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Simple and Efficient? Evaluation of Transitions for Task-Driven Cross-Reality Experiences

Nico Feld, Pauline Bimberg, Benjamin Weyers, Daniel Zielasko

Abstract—The inquiry into the impact of diverse transitions between cross-reality environments on user experience remains a compelling research endeavor. Existing work often offers fragmented perspectives on various techniques or confines itself to a singular segment of the reality-virtuality spectrum, be it virtual reality or augmented reality. This study embarks on bridging this knowledge gap by systematically assessing the effects of six prevalent transitions while users remain immersed in tasks spanning both virtual and physical domains. In particular, we investigate the effect of different transitions while the user is continuously engaged in a demanding task instead of purely focusing on a given transition. As a preliminary step, we evaluate these six transitions within the realm of pure virtual reality to establish a baseline. Our findings reveal a clear preference among participants for brief and efficient transitions in a task-driven experience, instead of transitions that prioritize interactivity and continuity. Subsequently, we extend our investigation into a cross-reality context, encompassing transitions between virtual and physical environments. Once again, our results underscore the prevailing preference for concise and effective transitions. Furthermore, our research offers intriguing insights about the potential mitigation of visual incoherence between virtual and augmented reality environments by utilizing different transitions.

Index Terms—Artificial, augmented, and virtual realities, User interfaces, Graphical user interfaces,

1 Introduction

The reality-virtuality continuum (RVC) [1] describes a spectrum of stages that range from the completely real to the completely virtual. On one end of the spectrum is the real environment stage, the actual physical world without any technological enhancements. Moving along the spectrum, there is the augmented reality (AR) stage, where virtual objects are superimposed on the real world. Further along, is the augmented virtuality (AV) stage, a primarily virtual environment incorporating real-world objects. At the far end of the spectrum lies the virtual reality (VR) stage, a virtual environment entirely simulated by computers, often experienced through VR head-mounted displays (HMD). Each stage in the RVC has its benefits and limitations concerning its use [2]–[9]. For example, VR allows for a higher place illusion than a Desktop-PC [10] in the real environment stage, but precise interactions and text entries are usually more difficult to perform [11], [12]. Therefore, it stands to reason that the inclusion of multiple stages can help an application serve a wider variety of use cases. Prior work already shows that this could benefit various use cases, like collaboration [3], [13]–[17], urban planning [18], design [11], [16], [19], [20], entertainment [21], and immersive analytics [4], [5], [8], [22]–[26]. Recent technical advancements, such as high-quality video see-through head-mounted displays (HMD), allow even easier access to multiple stages of the RVC, e.g., AR to VR and vice versa, without changing hardware. We denote this inclusion of multiple stages of the RVC into a single application as Cross-Reality (CR) in this work.

When utilizing multi-stage scenarios for an individual user, the application must provide a mechanism to transition between these stages [4]. The concept of transitions is not limited to CR and is commonly used by writers, filmmakers, and VR/AR developers to provide continuity to the experience or break the continuity on purpose to underline a change of context. Transitions can range from diegetic, seamlessly blending into an experience, to disruptive, where they may be abrupt or strange and potentially break the experience [4], [24]. Further, they can connect environments in different stages, like an excavation site of Roman ruins (AR) and a virtual replication of those sites (VR) [27], or environments on the same stage, like two subsequent levels in a VR Game.

The influence of transitions in different stages of the RVC and their subsequent implementation is the subject of extensive research [13], [24], [28]–[35]. However, in most study designs, the user's attention is primarily and exclusively directed toward the transitions rather than the task at hand. Many AR/VR applications do not require direct interaction by the user, e.g., a virtual museum [36], but even in these cases, a potential transition is rarely the focus but only a tool to accomplish a given task. Including a task in the evaluation of transitions could improve the ecological validity of the results. Some exceptions, like the work from Sisto et al. [37], indicate that the perception of a transition might change if the user focuses on a task rather than the transition. Moreover, the evaluation of transitions is often confined to a single context within the RVC, for instance, VR alone, without considering CR scenarios, which include multiple stages [28], [29], [33], [37], [38]. Therefore, we aim to explore the impact of a demanding task on the effect of transitions between two environments and whether this impact varies based on transitions within the same stage versus transitions across different stages. Hence, our research questions are: **(RQ1) How does the cognitive demand of a task influence the effects of transitions between two environments? (RQ2) Are these effects distinct when**

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transitioning between two environments within a single stage versus between two different stages of the RVC?

To explore **RQ1**, we investigate the effect of a demanding task first when transitioning within a single stage (VR-VR) and second when transitioning between two stages (VR-AR, i.e. CR). To explore the effect within a single stage and pick up previous work, we initially replicate established findings and methodologies from VR research within an engaging task using a dual-task design (memory game + transitions). In the second step, we then try to replicate these baseline findings in a CR setting to investigate the potential effect of a task when transitioning between two stages. Finally, in the last step, we compare our results to address **RQ2** and investigate any potential differences between transitioning within a single stage or between two stages.

Prior work shows that the change of environments has a negative impact on memory [39], [40], which could be mitigated or amplified by different transitions. Therefore, we decided to design a spatial memory task, that can keep the user's focus on the task, and that might be influenced by different transitions, as the change of environments impacts memory. In the following, we list the contributions we make to existing work:

1) We identify and classify common transitions in prior work and investigate their potential impact on the users' experience.
2) We present a dual-task design in the form of a cross-environmental spatial memory game that keeps the user engaged and isolates key performance measures.
3) We replicate existing findings of transitions in VR under cognitive demand and find that the efficiency of a transition has a major impact on Preference and Usability.
4) We compare these transitions between VR and CR and find that efficiency again has a major impact on Preference and Usability. Based on this finding, we hypothesize that transitions can support a cognitive separation of environments, and those with preview functionalities support visually incoherent environments.

We already published excerpts of our investigation of **RQ1** as an extended abstract at CHI'23 [41].

2 Related Work

Transitions are a common concept in films [42]–[44], games [45], and immersive experiences [24], [28], [33], [35]. In this section, we investigate common transitions, how they are used, and how they impact the user's experience in prior work. We start with transitions in pop culture, like films and games, in Section 2.1 and then move into evaluations of transitions in VR in Section 2.2. Subsequently, we discuss how transitions can be used as on- and off-boarding techniques for VR experiences in Section 2.3. Subsequently in Section 2.4, we discuss prior evaluations of transitions in CR. Finally, we elaborate on prior work investigating the impact of switching environments on memory as groundwork for our task design in Section 2.5. As the names for the transitions are not used consistently in prior work, we specify the names used in this paper for better readability, with the original names provided in brackets. A summary of identified transitions can be found in Table 1.

2.1 Transitions in Pop-Culture

Already in 1994, Messaris [42] surveyed various transitions in filmmaking between scenes, like a cut or fade to black, and how they support a narrative shift in terms of location, time, and reality. Cutting [44] later investigates the transitions of 24 movies in terms of location, time, and, in addition, characters and examines how these transitions are used in films to support or deliberately break continuity to suit the narrative. He finds a tendency in recent years to transitions that make the movie more fast-paced but still easy to follow, mainly by subsequent cuts.

Solarski [45] discusses the role of transitions in video games, emphasizing their importance in enhancing player engagement. He introduces the *Dramatic Curve* and *Transitions*, tools used in storytelling to manage plot information and heighten emotional experiences. He emphasizes that transitions in video games can serve multiple functions, like building tension, providing contemplative spaces, and creating contrasting aesthetics to enhance the user's experience.

2.2 Transitions in Virtual Reality

Similar to Messaris [42] and Cutting [44], who focus on transitions across two adjacent scenes[1] rather than on transitions inside a scene, we focus on transitions between two environments rather than transitions within a single environment. The most common use case for transitions in a single environment is for virtual locomotion [59]–[61]. As Weissker et al. [59] state, transitions are part of short-range teleportation that could help to mentally prepare for the position change. However, as VR is the only stage in the RVC that allows for virtual locomotion, transitions within a single environment are rare in the context of CR.

To conceptualize the usage of transitions between multiple environments, Grasset et al. [62] propose the "Transitional collaborative model" for immersive applications with multiple users in mind. In this model, a transition is separated 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.

To analyze which transition could be used in a VR experience, Men et al. [33] investigate the effect that four different transitions have on the degree to which a user felt present in the virtual environment. The four transitions differ in speed and degree of visibility and are triggered when the user enters a portal. With the **Cut** (orig. *SimpleCut*) transition, the user instantly gets teleported to the target environment without any visuals, being an implementation of the cut transition in filmmaking [42]. The second

1. A scene is a single act that takes place in a single location, with a single set of characters, during a single time frame. [58]

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TABLE 1
Summary of identified transitions in prior work with unified names for better readability. The required *Extended World Knowledge* indicates the amount of information about the physical/virtual environments a system must have to support this transition.

