Teleportation Destination Previews Support Memory Retention During Virtual Navigation

Zubin Datta Choudhary*
University of Central Florida
FL, USA

Ferran Argelaguet†
Inria Rennes
Rennes, France

Gerd Bruder‡
University of Central Florida
FL, USA

Greg Welch§
University of Central Florida
FL, USA

Abstract

Teleportation is one of the most widely used locomotion techniques in virtual reality (VR) because it is efficient, minimizes motion sickness, and enables large-scale spatial traversal with minimal effort. However, research on the Doorway Effect shows that spatial transitions can impair memory of information encountered just before the transition. Event Segmentation Theory (EST) explains this by proposing that salient changes disrupt a person's working memory representation, causing recently encoded information to be replaced and reducing its availability for retrieval. By extension, the design of spatial transitions in VR may influence whether memory is disrupted or preserved, which could be a consideration in applied contexts such as education and training. One way to mitigate such impairment is to provide predictive cues about the upcoming change to reduce disruption. In VR, this can be implemented through teleportation previews, which give users a glimpse of the destination before arrival. In this experiment, we adapted the Doorway Effect paradigm to examine how two teleportation design factors — preview availability and environmental change — affect memory. Using a within-subjects 2×2 design ($N = 27$), participants studied a set of 3D objects, then teleported either within the same environment or into a different one, with or without a preview of the destination. After each transition, they completed a visual recognition task. Results showed two key findings: (1) without previews, recognition declined when teleporting into a different environment compared to remaining in the same one, and (2) when transitioning between different environments, providing a preview improved recognition relative to no preview. Together, these results indicate that both the distinctiveness of environments and the availability of previews shape memory during VR transitions. We discuss how these findings align with EST, highlight the cognitive consequences of teleportation design, and provide guidance for designing transitions that better support memory in applied contexts such as education and training.

Index Terms: Teleportation, Previews, Environment Transitions, Visual Recognition, Memory.

1 Introduction

Locomotion is fundamental to the experience of virtual reality (VR), enabling users to explore diverse immersive virtual environments (VEs) and to transition seamlessly between them. This flexibility supports a wide range of applications, from education to training and simulation, by providing access to contexts that would otherwise be inaccessible. For example, students can move directly from a historical landmark into a molecular model or a simulated laboratory, gaining experiential access across disciplinary domains. The ability to move between VEs is of one of VR's most powerful affordances. Among the many available locomotion techniques, teleportation has become the de facto standard, as it is simple to implement, efficient, and minimizes motion sickness while allowing large-scale traversal with little physical effort [29]. Yet, despite its practicality, teleportation can introduce hidden cognitive consequences. Research has shown that teleportation can reduce spatial awareness [1,42], impair spatial memory [15], and induce disorientation [3]. Compared to joystick locomotion, it has been found to impose greater workload [21], although automated locomotion can lower such demands [23]. While prior work has examined teleportation primarily in terms of spatial cognition and workload, many VR learning and training scenarios depend on users' ability to retain non-spatial information across teleports. This leaves open the question of how teleportation design choices affect non-spatial memory processes, such as visual short-term memory for 3D objects.

When experiences depend on learning or memory, such as in education and training, the memory organization of the experience becomes especially critical. Event Segmentation Theory (EST) [55] provides one such framework. According to EST, individuals build structured working memory (WM) representations known as event models, which bind together the features of an ongoing experience into a coherent whole. The stability of these event models depends on how the individual perceives the flow of experience. When the current situation is coherent and predictable, the model is preserved and information remains accessible. By contrast, salient changes — such as context shifts [6], abrupt transitions [28], or unpredictable outcomes [35] — can prompt to update its model. This updating process replaces older information with incoming information, reducing its availability. The Doorway Effect exemplifies this mechanism: recall for information acquired just before a spatial transition often declines when a person moves from one room to another [38]. For example, introducing new environmental cues can destabilize the current event model, making updating more likely and reducing access to prior content. This effect has been replicated across real-world environments [40], desktop-based virtual environments [38], narrative comprehension tasks [44], and even imagined spatial transitions [26]. In each case, noticeable changes triggered WM updating, with the cost of reduced recall for earlier information. Findings in immersive VR, however, are mixed: three studies report null results [30, 52, 54], while one more recent study provides supporting evidence [39]. These inconsistencies and relevance raise important questions about whether and how VR transition design moderates the effect.

