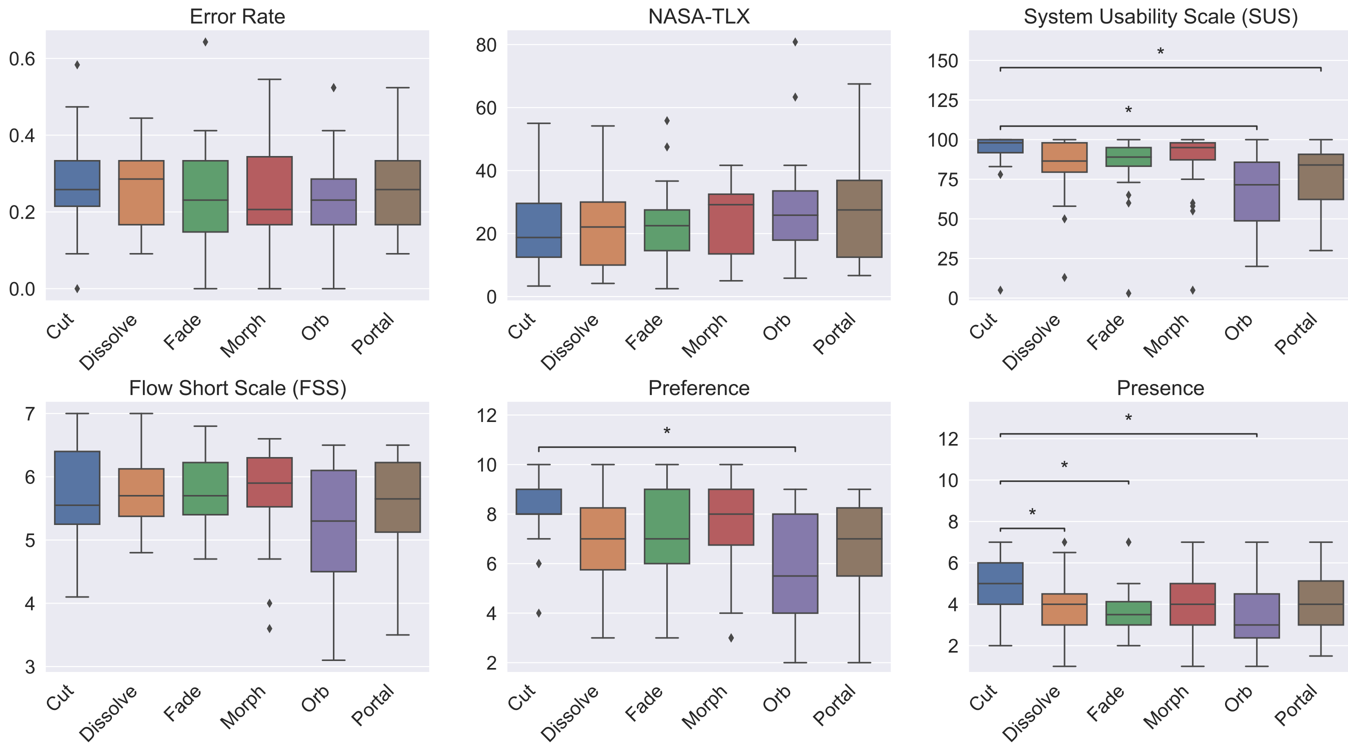


Figure 4: The descriptive statistics of our results. If the ANOVA/Friedman test was significant, corresponding post hoc tests were applied. The Bonferroni correction was used to compensate for multiple comparisons.

addition of a task negatively impacts presence. However, according to Slater [20], a questionnaire may have problems, or is even invalid, in capturing presence, especially when the task itself does not sufficiently provoke the participants to construct a mental model of it. In these cases, a subjective measure tends to be obscured by noise or other factors. We suspect this may have been a factor here and that usability shines through. We found the scores for SUS and presence weakly correlate: $r(142) = 0.265$, $p = 0.001$.

Because we aim to repeat this evaluation for a transition between VR and AR, our study design implied a few limitations that are not necessary for an experience in full VR. For example, we only considered real walking as a travel metaphor, which limited the interaction space and, most importantly, required a fixed position of the portal in the *Portal* transition. This may have had a negative impact on our results regarding *Portal* and could be reevaluated without these limitations if the target experience supports other travel metaphors. Furthermore, it should be noted that our design, compared to prior work, still provokes a high number and frequency of transitions to amplify possible effects. We argue that the results are more reflective for applications without a pure focus on transitions, but not necessarily to the present amount.

7 CONCLUSION

In this work, we first proposed a task that keeps the user engaged and allows for an evaluation of various transitions by requiring a realistic frequency of transitions and, thus, being externally valid. We then reevaluated six transitions based on related work by adding the proposed task and performing a quantitative user study. Our results indicate that the introduction of a task has an impact on the usability and preference of the transitions. The participant seemed to value efficiency over interactivity when solving a task, which contradicts prior work that did not include tasks in their evaluation. Further, we could not find a negative impact on task performance. Therefore, we suggest that when choosing a transition, one should consider efficiency at least as much as interactivity to achieve high usability. Further, a transition should be chosen in close conjunction with the intended task to solve with the intended system.

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