Transition	Description	Required EWK	Related Work
Cut	An instant teleport to the target environment without a visual animation.	Low	(Simple)Cut: [28], [33], Cycling: [38], Instant/Direct: [30]–[32], [46]–[48]
Fade	A fade-to-black that reveals the target environment.	Low	Fade: [28], [33], [47], [49], Blink: [29]
Dissolve	A transparent cross-fade from the current environment to the target environment.	Low-Medium	Dissolve: [28], Gradual: [30], Fade: [24], [31], [37], Fade to Cam: [49], *Not named*: [34]
Orb / Virtual Phone	An orb or phone that provides a preview to the target environment and triggers a transition.	Low	Orb: [28], Virtual Phone: [50]
Portal	A Portal that can be walked through to the target environment (optional preview).	Medium	Portal: [18], [24], [28], [33], [46], [51]–[56], Door: [13], [31], [57]
Offscreen	Hidden Parts of the current environment get gradually substituted.	Medium-High	Turn Around: [29], Offscreen: [37], Teleport: [55], *Not named*: [32]
TeleportBeam	A visual teleport beam animation inspired by TV movies like Star Wars or Star Trek.	Low	TeleportBeam: [24], Teleporter: [49]
Others	Transitions that we only find in a single publication, ranging from low to high required EWK.	Low	Rift (orig. *Transformation*) [28], Vortex [33], Flying [35], Möbius [48], Wipe [49], Gong [49], Video [49], Minigame [49], Dialog [49]
		Medium	Cutting Plane (orig. *SimpleCut*) [24], Virtual HMD [29], SuperFast [33], Sky Portal [50]
		High	Morph [37], OVRLap [38]

transition is the common **Fade** transition, where the screen fades to black and back again, revealing the new environment, also originating from filmmaking [42]. When using the **SuperFast** transition, the user gets moved to the target environment over a few seconds, resulting in visuals of a speed-up film. The last transition, the **Vortex** transition, displays a vortex animation before the user gets teleported to the new environment. They find that **Cut** resulted in a preserved Presence, while the most visible transition, the **Vortex** transition, breaks Presence.

Husung & Langbehn [28] compare six different transitions in terms of Presence, Usability, continuity, and Preference. Each transition is inspired by common transitions in film-making or existing VR experiences. Next to the **Cut** and **Fade** transitions, they also include the **Dissolve** transition, where the new environment fades in while the current environment fades out by changing their transparency. With the **Rift** (orig. *Transformation*) transition, they introduce a transition with the visuals of a bursting rift around the user that reveals the new environment. Further, they include the common **Portal** transition, which provides a preview of the target environment and, when walked through, teleports the user there. Lastly, with the **Orb** transition, the user can display an orb that allows seeing through it into the target environment and teleport by bringing the orb to their head. In their study, a participant tries each transition across various environments at their own pace. They find that the participants prefer transitions with higher continuity, interactivity, and Presence, like **Portal**, rather than fast ones, like **Cut**. While the results seem to contradict the findings of Men et al. [33], Men's transitions require the user to enter a solid portal without a preview of the target environment to trigger the transition. This makes them comparable to variations of the **Portal** transition from Husung et al. [28] rather than entirely distinct transitions. Further, no specific task is given to a participant in both studies, meaning the transitions became their primary focus. Consequently, the results are from experiments that isolate effects and, thus, are internally valid while having a lower ecological validity, as discussed before.

A study conducted by Schjerlund et al. [38] investigates, in the context of an object manipulation task, the idea of overlaying two environments rather than perceiving only the active environment and switching via the **Cut** transition. Their proposed **OVRlap** technique displays the inactive environment as a transparent overlay over the current environment, similar to the **Dissolve** transition, and their results show that their transition enhances the user's spatial awareness and results in higher efficiency compared to the **Cut** transition. Their findings indicate that different transitions can also impact task efficiency, emphasizing the inclusion of a task when evaluating transitions.

Oberdörfer et al. [29] investigate the effect of three transitions in VR on sickness, Presence, virtual body ownership, efficiency, and naturalness embedded in a selection and memory task. Next, to **Fade** (orig. *Simulated Blink*), they evaluate a **Offscreen** (orig. *Turn Around*) transition and a **Virtual HMD** transition. With the **Offscreen** transition, the environment behind the user is substituted by the new environment on button press, and by turning around, the user transitions to the new environment. Once the user has turned around by 180°, the complete environment gets substituted by the new environment, making the transition complete. The **Virtual HMD** transition adds a virtual HMD to the environment, which the user can either put on or off to enter or leave the other environment. They find no effect of the transitions on virtual body ownership and Presence, but the faster **Offscreen** transition is rated as the most efficient and preferred, while the other two, more continuous and physical transitions, are rated as the most natural and dynamic. The findings suggest that the impact of transitions could be dependent on the measures applied and the setting in which it is used.

Sisto et al. [37] investigate the concept of smooth tran-

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sitions. In their study, a participant has to perform an assembly task while the environment around the participant slowly transforms into another environment. Their smooth transition is a composite of various transitions depending on the object types in the environment. For example, the floor and ground get substituted via a **Dissolve** (orig. *Fade*) transition, objects behind the user get substituted with the **Offscreen** transition, and some objects are morphed into new objects based on their geometry, via the introduced **Morph** transition. Their results show that these smooth transitions are scarcely recognized and barely disturb the user. While the authors do not compare different transitions with each other, their results show that the perception of transitions changes if the user focuses on a task rather than the transitions.

Instead of transitioning to a new environment, Wang et al. [46] propose the *SceneFusion* technique, which merges the two environments into a wider, combined environment. This approach makes a transition between both environments obsolete. They evaluate their approach against a **Cut** (orig. *Instant Teleport*) and **Portal** embedded in a pick-and-place task and find an improved Task Time, Movement distance, Task Load, and Preference for *SceneFusion* compared to the two transitions. These results show that the proposed *SceneFustion* technique is an alternative to common transitions. However, as it requires morphing both environments into a new one, its usage is limited to virtual environments only. Further, it potentially requires virtual locomotion as the resulting environment might be too large to allow for real walking.

2.3 On- and Offboarding as Transitions

To ensure a user-friendly and comfortable VR experience, a user can be guided when they start (onboard) and end (offboard) a VR experience, especially when a hardware change is required. This can include tutorials, applying preference settings, or device calibrations [63], [64]. In this section, we only focus on on- and offboarding techniques applicable to HMDs. A popular approach for onboarding is using a so-called *Replica*. Before entering the target virtual environment, the user is first put into a virtual replication of their physical environment and transitions to the target virtual environment in the next step. With this replica, the transition from the real environment to VR is separated into multiple smaller transitions. This approach is also suggested by Sproll et al. [65], who propose separating onboarding into multiple stages to evoke anticipation and involvement for the user.

In their evaluation of additional methods to measure Presence, Slater & Steed [57] use a replica for onboarding and offboarding and change the physical environment during the experiment, unnoticed by the user. With a custom questionnaire, they measure Presence and a surprise score on how surprised the user is about the changed physical environment. They find that the surprise score positively correlates with Presence and, thus, is a potential indicator of Presence. In two subsequent studies, Steinicke et al. find a positive effect in terms of Presence [51] and distance estimation [52] when onboarding with a replica, when compared to onboarding without a replica. All three studies use the **Portal** transition to allow the user to move from the replica to the virtual environment.

Valkov & Flagge [32] do not only investigate the effect of a replica but also the effect of a smooth transition from the replica to the target virtual environment by using **Offscreen** transitions, rather than a **Cut** transition. They find that the proposed smooth transition does increase the user's awareness of the virtual environment and confidence in traversing it.

Horst et al. [49] define *Outro-Transitions* as an offboarding technique that guides the user from VR back to reality when removing the head-mounted display. They investigate eight transitions and how they are suitable as outro-transitions when initiated by the user or a presenter. Next to **Fade** and **Dissolve**, they use a **TeleportBeam** (orig. *Teleporter*) transition, inspired by movies like Star Trek and Star Wars, an audial **Gong**, an instructive **Video**, an interactive **Wipe**, a **Minigame** and a **Dialog** transition. They find that the participants favor short transitions, like **Fade**, **Dissolve**, and **Video**, with little disturbance during usage. **Minigame** and **Wipe** are not favored, as the participants perceive their high interactivity as "complicated" and "impractical".

Knibbe et al. [66] explore possible offboarding techniques in a qualitative user study. Their participants are immersed in one of four scenarios (gaming, illusion, perception, and cognition) and are suddenly asked to remove the headset after approximately 10 minutes. As this sudden exit is not perceived well, the participants should propose possible techniques to smooth this experience. They suggest smooth transitions to support offboarding, like a **Dissolve** transition or scale alignments to adjust the virtual environment to the dimensions of the physical environment. Further, they identify possible issues that could negatively impact the offboarding experience, like a changed physical environment, similar to Slater & Steed [57], or a different social setting, e.g., when additional people enter the room while the participants are immersed in the virtual environment.

Soret et al. [31] evaluate **Cut** (orig. *Direct Transition*), **Dissolve** (orig. *Fading Transition*) and **Portal** (orig. *Door Transition*) as offboarding transitions, in isolation without an engaging task. Comparable to Husung & Langbehn's findings, **Portal** receives the highest ratings in Preference due to its interactivity.

2.4 Transitions in Cross Reality

The previous two sections investigate prior work about transitions in VR and from a real environment to VR and vice versa to enhance on- and offboarding. In this section, we discuss prior work that investigates transitions in CR. In 1997, Kijima & Ojika [19] propose their prototype of an optical see-through headset that allows for interconnection between a physical workstation and a virtual environment by displaying virtual content next to the physical workstation and provides examples of its application. The first investigations of transitions in CR begin in 2001 by Billinghurst et al. [35], where a user can read a Magic Book in AR and then transitions into the described book scene in VR via a **Flying** transition. With **Flying**, the viewpoint of the user gets moved into the scene on the book, creating a flying

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illusion. Eissele et al. [34] then apply this idea of transitions between stages in smart production environments in 2006 and implement a prototype in which the user can transition between AR and VR via the **Dissolve** transition. Their results indicate that their prototype is more efficient than a single-stage system, even with the limited hardware at that time. Due to technical advancements, research on seamless CR has become more frequent in recent years [25], [67]–[69].