Given that predictive cues about an upcoming event can mitigate the memory impairment [35], we were motivated to explore teleportation destination previews. While many design parameters merit investigation, such as transition speed, preview fidelity, and animation styles, our experiment focused on two core variables that directly modulate predictive information: preview availability (the presence of predictive information) and the magnitude of environmental change (the degree of visual and contextual shift between environments). Firstly, previews provide users with a glimpse of the destination environment before teleporting [20]. Rather than placing users instantaneously into an unfamiliar space, previews allow

*e-mail: zubin.choudhary@ucf.edu
†e-mail: ferran.argelaguet@inria.fr
‡e-mail: bruder@ucf.edu
§e-mail: welch@ucf.edu

them to anticipate and prepare for the upcoming change. From the perspective of EST, previews are relevant because they increase predictability: when individuals can anticipate the transition, the current event model can be adapted rather than abruptly replaced, preserving access to recently encoded information [35]. By contrast, teleportation without previews offers no opportunity for the individuals to anticipate the destination, making the transition abrupt and more likely to disrupt memory. The second factor is the magnitude of environmental change, which serves as a control variable grounded in prior work. In the classic paradigm [38, 40, 41], memory declined more when participants moved between rooms compared to remaining in the same one. VR allows this manipulation to be extended by altering perceptual features such as spatial layout, visuals, and auditory cues, thereby influencing how substantial a transition feels and how well prior information is remembered [5]. Although well motivated by EST, the impact of perceived change magnitude has not been explicitly tested in VR across VEs.

To investigate these questions, we conducted a within-subjects experiment using a 2×2 full factorial design ($N = 27$). The independent variables were (1) preview availability (preview vs. no-preview) and (2) magnitude of environmental change (same vs. different VE). On each trial, participants remember five 3D objects in a VE and then teleported either within the same environment or into a perceptually distinct one, with or without a preview of the destination. After each transition, participants completed a visual recognition memory task: they were shown a probe object (one of five objects or not) and asked to indicate whether it had been part of the prior set of objects.

The contributions of this paper are twofold. First, it extends research on the Doorway Effect into immersive VR, examining how teleportation — the most widely used locomotion technique — interacts with recognition memory during environment transitions. Second, it isolates two design factors, the availability of previews and the perceived distinctiveness of environments, and shows how the effect interacts. Together, these findings link transition design with cognitive theory and offer practical considerations for building VR experiences that better support memory in applications such as education and training.

The rest of the paper is structured as follows: Section 2 provides an overview of related work. Section 3 describes our experiment. The results are presented in Section 4 and discussed in Section 5. Section 6 concludes the paper. Throughout, we use “transition” to describe participant movement from one VE to another, and “traversal” to describe movement within a single VE.

2 Related Work

This section presents and discusses relevant research on teleportation, focusing on its impact on user cognition. We then delve into key aspects of human memory organization, including EST, and the cognitive effects of spatial transitions, such as the doorway effect.

2.1 Teleportation and Cognition

A unique affordance of VR is the ability to employ a variety of locomotion techniques for transitioning between environments while maintaining high levels of immersion. A large body of research has examined the trade-offs between different locomotion techniques depending on the context of the VR experience [2]. Among these, teleportation is one of the most widely accepted methods. It is intuitive, simple to implement, minimizes motion sickness, and enables large-scale traversal with minimal physical effort [8, 11, 22, 25].

Despite its practicality, Martinez et al. [29] note that cognitive consequences of locomotion techniques remain statistically less explored compared to performance and usability metrics. Investigating cognition in VR is inherently challenging, yet researchers have examined impacts on spatial cognition [17, 36, 43] and cognitive load [4]. These studies suggest that locomotion shapes spatial cognition (e.g., spatial understanding, memory acquisition) because the nature of movement through an environment directly influences how spatial representations are formed. Teleportation, for example, has been shown to negatively impact spatial understanding and memory when compared to natural walking techniques [24, 34]. Specific teleportation design choices can further alter outcomes: changes in teleportation cues affect spatial awareness of objects [42], post-transition spatial memory [14], and even teleportation duration influences memory outcomes [15]. In terms of cognitive load, teleportation has been found to impose greater workload than joystick locomotion [21], whereas automated locomotion generally affords lower workload [23].