To investigate the effect of gradual transitions against instant transitions on virtual body ownership and spatial Presence, Jung et al. [30] conduct a study based on the rubber hand experiment by Botvinick and Cohen [70]. While sitting at a desk, the participant transitions from AR to VR either with the **Cut** or the **Dissolve** transition. Then, their virtual hand is attacked by a knife and crawled over by a spider. Their results show that a participant using the **Dissolve** perceives a higher virtual body ownership and spatial Presence than one using **Cut**.

George et al. [50] evaluate a **Virtual Phone** transition and a **Sky Portal** as two possible transitions between an AR and VR environment, both providing a preview of the other environment before transitioning. With the **Sky Portal** transition, a portal is always present above the user on the ceiling of either environment. By looking at the portal, they see the other environment with a bird's eye view. To trigger the transition, the user simply has to press a button on their controller, and they get teleported into the other environment. Similar to the **Orb** transition, the **Virtual Phone** transition allows the user to peek into the other environment by holding a virtual phone that, on button press, displays a window into the other environment. Rather than moving the virtual phone close to the head, like with **Orb**, the user has to press the button twice to get teleported into the other environment. The **Virtual Phone** transition outperformed the **Sky Portal** transition in all measures. The authors assumed that, while **Sky Portal** is easy to understand, it has major Usability issues and a negative impact on spatial orientation.

An evaluation of transitions in CR is performed by Pointecker et al. [24], who evaluate four transitions regarding user experience, continuity, and simulator sickness between a VR and an AR environment. Next to **Dissolve** (orig. *Fade*) and **Portal**, they include the **TeleportBeam** transition and introduce the **Cutting Plane** (orig. *SimpleCut*) transition, where the current environment gets cut away by a moving plane, revealing the target environment. Their results indicate that faster transitions, like **Dissolve**, are perceived as more pragmatic, while transitions with high visibility, like **Portal**, are perceived as more pleasing. The participants are assigned a simple task, but it is not a part of their evaluation.

2.5 Impact of Switching Environments on Memory

While it might be beneficial to separate an experience into multiple environments or stages, as related work shows, there can also be drawbacks, for example, a negative impact on memory. This is shown by Shin et al. [39], who conduct a user study in which a participant starts in one of two virtual environments and is told to memorize certain objects. The participants are divided into four groups. The memory of the first group is instantly tested in the same environment, and the memory of the second group is tested 24 hours later in the same environment by recalling the objects. Respectively, the third and fourth groups are tested instantly/after 24h in the other environment. They conclude that recalling is more efficient when done immediately after the memorization and if done in the same virtual environment. While they do not evaluate different transitions, they show that memory may be a potential measure to investigate the effects of transitions.

Lamers and Lanen perform a similar study [40]. Rather than using two virtual environments, like Shin et al. [39], one environment is in VR, and one is a real environment, and the recalling took place after 24h in all conditions. While they do not find any effect of the real or the virtual environment on recalling, they find an interaction effect between the environments and, thus, also conclude that switching the environment does impact the ability to recall, but the stage of the environments in the RVC does not.

This is also supported by the results of Roo et al. [71], who find that switching only the stage in the RVC, but not the environment, seems to have no impact on the ability to recall. In their study, a participant had to recall an object's position in a miniature world on a desk while being in reality or VR. The object is then removed, and the participant has to recall its position either in the same stage (AR→ AR, VR→ VR) or the other (AR→ VR, VR→ AR). They find no significant differences between all four conditions regarding position recall. A subsequent study shows that an additional change in viewport also has no impact on position recall.

2.6 Discussion

In summary, prior work shows that transitions can be pivotal in supporting Presence, Usability, and continuity. Furthermore, it seems that visual transitions that keep continuity are most preferred [24], [28], [31], [33]. In conjunction, Auda et al. [72] propose three principles for CR systems using transitions to switch between stages based on the findings of prior work. The first principle states that one should use smooth transitions to, e.g., keep awareness of the physical environment [32] and increase Presence [51]. The second principle states that one should use suitable metaphors for such transitions like portals [4], [46], [50]–[52], [54] that allow a preview of the target environment to increase Presence and interactive objects like books [35], phones [50] or orbs [28]. The last principle states that the transitions should be user-initiated. That includes that the user can initiate the transition, control the transitions (e.g., the speed of the transition), and, if there are multiple possible target environments, they should be identifiable and selectable before the transition. However, we assume that the lack of cognitively demanding tasks in prior work makes a projection to ecological validity still difficult.

As Schjerlund et al. [38], Oberdörfer et al. [29] and Sisto et al. [37] demonstrate, transitions further have an impact on task performance and unnecessary high interactivity and complexity may have a negative effect on Preference [24], [29], [49]. Therefore, for **RQ1**, we expect additional insights by evaluating transitions in the context of a memory task, as memory is impacted by environment changes [39], [40]. Given that the research on transitions in CR is still

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

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

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

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

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

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

Fig. 1. The six selected transitions for this evaluation. They are re-implementations of the work by Husung & Langbehn [28].

in an early stage, we further see potential in investigating if these insights differ when transitioning across stages of the RVC (**RQ2**). However, we do not have any hypotheses regarding both research questions based on the discussed related work. Therefore, the investigations of **RQ1** and **RQ2** are performed as exploratory analyses.

3 Transition Selection & Implementation

When focusing on implementation, transitions can be categorized by the required *Extend of World Knowledge* (EWK). EWK describes the knowledge the system has about the environment that it displays [1]. A high EWK indicates that the system has much information about the environment, e.g., geometry or lighting, and can use it and quickly adapt to environmental changes, like when an object moves. VR systems typically immerse their users in environments that are largely digital, which makes knowledge about the world accessible, leading to a high EWK. However, this is usually much less of a case for AR systems, as most AR hardware only captures rudimentary information about the physical environment, e.g., by using a depth sensor. When it comes to implementing transitions, a **Cut** requires almost no EWK, but a morphing environment transition, like in the work of Sisto et al. [37] or Wang et al. [46], requires a high EWK, as the environment itself changes, and, thus, is not always suitable as a transition in AR and CR.

In our work, we categorize transitions into so-called *Environmental Transitions* and *User-Centered Transitions*. *Environmental Transitions* provide the illusion that the environment itself changes rather than the user being moved to another environment. Examples include two environments being overlayed with a transparency effect [38], the environment gradually changing over time [32], a plane cutting through the current environment and revealing the new one [24], or morphing the current environment to the new environment [37], [46], as previously mentioned. These transitions usually require a high EWK, as they require much information about the environments they are changing.

In contrast, *User-Centered Transitions* focus on the user and the illusion that the user is moving to another environment and requires minor EWK. Common *User-Centered Transitions* are **Cut**, **Fade** or **Portal**. We focus on a selection of transitions that require minor EWK in our evaluation, as they have fewer technical requirements and, thus, cover more potential use cases in CR. We re-implement the transitions used by Husung & Langehn [28] since they already provide a sound collection of such transitions common in related work. We applied minor adjustments, mainly based on recommendations from their participants. Further, by preserving the foundational context of the original study, we can precisely attribute the outcomes to the task's influence or, respectively, the influence of CR. The following paragraphs briefly describe each transition, its implementation, and its potential benefits. In our implementation, each transition is triggered by a simple button press on either controller. Our final implementations are presented in Figure 1.

Cut: This transition is mainly inspired by film-making [42], [43]. When the transition is initiated, the user "*teleports*" instantly to the target environment without additional visual or audio effects. Therefore, there is no noticeable transition phase for the user. According to Husung & Langbehn [28], this transition seems to break the continuity of the experience and receives low Preference ratings. Based on these findings, Pointecker et al. [24] exclude **Cut** from their evaluation, as they focus on 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 in our evaluation.

Dissolve: After the initiation, the current environment dissolves into the target environment in the transition phase by linearly blending the other environment over the current environment via transparency. We use the same duration for this transition as in previous work [28] of $1.3s$. This transition is inspired by film-making as it can bridge two environments [42], [43], [73], tending to be a better option than **Cut** in terms of continuity [28]. Some implementations, like the **OVRLap** technique [37], utilize additional depth information to create the illusion that the environment itself dissolves into a new one, fitting more into the environmental transition category. However, this requires higher EWK, and therefore, we do not use additional depth information.

Fade: With this transition, the screen linearly fades to black, the user gets "*teleported*" to the other environment without noticing it, and the screen linearly fades back to normal vision with, again, a total duration of $1.3s$. This transition is commonly used in films and VR experiences to separate two environments or storylines but is perceived more as a "*slideshow*" than providing a continuous experience.

Rift: An animated circular rift bursts around the user and reveals the target environment over $1.3s$. Husung & Langbehn [28] call this transition "Transformation", inspired by the VR game "NVIDIA VR Funhouse", and chose it as it uses VR-specific features. In their evaluation, it receives the lowest Usability score due to its "*unnatural feeling*".

Orb: A floating orb ($d = 20cm$) is spawned on initiation, which displays a 3D preview of the other environment. By moving the orb closer to their face, the user transitions to the other environment. This transition is mainly inspired by the game "Budget Cut" and offers high interactivity but requires less movement than **Portal**. The **Orb** receives the highest user rating in previous work [28]. In contrast to their implementation, we do not place the orb in the environment, but the user can spawn it via a button press, hovering over one of the controllers at any time. This makes the transition's initiation independent of the user's current position.

Portal: In the initiation phase (see Section 2), the user can open a portal ($1m$ x $2.25m$) in the current environment and see the other environment through the portal in 3D. The user can now transition simply by walking through the portal, which closes behind the user. The **Portal** transition requires the most interactivity and movement of all transitions, resulting in a high user rating in prior evaluations [28], [31]. Because a few participants state in Husung & Langbehn's study [28] that they are afraid to stumble when walking through the oval-shaped portal, we changed the shape of the portal to rectangular. While the portal transition itself requires low EWK, suitable placement of the portal might require some EWK to allow enough space to enter the portal [74]. To guarantee enough space to physically walk through the portal at all times, the portal is placed automatically rather than manually by the user, similar to the implementation of Freitag et al. [53] and Pointecker et al. [24]. In our case, we always place the portal in the center of the environment facing the user. Placing the portal automatically can lead to placement outside of the user's vision and, thus, to confusion.

4 Memory Task

To investigate the transitions while the user is engaged in a task, we need to design a cognitively demanding task that requires the user to transition between two environments. As discussed in Section 2.5, changing between environments has an impact on the ability to recall memory. This effect might be influenced by the transition used for the environment change. Further, memory tasks, which often involve the retention and manipulation of information, are inherently cognitively demanding [75] while simultaneously slow-paced. Consequently, excessive use of transitions should be avoided in the task design to enhance the method's applicability in real-world scenarios. Therefore, we decided to design a spatial memory task that requires a steady, but moderate number of transitions to investigate our research questions. In this memory task, the player must find two identical objects hidden under a set of boxes. Each turn, the player is only allowed to open two boxes at the same time. We place the boxes evenly across two environments to force the user to transition between them. As the user has to solve a memory game and transition between two environments, this task design represents a common dual-task design [76].

Additionally, we aim to maintain consistent user engagement across different environments, encouraging occasional transitions rather than frequent ones within a brief time frame. To achieve this, we introduce two categories of objects. If an object is in the *Environment Category*, its appearance corresponds with the environment in which it is hidden. In our case, we chose a virtual office and a virtual farm for our environments. As there are two environments, there are two sets of objects in the *Environment Category*, one for each environment. An object in the *Environment Category* for the office environment could then be a folder, a desk lamp, or a cup. For the farm environment, it could be a box of apples, a beehive, or a pumpkin. 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 an object is in the *Cross Category*, its appearance corresponds to no particular environment but is coherent with the other objects in the category. In that case, the appearance of the objects in this category is, in our case, pirate-related, like a bomb, a skull, a compass, or a treasure map, as they clearly do not belong to an office or a farm. These objects are also hidden under boxes in the environments, but their counterpart is always hidden in the other environment. Thus, if the user reveals an object of the *Cross 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

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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 the other environment at any time.

A simple gamification element is applied, where the user gains points for found pairs and loses points in case of a mismatch against better knowledge. This element is introduced to prevent simple try-and-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. We decided to use such a gamification element rather than applying time pressure to increase difficulty, as this could push the user to unwanted try-and-error approaches instead of using their memory. To minimize the effect of the user's random selection of the boxes, the order in which the objects are revealed by the user is predefined by defining the content of a box only when the user first opens it. This keeps the order of discovery the same for each user. Further, by placing the boxes in the environments and not, e.g., in a grid on a table, we add an additional spatial component to our memory task to motivate the user to build spatial maps. This could help the user further by building additional thought bridges to spatial content. Spatial orientation plays a role in many applications, and for this reason, we also want to confront the different transitions with this factor to provoke possible differences. Thus, we assume in advance that **Portal** is not the fastest method to perform, but through the avoidable consistent spatial overlay as well as mental integration between different spaces, advantages could show up in just this spatial component of the memory game.

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*. While being in the *Exploration Phase*, the user is gathering information about the memory game. If the user knows at least one pair, the user is in the *Searching Phase*. In this phase, we assume the user is trying to find the known pair using their memory. Therefore, the *Searching Phase* is suitable for measuring task performance measures, like Error Rate. The *Exploration Phase*, on the other hand, might give insights into strategies on how the users gather information about the memory game, e.g., the order of boxes opened, which, however, is not part of our evaluation.

5 Study I: Transitioning between VR environments

With this first study, we investigate the effect of a cognitively demanding task on transitions in VR in regards to **RQ1**. We used a 1x6 within-subject study design, the one factor being the transition method. The study is approved by the local ethics council.

5.1 Procedure

After a short introduction, each participant signs a consent form and answers a few demographic questions. Then, they are introduced to the VR hardware and assigned their first condition. The conditions are balanced using a Latin Square design. Each participant is shown a short video introducing the memory task in VR upfront their first assigned condition. Further, a short clip is shown in each condition, describing the current transition. Then, each participant has a short trial phase. In the first condition, each participant has to find one pair of the *Cross Category* (see Section 4) to get familiar with the memory task. In the following conditions, they are only asked to use the current transition four times, as they are already familiar with the memory task. The experimenter starts a new recorded memory game when the participant has no further questions. The participant is reminded that there is no time pressure and is asked to solve one complete memory as the main task. After finishing the memory task, each participant completes questionnaires regarding the currently used transition. Then, the next condition is started with the trial phase. After the participants finish all six conditions, they complete a final questionnaire. The procedure, which includes the introduction, six trial and task phases, and eight questionnaire phases, takes approximately 90 minutes for each participant.

5.2 Apparatus & Virtual Environment

The study takes place in an empty room with a desk and seat for the participants to answer the questionnaires on a laptop. We provide a play space of $\sim 4m$ x $4m$ for the actual task. For this study, we designed two environments to fit entirely in the play space. Both environments and the memory task are described in detail in Section 4. Please refer to the video in the supplement materials for a detailed depiction. Six objects of the *Environment Category* and four of the *Cross Category* are hidden in each environment. This results in ten boxes per environment and ten pairs in total. We place the boxes in a way that they are evenly spread in a radius of $\sim 1.5m$. Figure 2 shows both of the environments used in the study, along with the boxes. We use an HTC Vive Pro with a wireless adapter and the standard HTC VIVE controllers. The study is implemented with Unity 2021.3 and XR Interaction Toolkit 2.0.4. For the environments and the objects, we use assets from Synty Studios[2].

5.3 Measures

To investigate both research questions, we measure six subjective measures and two objective measures and gather additional qualitative information. As we perform exploratory analyses, they are a representative collection of measures used in related work.

Usability: To measure the Usability of each transition, we use the *System Usability Scale* (SUS) questionnaire [77] after each condition. Differences in Usability between transitions may give us insights into how suitable a transition is for the given task in relation to the other transitions.

2. https://www.syntystudios.com/

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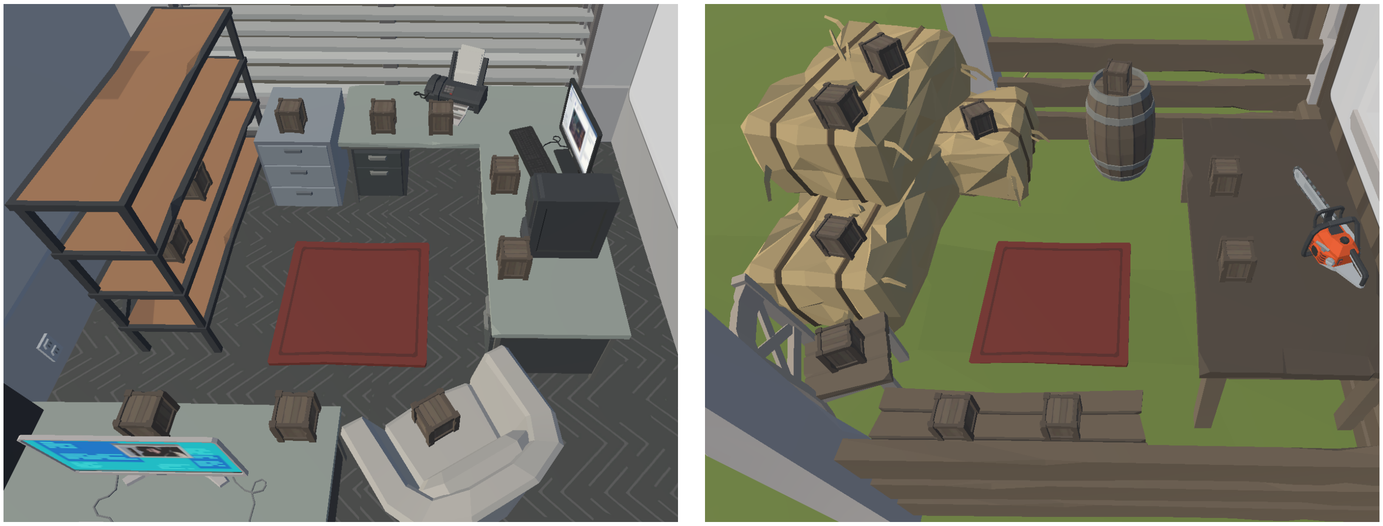

(a) The office environment (b) The farm environment

Fig. 2. Overview of both environments the participants are in to solve the memory game, and between which they could freely transition. The objects for the memory are hidden under the brown boxes.