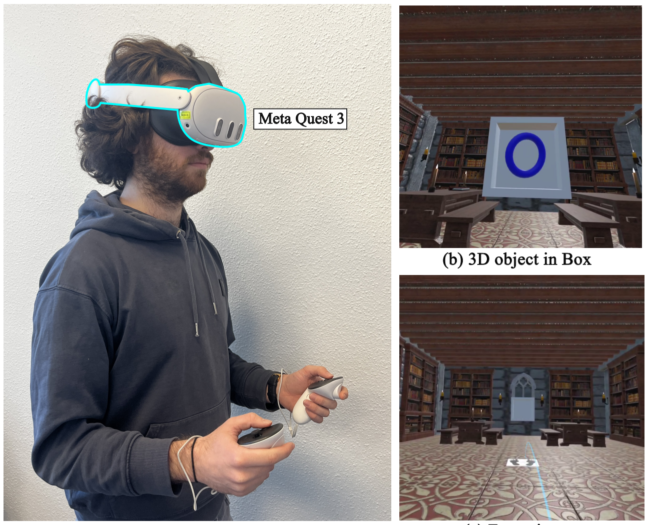
Teleportation in VR admits numerous design variations. One dimension concerns the speed of travel: transitions may be instantaneous, as in snap or cut teleportation, or more gradual. Gradual transitions introduce additional considerations such as animation style, where designers commonly employ fade sequences or warping animations [12]. Teleportation can also incorporate interactive elements; for example, SliVR by Linne et al. [27] presents users with a hub interface through which they can explore and select among multiple destinations. Another prevalent design component is the use of previews—visual or multimodal cues depicting the destination environment—also featured in SliVR. Previews can take several forms, including faded visual glimpses, directional indicators, or viewpoint cues [20]. By employing multi-step teleportation via incremental jumps, Rahimi et al. [42] demonstrated that intermediate continuity cues can enhance spatial awareness. Although these steps are not explicit previews, the findings suggest that providing preparatory perceptual information helps users better anticipate environmental changes. While prior work has primarily examined these design variations through the lens of spatial cognition [15], the role of prediction may have broader implications. Previews not only support orientation and navigation but may also influence how users organize and retain information during VR experiences. This raises the possibility that teleportation previews could affect memory processes beyond spatial updating—an open question that motivates the present work.

2.2 Memory Organization and Spatial Transitions

According to EST, people construct structured working memory representations known as event models, which bind together features of ongoing experience into a coherent, real-time understanding of events [55]. Because WM is capacity-limited, these models can only preserve a finite amount of information. Their stability depends on how the experience unfolds: when the situation is coherent and predictable, the model is preserved and recent information remains accessible. By contrast, salient disruptions — such as context shifts, abrupt transitions, or unpredictable outcomes — introduce new information that destabilizes the model. To adapt, the system updates the model by incorporating the new context, often replacing prior content and reducing its availability for recall.

Empirical evidence supports this account across several domains. Heusser et al. [18] showed that altering visual backgrounds during an object memory task was sufficiently disruptive to impair recognition performance. Similarly, Raccah et al. [37] found that changing speaker gender identity in spoken narratives reduced recall. These findings suggest that when experiences are disrupted, event models are updated to accommodate the change, but at the cost of recently encoded information.

The Doorway Effect provides a well-established example of this process. Visual recognition memory declines when people move between rooms, as first demonstrated by Radvansky and Copeland [38]. In their interactive, screen-based experiment, participants carried objects either within a single room (no-shift) or across a doorway into a new room (shift). Memory was worse in the shift condition, consistent with the idea that spatial transitions are dis-



(a) Participant (b) 3D object in Box (c) Footprint

Figure 1: (a) Annotated photo showing a participant completing the experiment, wearing a Meta Quest 3 while holding both controllers. (b) In-VR screenshot of the floating box in which the 3D objects were presented. (c) In-VR screenshot of the footprint where participants were instructed to stand to view the 3D objects in the box.

ruptive enough to impair recall. Subsequent work has extended this paradigm by examining factors such as screen size and immersion [40], participant age [41], additional cognitive load [30], and doorway spatial layout [5].