Flow: With Flow, we expect to get insights on how well a transition can create a mental bridge between both environments without breaking the user's Flow. We measure Flow instead of continuity as done by prior work [24], [28], 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, as it describes the effortless absorption in activities, where the subject is highly motivated by and committed to their task without obvious external rewards [78]. To measure Flow after each condition, we use the *Flow Short Scale* (FSS) [79].

Presence-related Questions: Measuring Presence allows us to investigate if the given task has an impact on the perceived Presence. To investigate Presence, we use the Presence-related questions previously used by Husung & Langbehn [28], originating from the evaluation by Men et al. [33], after each condition. A score is calculated as the mean of two 7-point Likert scale questions. An evaluated questionnaire, like the *Slater-Usoh-Steed* questionnaire [80], potentially yields more robust results. However, in our study, Presence is not a core measure and thus only addressed minimally by the two Presence-related questions. This approach not only helps maintain a clear focus on our primary objectives but also significantly reduces the questionnaire completion time.

Task Load: We measure Task Load via the *NASA-TLX* [81] to investigate if a transition may amplify or mitigate the Task Load induced by our task design. We measure the Task Load after each condition.

Preference: We ask each participant to rate each transition after each condition on a scale from 1-10. We include this measure to investigate if the Preference of interactive transitions found in related work [24], [28], [31], [33], [50] still applies in our tasks-based scenario.

Error Rate: We use the memory task's Error Rate as our main performance indicator. 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 is only measured while the participant is in the *Search Phase*.

Task Time: We measure Task Time as the time a participant needs to solve one complete memory. As mentioned in Section 5.1, the participant is instructed not to focus on speed but on making as few errors as possible. Therefore, we use Task Time not as an indicator of performance but as a control variable.

Simulator sickness: To investigate if our results might stem from induced simulator sickness, we use the *Fast Motion Sickness Scale* (FMS) [82] after each condition to measure simulator sickness as a control variable.

Qualitative information: Finally, the participants could leave comments on what they like or dislike about the current transition after each condition and leave additional comments in the final questionnaire.

Additionally, we measured the **Head Movement**, **Head Rotation**, and **Number of Transitions**, but they are not part of the analysis. A detailed report of these measures can be found in the supplement material.

5.4 Participants

24 Participants took part in the study and received 10€ each for participating. This convenience sample was drawn from a mailing list of our university. Their age ranged from 20 to 41 years with $Mdn = 24.00, IQR = 23.00-28.00$. 8 (33.3%) participants identified as female, 15 (62.5%) as male, and 1 (4.2%) as diverse. 18 (75%) stated prior experience with VR and 14 (58.3%) with 3D video games. 2 (8.3%) participants stated to be left-handed. With two more participants, a difference in the mean age by 0.75 years, and similar reported experience, our sample is close to the one used by Husung & Langbehn.

5.5 Analysis

In this section, we perform an exploratory analysis of the measures collected in the user study. The descriptive statis-

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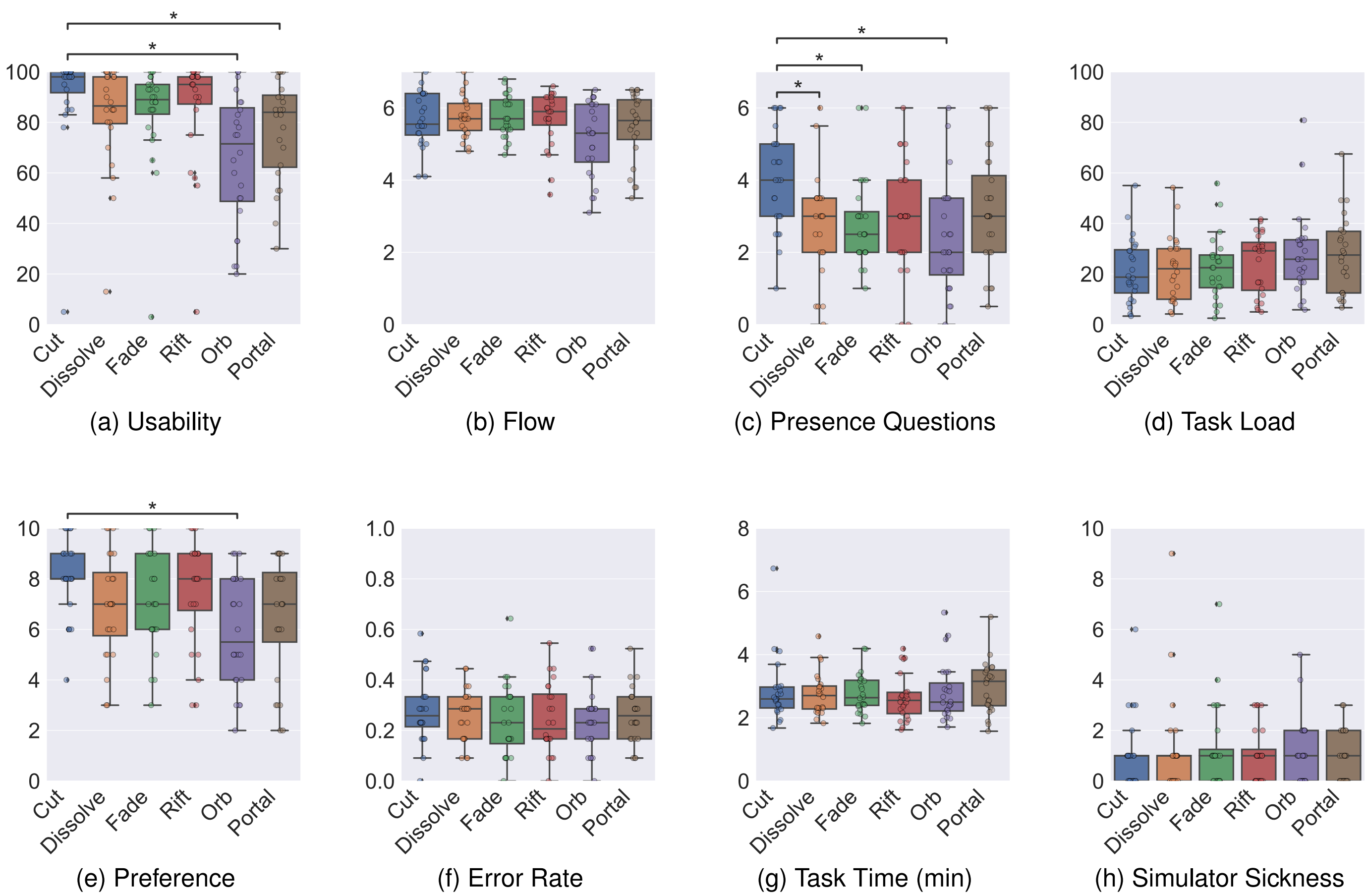

Fig. 3. The descriptive statistics of our results for Study I ($N = 24$), along with the significant post hoc tests.

tics are depicted in Figure 3. The inferential statistics are listed in Table 2. As reporting all results is crucial for reproducibility [83], the complete data and a detailed analysis results report can be found in the supplement material. 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, pairwise t-tests or Dunn tests with Bonferroni corrections are applied as post hoc tests, as is the default in the used SPSS Version 29. We use a significance level of $\alpha = 0.05$ for all statistical tests.

The tests indicate significant differences between all conditions for Usability (SUS-Score), Flow (FSS-Score), Presence-related Questions, and Preference. The post hoc tests reveal differences in Usability (SUS-Score) between **Cut** and **Orb**, and **Cut** and **Portal**. For the Presence-related Questions, they reveal a difference between **Cut** and **Dissolve**, **Cut** and **Fade**, and **Cut** and **Orb**. Further, we find differences in Preference between **Cut** and **Orb**. No post hoc test was significant for Flow (FSS-Score).

5.6 Discussion of Study I

Based on the analysis results, we hypothesize that the introduction of a task seems to affect how a transition is perceived and adopted by the user in a VR experience. The participants rate the Usability of **Orb** and **Portal** significantly lower than the Usability of **Cut**. These results differ from those from Husung & Langbehn [28], where **Rift** has the lowest Usability and significant differences are present between **Cut** and **Orb** & **Portal**. Further, the participants rate **Cut** the highest and **Orb** & **Portal** the lowest in terms of Preference, again contrary to prior results [28], [30], [31], where **Cut** is rated the lowest. This is also backed by the attributes of each transition we extract from the participants' comments. Four people explicitly state that **Cut** is *"fast"* and/or *"efficient"* (P4-I, P5-I, P13-I, P17-I). In contrast, 7 participants state for **Orb** and 6 for *Portal* that they are *"unnecessarily complex"* (P1-I, P4-I, P5-I, P11-I, P13-I, P16-I, P17-I, P22-I, P23-I), *"cumbersome"* (P4-I, P16-I), and *"slow"* (P16-I) to use. While these findings differ from the replicated study [28], possible explanations can be found in other related work previously discussed in Section 2. The investigation by Horst et al. [49] on evaluating outro-transitions reveals a low Preference ranking for transitions with high interactivity due to their unnecessary complexity in the context applied. A similar pattern emerges in the evaluation of CR transitions performed by Pointecker et al. [24], where the fastest transition is rated the most pragmatic. Further similarities can be found in the study conducted by Oberdörfer et al. [29], as the fastest transition is ranked highest in terms of Preference, again indicating the importance of efficiency. Extending these findings, the high Usability and Preference of **Cut** indicate a high need for efficiency when

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Measure	Test			p
Usability (SUS)	$\chi^2(5) = 23.152$			$< \mathbf{.001}$
	Cut (Mdn=98.00)	$>$	Orb (Mdn=71.50)	$< \mathbf{.001}$
	Cut (Mdn=98.00)	$>$	Portal (Mdn=71.50)	**.018**
Flow (FSS)	$\chi^2(5) = 12.618$			**.027**
	-			
Presence Questions	$\chi^2(5) = 20.682$			$< \mathbf{.001}$
	Cut (Mdn=4.00)	$>$	Dissolve (Mdn=3.00)	**.018**
	Cut (Mdn=4.00)	$>$	Fade (Mdn=2.50)	**.045**
	Cut (Mdn=4.00)	$>$	Orb (Mdn=2.00)	**.001**
Task Load (NasaTLX)	$\chi^2(5) = 6.998$			.221
Preference	$\chi^2(5) = 14.184$			**.014**
	Cut (Mdn=8.00)	$>$	Orb (Mdn=5.50)	**.027**
Error Rate	$F(5, 115) = 0.363$			.873
Task Time	$F(3.545, 81.532) = 0.732$			.557
Simulator Sickness (FMS)	$\chi^2(5) = 1.544$			.908

TABLE 2
The results of the analysis of Study I ($N = 24$). Only the significant post hoc tests (if applied) are reported. For a detailed report, please refer to the supplement material.

Measure	Test			p
Usability (SUS)	$\chi^2(5) = 28.894$			$< \mathbf{.001}$
	Cut (Mdn=94.00)	$>$	Portal (Mdn=78.00)	$< \mathbf{.001}$
	Dissolve (Mdn=86.50)	$>$	Portal (Mdn=78.00)	**.031**
	Fade (Mdn=94.00)	$>$	Portal (Mdn=78.00)	**.002**
Flow (FSS)	$\chi^2(5) = 9.398$			.094
Presence Questions	$\chi^2(5) = 25.564$			$< \mathbf{.001}$
	Fade (Mdn=3.50)	$>$	Rift (Mdn=2.75)	**.011**
	Fade (Mdn=3.50)	$>$	Orb (Mdn=2.75)	**.028**
	Fade (Mdn=3.50)	$>$	Portal (Mdn=2.50)	**.013**
Task Load (NasaTLX)	$\chi^2(5) = 15.458$			**.009**
	Fade (Mdn=19.17)	$<$	Orb (Mdn=26.25)	**.031**
	Fade (Mdn=19.17)	$<$	Portal (Mdn=31.25)	**.005**
Preference	$\chi^2(5) = 8.830$			.116
Error Rate	$F(5, 125) = 1.347$			.249
Task Time	$F(5, 125) = 0.897$			.486
Simulator Sickness (FMS)	$\chi^2(5) = 6.745$			.240

TABLE 3
The results of the analysis of Study II ($N = 26$). Only the significant post hoc tests (if applied) are reported. For a detailed report, please refer to the supplement material.

the transition is not in focus.

While the results of the Usability ratings and the user comments indicate a higher efficiency of **Cut** against **Orb** & **Portal**, we find no significant differences in the Error Rate and Task Time, indicating that the efficiency of a transition, given our sample size, had at least no strong effect on the users' memory. Further, the transitions do not provably affect the overall Task Load and Flow.

Similar to Usability, the reported scores of the Presence-related Questions differ from prior work [28], [30]. Their participants rated Presence in the **Orb** and **Portal** conditions significantly higher than the other four transitions, and **Cut** is rated the second lowest. Our participants, on the contrary, scored **Cut** the highest in terms of the Presence-related Questions and left only average scores for the **Orb** and **Portal** conditions. It seems counter-intuitive that the addition of a task negatively impacts Presence. However, according to Slater [84], questionnaires may be rendered 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 find the scores for SUS and the Presence-related Questions weakly correlate with $r(142) = 0.265, p = 0.001$.

In conclusion, regarding **RQ1**, which aims to investigate how a demanding task influences the effects of transitions, our results of Study I indicate that in VR, the introduction of a demanding task has a positive effect on the Usability and Preference of efficient transitions. However, this introduction seems to have a negative effect on Usability and Preference for interactive transitions.

6 Study II: Transitioning between AR and VR environments

With the following study, we want to investigate whether the effects found in Study I regarding transitions in VR also apply to transitions in CR. We apply minor adjustments to the study design. We change the used hardware to a Varjo-XR 3, which supports both VR and AR without the need for a hardware change. As the Varjo-XR 3 requires a cable, we use a VR ceiling cable-management system to minimize the movement limitations a cable induces. Further, we change the virtual office environment with a physical office environment and adjust the farm environment to fit with the new physical environment. Both the virtual farm environment and the physical office environment are depicted in Figure 4. The second study also received approval from the ethics council of our institution.

6.1 Participants

26 Participants took part in the study, of which 5 (19.2%) already took part in Study I. They were compensated with 10€ each for participating and drawn as a convenience sample from a mailing list of our university. The participant's age ranged from 20 to 35 years with $Mdn = 24.50, IQR = 22.75 - 28.00$. 8 ($30.8\%$) participants identified as female, 18 (69.2%) as male. 20 (76.9%) stated to have prior experience with VR, 9 (34.5%) with AR, and 9 (34.5%) with 3D video games. 2 (7.7%) participants stated to be left-handed.

6.2 Analysis

The descriptive statistics are depicted in Figure 5. The inferential statistics are listed in Table 3. The complete data

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(a) The office environment in AR

(b) The farm environment in VR

Fig. 4. Overview of the office environment in AR (a) and the farm environment in VR (b). The layout of the farm environment is adapted to fit within the office environment, so the risk of hitting physical objects is minimized.

and a detailed analysis results report can be found in the supplement material. Again, we use a one-way ANOVA with repeated measures for parametric and a Friedman test for non-parametric measures to identify the effects of the transitions. We report them as significant when $p <= 0.05$ and apply t-tests or Dunn tests with Bonferonni corrections as post-hoc tests in such a case. The Friedman tests reveal differences between all six conditions for Usability (SUS-Score), the Presence-related Questions, and Task Load (NasaTLX). The post hoc tests for Usability (SUS-Score) yield differences between **Cut** and **Portal**, **Dissolve** and **Portal**, and **Fade** and **Portal**. For the Presence-related Questions, they yield differences between **Fade** and **Rift**, **Fade** and **Orb**, and **Fade** and **Portal**. Further, we find differences for Task Load (NasaTLX) between **Fade** and **Orb**, and **Fade** and **Portal**.

6.3 Discussion of Study II

Similar to Study I, our findings indicate that within this CR context, the introduction of a task influences how users perceive the transitions. **Portal** was rated significantly lower than **Cut**, **Dissolve**, and **Fade** in terms of Usability, with **Cut** and **Fade** receiving the highest ratings (Mdn=94.00). In terms of Preference, we found no significant differences between the six conditions, with **Cut** and **Fade** receiving the highest ratings (Mdn=8.00). The high ratings for **Cut** and **Fade** in Usability and Preference are backed by the comments left by the participants in Study II. **Cut** was labeled as *"fast"* (P8-II, P13-II) and *"responsive"* (P4-II, P19-II) and **Fade** as *"smooth"* (P13-II, P16-II, P18-II, P20-II) and *"helpful for orientation"* (P5-II, P9-II). **Portal**, on the other hand, was labeled as *"cumbersome"* or *"to complex"* (P3-II, P4-II, P5-II, P6-II, P7-II, P8-II, P10-II, P12-II) and *"unsuited for this task"* (P2-II, P4-II, P9-II, P12-II, P21-II). Further, the additional cable of the Varjo XR-3 was highlighted as obstructive, especially for the **Portal** transition. As mentioned previously, in contrast to the wireless HTC Vive in Study I, the Varjo-XR3 used in Study II requires a cable and, thus, limits the participant's movement, even when a ceiling cable-management system is used. This also may have had a higher impact on **Portal** than on the other transitions, as the user has to rotate and walk more often compared to the other transitions [53]. Thus, the general complexity and the obstructive cable possibly lead to low ratings in Usability and Preference for **Portal**. These results again differ from the results from Husung & Langbehn, where the transitions **Orb** and **Portal** positively stood out, but are aligned with the other prior work regarding the impact of efficiency [24], [29], [49], as already discussed in Section 5.6.

The differences in Usability and Preference, however, are not reflected in the Error Rate and Task Time, again indicating no strong effect on the user's memory, regardless of the efficiency of a transition.

Still, **Fade** received a significantly lower score for Task Load than **Orb** and **Portal** and a higher score in the Presence-related Questions than **Rift**, **Orb**, and **Portal**. We found no differences in Flow. The score for the Presence-related Questions should again be taken with care, as the correlation between these questions and the SUS-Score previously indicated in Study I is also present in the results of Study II, with a medium correlation of $r(154) = 0.319$, $p < 0.001$. Further, comparing the scores of those questions between multiple stages of the RVC seems to be an additional factor in producing inconclusive results for an indication of Presence [85]. However, with the low Task Load and the high ratings in Usability and Preference, **Fade** could help reduce the cognitive demand in Study II.