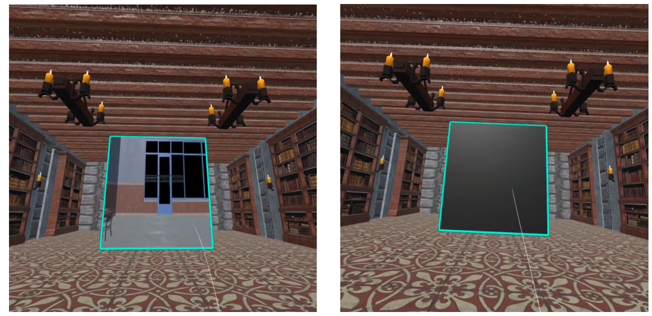
By extension, VR transitions — and their specific design — may produce similar memory effects depending on how disruptive the transition is perceived to be. As described in Section 2.1, VR allows transitions to be designed in diverse ways, but not all variations may destabilize memory to the same degree. One element of particular interest is the use of destination previews. Previews have been shown to improve spatial awareness, and by offering a glimpse of the upcoming environment, they also support prediction. From the perspective of EST, increasing predictability helps stabilize event models, reducing the likelihood that recent information is overwritten. Building on this reasoning, we designed a human-subject experiment to investigate the memory effects of teleportation previews during virtual navigation.

3 Experiment

In this section, we describe our human-subject experiment. The experimental protocol was approved by the ethical review board of our university.

3.1 Participants

Our experimental procedure and recruitment of participants were approved by the institutional review board of our university under protocol number 2025/468. A total of 27 participants were recruited from the university community (15 male, 10 female and 2 non-binary, ages between 22 and 36, $M = 26.40$, $SD = 3.80$). All of the participants had normal or corrected-to-normal vision; 6 wore glasses and 5 wore contact lenses during the experiment. None of the participants reported any visual or vestibular disorders, such as color or night blindness, dyschromatopsia, or a displacement of balance. All participants were affiliated with the university (students or staff) and were familiar with VR technology who responded to open calls for participation. While we did not collect detailed VR experience levels, none were first-time users.



(a) Preview (b) No Preview

Figure 2: Screenshots showing the portals in the experiment with (a) Preview, and (b) No Preview.

3.2 Material

The physical setup and the virtual experience is described below.

3.2.1 Physical Apparatus

The experiment trials required participants to remain standing. During breaks and questionnaire completion, they were seated. The study was conducted within an empty laboratory space with dimensions of $5m$ (length) $\times$ $5m$ (width)). For the VR experience, participants donned a Meta Quest 3 [32] head-mounted display (HMD), offering a native resolution of 2064×2208 per eye at a refresh rate of 120 Hz. The HMD's integrated inside-out tracking system was used, and participants interacted with the VE using tracked controllers.

3.2.2 Virtual Experience

We describe two parts of the virtual experience in this section, the design of the VEs and teleport transition design via portals.

Virtual Environments We prepared six VEs, varying in visual, auditory and spatial characteristics. Every environment consisted of a floating box and a footprint, $5m$ and $4.5m$ away from the participant's starting location in the same direction. Once they teleported onto the footprint, they viewed 3D objects in the floating box, at eye level (based on the virtual height of the HMD). Upon exposure of the 3D objects, a portal was presented behind the participant, at the same starting location, indicating them to transition into the next environment.

As explained in Section 1, we aimed for participants to perceive distinct spatial and environmental transitions; therefore, each environment had unique visual and auditory characteristics. We had the following six environments: environment 1 (bedroom [49]), environment 2 (library [51]), environment 3 (coffee shop [48]), environment 4 (castle dock [47]), environment 5 (spaceship [46]), environment 6 (office [50]) and then back to environment 1. Please refer to Figure 3 for visual representations of the environments. In this experiment, participants either transitioned into a different environment or the same environment. For the same environment condition, participants experienced environment 1 only, so the portal transitioned them back to environment 1. For the different environments condition, participants began in environment 2 followed by 3,4, and 5, and then would return back to environment 1 until all trials were completed. Note that each soundtrack per environment was unique, providing an ambient sound. All rendering was done directly on the HMD. To develop the audio-visual environment, we used Unity 6000 (LTS).

Virtual Environment Transition Design Participants transitioned between the virtual environments using a teleportation-based interaction implemented with the Meta XR SDK [31]. To move within a VE, participants used the joystick on their right controller to select a destination on the floor, indicated by a curved arc originating from the controller and a circular landing marker where the arc intersected the ground.

To transition into the next VE, participants selected the portal initially positioned 4.5 m in front of them using a straight-line raycast from their dominant-hand controller. This portal consisted of a flat 2.5×2.5 m surface floating above the floor so that the box is at eye level and facing the participant. Depending on the condition, the portal either displayed a 2D live preview of the upcoming environment (preview condition) or a black, non-informative surface (no-preview condition), as shown in Figure 2. The live preview was generated using a virtual camera placed at the starting location of the next environment, adjusted for participant height.

To initiate a transition, participants pointed at the portal, causing its border to highlight yellow. Pressing the trigger turned the border green, confirming successful interaction. The transition sequence then unfolded over six seconds: during the first three seconds, the screen faded to black while the current environment's audio volume reduced smoothly to zero; the participant was then teleported to the next environment's starting location; finally, the scene faded back in over three seconds while the new environment's audio faded in from silence. Upon arrival, participants faced away from the floating box containing the memory stimuli, requiring them to turn around to view and engage with the new environment.

3.3 Methodology

3.3.1 Study Design

To investigate the teleportation transition design on users' memory performance after experiencing a spatial transition, we prepared a full factorial 2×2 within-subjects study design with the following independent variables:

1. *Preview:* The user will see a preview of the next environment through the portal prior to transition (*Prev*) or not (*NoPrev*).

2. *Environment change:* They will either transition between different environments (*DiffEnv*) or the same environment (*SameEnv*).

Each participant experienced a total of four conditions (see Table 1), which were counter-balanced via a Latin square design.

Table 1: Abbreviations for Experimental Conditions

Condition	Description
Prev-DiffEnv	Preview + Different Environments
NoPrev-DiffEnv	No Preview + Different Environments
Prev-SameEnv	Preview + Same Environment
NoPrev-SameEnv	No Preview + Same Environment

3.3.2 Memory Task

To study the effects of teleportation previews and magnitude of change across VEs on users' memory, we primarily measured participants' visual recognition performance after transitioning. The task was a modification of the seminal experiment by [38], which demonstrated the Doorway Effect in a non-immersive VE.

In this experiment, participants were immersed in a VE. At one end of the environment was a floating box (which was open facing the user) slightly above eye level. Half a meter in front of the box was a footprint on the floor indicating where participants should stand. Standing on the footprint triggered the first bell sound and began displaying 3D objects after 100*ms* in the floating box. In each environment, five unique 3D objects were presented. The objects varied in shape (cube, sphere, pyramid, cone, prism) and color (red, green, blue, yellow), resulting in a total of 20 possible 3D objects. Each object was displayed for 120*ms* with no time between objects. After displaying all five objects, the presentation ended with a second bell sound. Participants then transitioned to the next VE by turning around and interacting with the portal. On entering the new VE, a memory test was administered. Each condition consisted of twenty trials, out of which four trials did not have a memory test. These trials were labeled as *skip* trials.

3.4 Measures

3.4.1 Visual Recognition and Confidence

In the memory task, participants first studied a sequence of five 3D objects presented within a VE. With a 100 ms delay after entering the new environment, a visual recognition questionnaire was shown on a UI panel. During this questionnaire, traversal within the VE was disabled to ensure focus on the task. The UI presented a single probe object and asked: *Q1: Do you remember this object from the last environment?* Probe objects came in two types: (1) Exists (one of the five objects studied before the transition), or (2) Missing (a novel object not previously shown in the prior VE). They responded "yes" for exists probes and "no" for missing probes. Immediately after, they rated their confidence on a five-point scale: *Q2: How confident are you with your response?* (1 = least, 5 = most).

Each participant completed twenty transitions, sixteen of which were followed by recognition tests (twelve "exists" probes and four "missing" probes). The remaining four transitions were filler trials with no recognition test. These filler trials were randomly interleaved with the test trials to reduce participants' ability to anticipate when a recognition test would occur, thereby discouraging strategic encoding or rehearsal. Recognition performance was measured as the proportion of correct responses across probe types, following the approach of [38].