We assume this effect may stem from the visual incoherence between both environments. In our study, while the virtual farm in VR has low poly models, colorful textures, and simple lighting, the physical office differs greatly, with real objects, darker colors, and realistic lighting. Through the concurrent camera adjustments by the Varjo XR-3[3], the lightning can even be different throughout multiple transitions. While the environments may be visually coherent individually, they are incoherent to each other. With this visual incoherence, a user may perceive the two environments as more isolated. Transitions for which the user does not

3. https://varjo.com/use-center/get-to-know-your-headset/mixed-reality/

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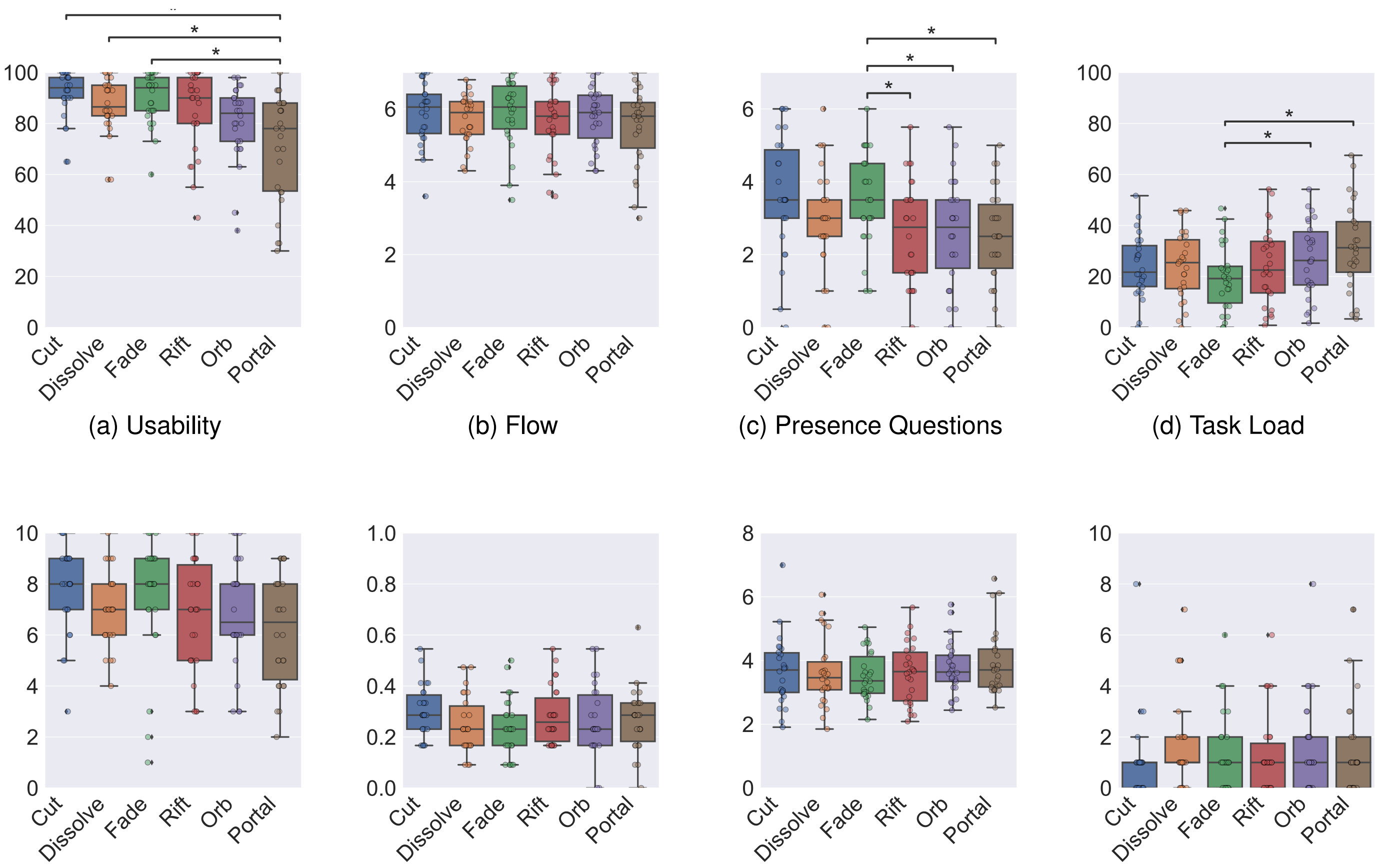

(a) Usability (b) Flow (c) Presence Questions (d) Task Load

(e) Preference (f) Error Rate (g) Task Time (min) (h) Simulator Sickness

Fig. 5. The descriptive statistics of our results for Study II ($N = 26$), along with the significant post hoc tests.

perceive both environments simultaneously, like **Fade**, may help the user to adjust to the new context. This is backed by the results reported by Husung & Langbehn [28] where **Fade** is more perceived as a *"slideshow"* than providing a continuous experience. In our user study, P9-II even describes **Fade** as a *"eye-reset"* that made adjusting to the new environment easier. The importance of visual coherence in XR, especially in AR applications, is already well-researched in related work [86]–[88] and has been recently applied by Pointecker et al. [23] to the CR context.

Summing up, the findings of Study II suggest that, regarding **RQ1**, a demanding task also has an impact on the effects of transitions in CR. Further, they indicate that certain transitions might mitigate the negative effects of visual incoherence between two environments.

7 Meta-Discussion

The results of Study I and Study II both indicate an impact of a demanding task on the effects of transitions in the RVC, which was the subject of our first research question **RQ1**. The impact was mostly noticeable in the highest scores in Usability and Preference for **Cut** in both studies, while **Orb** and **Portal** received low scores. To investigate our second research question (**RQ2**), we now further investigate the differences between the two studies. Therefore, we apply Mann-Whitney-U tests and independent t-tests with Bonferonni corrections between the results of Study I and Study II and investigate each transition in the following. In this section, we only report the significant results. Please refer to the supplement material for a detailed report.

7.1 Cut

Cut received the highest scores in Usability and Preference in both studies, indicating a general acceptance of this transition for VR and CR. Further, we find no significant differences in all measures between Study I and Study II. The high Preference and Usability ratings of **Cut** in both Studies are surprising, as the transition is often only used as a baseline [28], [30], [32], [38] or explicitly excluded due to its lack of continuity [24] in prior work. Further, **Cut** violates the first two principles proposed by Auda et al. [72] that transitions in CR should be smooth and utilize metaphors. But our results again indicate that **Cut** is a viable transition in a task-driven context.

7.2 Dissolve, Rift, and Fade

While **Dissolve** and **Rift** do not stand out negatively or positively in both studies, **Fade** received a positive rating for Task Load and in the Presence-related Questions in Study II. Compared to Study I ($Mdn = 2.50, IQR = 2.00 - 3.12$), a Mann-Whitney-U test even reveals a significant increase in the Presence-related Questions for Study II ($Mdn = 3.50, IQR = 3.00 - 4.5$) with $p = 0.043$. As mentioned

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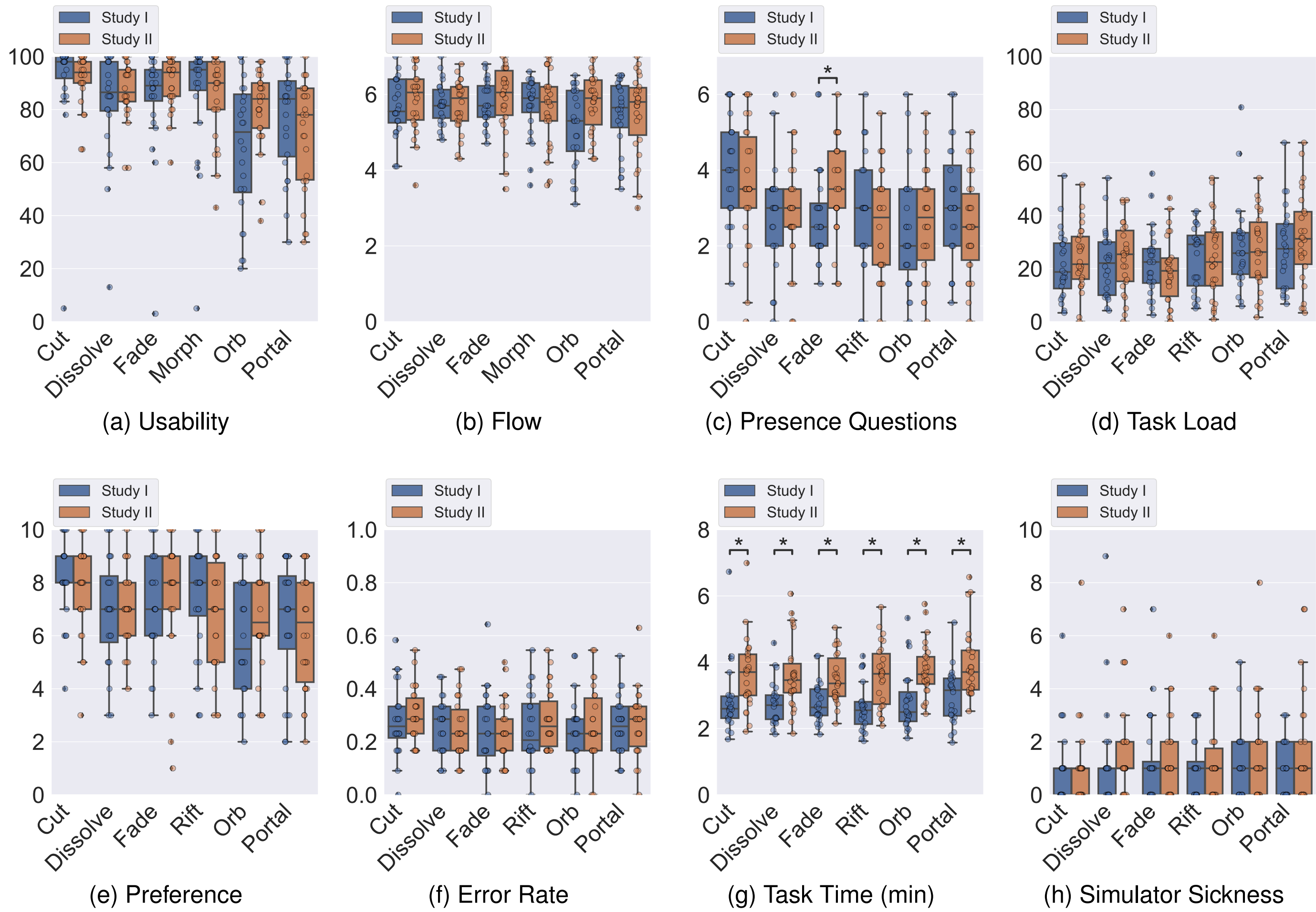