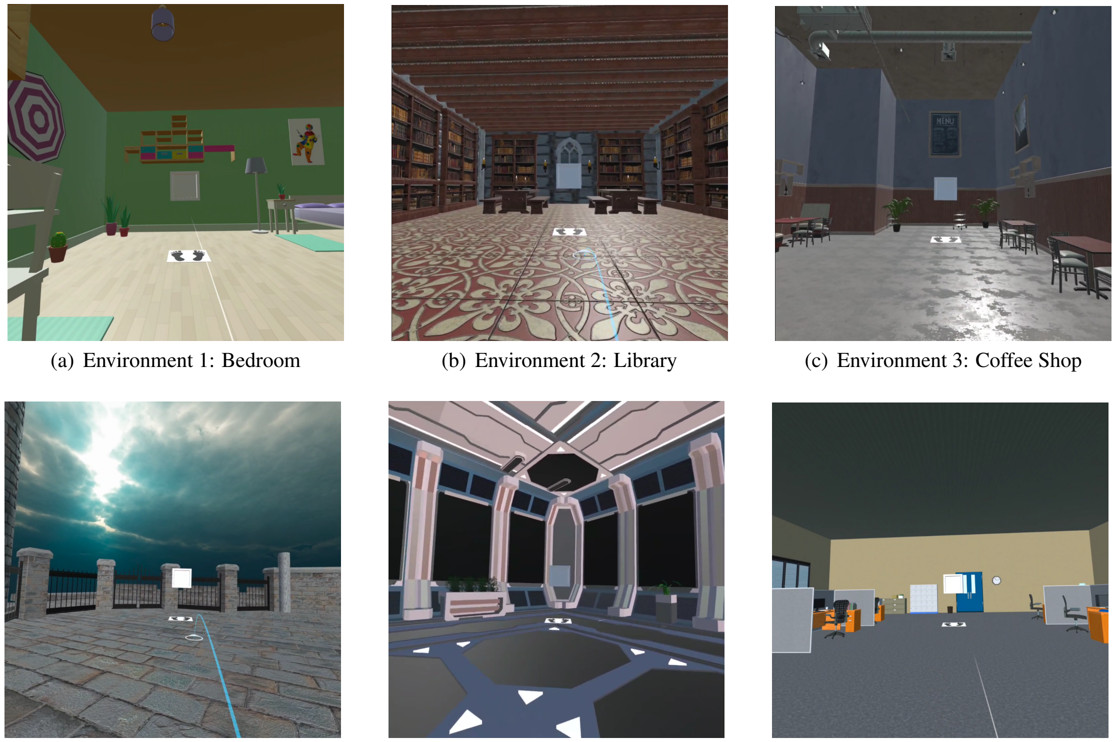
3.4.2 Subjective Task Load

After each condition, participants would remove the HMD, and answered the Raw Task Load Index (R-TLX) questionnaire [16]. The R-TLX consists of six questions, each corresponding to one dimension of the perceived workload. For each dimension (mental demand, physical demand, temporal demand, performance, effort, and frustration), the participants provide a score on a scale, from 1 ("Very low") to 7 ("Very high"). Compared to the NASA Task Load Index (NASA-TLX) questionnaire [16], the R-TLX scale eliminates the subjective weighting process and the ratings are averaged. According to a review of 29 studies, by Hart et al. [16], in which R-TLX was compared to NASA-TLX, the weighting process was found to be either more sensitive, less sensitive, or equally sensitive, so the authors recommend either scales.

3.5 Procedure

Upon arrival, participants read through a consent form and provided their signed consent to participate in the experiment. The experimenter then described the task protocol and pre-exposed them to all the six VEs in VR. They also familiarized themselves with the memory task and portal interaction, which took approximately six minutes. For task details, please refer to Section 3.3.2.

Participants were presented with five unique 3D objects in a VE and instructed to transition to the next VE via the portal. Upon entering the next VE, they were asked a memory question via a user interface. Participants answered the questions using their controller and then proceeded to learn the next five unique 3D objects in the new VE. Per condition, they transitioned twenty times, and the questionnaire was administered sixteen times. Four transitions did not lead to the questionnaire. After each condition, participants removed the HMD, and the experimenter administered a 5-minute



(a) Environment 1: Bedroom (b) Environment 2: Library (c) Environment 3: Coffee Shop

(d) Environment 4: Castle Dock (e) Environment 5: Spaceship (f) Environment 6: Office

Figure 3: Virtual experience comprised of six distinct environments, each with unique visual, auditory and spatial characteristics. Above are screenshots of the environments in VR from the experiment and each soundtrack was unique.

break. During the break, participants answered the R-TLX questionnaire and some general questions about their experience so far. This process was repeated for all four conditions.