Fig. 6. The descriptive statistics of both studies. For the comparison, Mann-Whitney U tests or independent t-tests are used.

in Section 6.3, we assume that this might stem from the visual incoherence between both environments in Study II. Therefore, **Fade** might pose a suitable transition if the environments are visually incoherent, which needs further investigation. While the potential effect of visual incoherence is only found in Study II, we do not assume that this issue is only present in CR. Visual incoherence can also appear between two VR environments when there is a large visual difference between them. However, as the visual characteristics of a physical environment can not be changed in CR, it might be reasonable to adjust the virtual environment accordingly to achieve visual coherence between both environments.

7.3 Orb

While no tests for **Orb** reveal significant differences between both studies, Figure 6 indicates a possible trend for higher Usability, Flow, and Preference in Study II. In Study II **Orb** is labeled as "*fast*" (P1-II), "*easy*" (P8-II, P17-II), and "*useful*" (P1-II, P4-II, P9-II) due to its ability to preview the other environment, leading to a "*good orientation*" (P14-II). As negatives, the preview is also stated to be "*unnecessary*" (P7-II, P12-II, P16-II), and the transition as "*not suited for this task*" (P11-II), but the many negative comments of being "*unnecessary complex*" (P1-I, P4-I, P11-I, P13-I, P16-I, P22-I, P23-I) of Study I are missing in Study II. As the implementation of **Orb** does not change from Study I to Study II, it may be that the "complexity" of **Orb** is more tolerated when transitioning from VR to AR and vice versa. P10, for example, comments that the required arm movement enhanced the feeling "*of switching between the virtual world and reality*". Again, the visual incoherence could be a possible explanation for why **Orb** was received differently in Study II, as it, like **Fade**, might help to create a mental bridge between both environments. As **Orb** did not receive high Usability and Preference scores in both studies, but the preview was stated as useful, but unnecessary for our task, **Orb** might still be a good choice for tasks where a user only wants to peek into the other environment, rather than fully transition.

7.4 Portal

For **Portal**, there are no significant differences found in test results for all measures between Study I and Study II. Similar to **Orb**, it received low Usability and Preference scores, and the participant labeled it as "*unnecessary complex/cumbersome*" (P4-I, P5-I, P16-I, P17-I, P22-I, P3-II, P4-II, P5-II, P6-II, P7-II, P8-II, P10-II, P12-II) and "*not suited for this task*" (P8-I, P13-I, P2-II, P4-II, P9-II, P12-II, P21-II) in both studies. So, **Portal** may work better for a task that involves physical movement as part of the task itself. An example of this is users physically walking between two connected environments, like the private desk in AR and the collaboration space in VR in the prototype for virtual city tours by Feld & Weyers [89].

7.5 Task Time

For all six transitions, we found a general increase in Task Time between Study I and Study II with $p <= 0.022$. We assume this difference in Task Time could be caused by higher cognitive demand, the changes in the layouts of the environments, or the limited movement imposed by the used hardware in Study II. If a higher cognitive demand is the cause, it would likely affect the Error Rate as well. Since there are no significant differences in Error Rate between the studies, we conclude that the differences in task completion time are more likely due to the larger environment or the movement limitations. To investigate this further, we compare the total Head Movement and Head Rotation between both studies. For Head Movement, an independent t-test reveals a significant difference between Study I ($52.07m \pm 7.89m$) and Study II ($73.46m \pm 7.82m$) with $p < .001$. For Head Rotation, an independent t-test reveals a significant difference between Study I ($7843.45° \pm 1564.53°$) and Study II ($8912.30° \pm 1466.13°$) with $p = .016$. Given that the task stayed the same between both studies, a difference in movement indicates that the users had to walk over longer distances due to different layouts in the environments. However, since the layouts in Study I and Study II are all circular, the change in these layouts does not necessarily cause the difference in Rotation. This difference in Rotation could be an indication that the participants changed their behavior due to the attached cable. We also identified a noticeable motion blur on fast Head Rotations in AR with the Varjo-XR3, which may also have contributed to a change in behavior. In conclusion, we are not able to pinpoint the exact cause of the higher Task Time in Study II, as we found indications for the change in layouts and the movement limitations in Study II.

7.6 Take away

Summing up, we found indications that visual incoherence, the change in layouts, and limited movement may impact our results of Study II compared to Study I. These factors, however, do not stem from the characteristics of CR itself, but from the (visual) designs and the used hardware. Therefore, we assume the impact of a demanding task on the effects of transitions with regard to **RQ2** does not change when switching within a single stage (Study I) or switching across two stages of the RVC (Study II). Based on our results for both studies, we recommend considering efficiency when choosing a transition for a demanding task. For visual incoherent environments, we further recommend evaluating transitions that might mitigate the negative effects of visual incoherence. Finally, interactive transitions, like **Orb** and **Portal**, might only be suitable for tasks, where the interactivity can be connected to the task itself, like physical walking or only peeking into the other environment.

8 LIMITATIONS

It is important to acknowledge certain limitations inherent in our design. Compared to prior research of transitions [24], [28], [31], [33], [37], [50], our task design provokes a higher number and frequency of transitions to amplify possible effects. We argue that the results are more reflective for applications without focusing on transitions, but not necessarily to the amount present in our study. In addition, according to the third principle proposed by Auda [72] for transitions in CR, the parameters, like the transition speed for **Dissolve**, **Fade**, and **Rift**, should be user-controlled, which is not the case in our work. Further, these parameters are not evaluated beforehand, so tweaking these might improve the overall reception of these transitions.

As mentioned in the discussion sections, the results of the Presence-related Questions must be taken with caution. While these questions are based on related work (e.g. see Husung & Langben [28]), an evaluated questionnaire might give more robust results. However, measuring Presence via questionnaires can also render invalid results when the task is not able to create a mental model of Presence [84]. Further, comparing Presence across multiple stages with a questionnaire that is only designed for a specific stage (e.g., VR), may also lead to inconclusive results [85], [90].

Next to the limitations of our implementations and the measurement of Presence, we are aware that not only the stages of the RV continuum but also the hardware and the environments slightly change in Study II, and thus, the results of their comparison have to be taken with caution. While the used Varjo XR-3 provides a high resolution and low latency, there are still issues that impact the overall user experience. Next to the aforementioned required cable and the motion blur, the distance between the user's eyes and the cameras used for AR creates a discrepancy in the depth and size estimation between virtual and physical objects. As there is no solution to the issue, a developer can only choose between multiple trade-offs specific to their use case [4]. Further, we observed a learning effect identified through the user behavior in both studies due to the within-subjects design. Although we employed a Latin Square design to mitigate these effects, this approach likely contributed to an increased variability in our data.

9 CONCLUSION

In this work, we first investigate common transitions in prior work and identify a gap in research regarding the evaluation of transitions within a cognitively demanding task. To investigate this research gap, we first propose a cognitively demanding task that keeps the user engaged and allows for evaluating various transitions by requiring their frequent use during the completion of the task. We then reevaluate six transitions based on related work by adding the proposed task and performing two quantitative user studies in VR and CR. Regarding our first research question **RQ1**, if a cognitively demanding task impacts the effects of transitions, our results indicate that introducing a task impacts the Usability and Preference of the transitions both

4. https://developer.varjo.com/docs/get-started/camera-render-position

in VR and in CR. The participants seem to value efficiency over interactivity when solving a task, while no effect on task performance is found. Based on the results of Study II, we further hypothesize that transitions can also mitigate the effect of visual incoherence between two environments. However, a transition should still be chosen in conjunction with the intended task to solve within a system. In terms of our second research question **RQ2**, specifically in regards to the task-related impact on switching within a single stage compared to switching between two stages of the RVC, we found no difference between VR and CR.

In conclusion, we recommend considering efficient transitions and taking visual incoherence into account when choosing a transition. Additionally, when interactive transitions are chosen, it should be attempted to seamlessly integrate their interactivity into the task. Examining the research gap regarding the impact of transitions on visual coherence, especially in CR, highlights a promising subject for future work.

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