After completing all conditions, participants filled out a post-questionnaire assessing their demographics and prior VR experience, and answered general questions about their overall experience. Finally, the experiment concluded. It took up to one hour.

3.5.1 Hypotheses

Building on the motivations in Section 1, we formulated three hypotheses regarding the influence of destination previews and contextual shifts on recognition memory:

H1 Previews improve recognition during different-environment transitions. (*Prev-DiffEnv* > *NoPrev-DiffEnv*)
We consider that predictive cues reduce the cognitive disruption typically caused by transitioning into a perceptually distinct environment.

H2 Without previews, same-environment transitions yield better recognition than different-environment transitions.
(*NoPrev-SameEnv* > *NoPrev-DiffEnv*)
This hypothesis aligns with prior research on context stability, predicting a performance drop when participants encounter an event boundary without prior information.

H3 Previews will not significantly impact on recognition performance during same-environment transitions.
(*Prev-SameEnv* ≈ *NoPrev-SameEnv*)
This reflects the expectation that predictive information provides limited marginal benefit when the transition itself is already minimally disruptive.

4 Results

We analyzed the responses with repeated-measures analyses of variance (RM-ANOVAs) and Tukey multiple comparisons with Bonferroni correction at the 5% significance level. We confirmed the normality with Shapiro-Wilk tests at the 5% level and QQ plots. Degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity when Mauchly's test indicated that the assumption of sphericity was not supported. As an effect size, we report the partial eta squared (η_p^2), whereby a value of 0.01 is considered a small effect, 0.06 a medium effect, and 0.14 a large effect [9]. Analysis and figures were done using RStudio version 2024.12.0.

4.1 Visual Recognition Performance

We did not find any main effects from our two independent variables *previews* and *environment change* on participants' visual recognition memory performance. After performing post-hoc tests, we found a significant interaction effect (*previews* × *environment*) on participants' visual recognition memory performance, with the following pairs significant: (*NoPrev-SameEnv*>*NoPrev-DiffEnv*) and (*Prev-DiffEnv*>*NoPrev-DiffEnv*). Full statistical results are reported in Table 2 and box plot in Figure 4(a).

Table 2: Statistical test results for participants' visual recognition memory performance.

Factor	$F(1,26) =$	p	η_p^2
Previews	0.76	0.38	0.29
Environment Change	1.09	0.30	0.04
*Previews**Environment*	11.52	**0.002**	0.31

(a) Recognition (b) Confidence (c) R-TLX

Figure 4: Box plots illustrating participants' (a) visual recognition performance, (b) confidence scores, and (c) subjective workload as measured by the R-TLX scale. The x-axis shows the preview conditions (*NoPrev* and *Prev*), while the color of the bars indicates the environment transition type (blue for different environments, red for the same environment). The y-axis for (a) represents the number of hits (0–16), for (b) confidence scores (1–5), and for (c) R-TLX scores (1–7). R-TLX provides average task load along with six other dimensions: performance, effort, frustration, mental demand, temporal demand, and physical demand. Horizontal bars and asterisks indicate statistical significance ($* \ p<0.05$).

4.2 Confidence Scores

We found a significant main effect of environment change on participants' confidence scores, but no effect of previews. As shown in Figure 4(b), confidence was lower when participants transitioned between different environments compared to remaining in the same one. Post-hoc tests revealed no significant interaction effects. Complete statistical results are provided in Table 3, with box plots shown in Figure 4(b).

Table 3: Statistical test results for participants' confidence scores.

Factor	$F(1,26) =$	p	η_p^2
Previews	0.48	0.49	0.02
Environment Change	10.19	**0.003**	0.28
*Previews*Environment*	0.64	0.43	0.02

4.3 Subjective Task Load

From the R-TLX questionnaire, we measured overall task load as well as six sub-dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration. We found a significant main effect of environment change on perceived performance, frustration, and effort. As shown in Figure 4(c), transitions between different environments associated with lower perceived performance, higher frustration, and greater effort. Post-hoc analyses further revealed a significant interaction effect on mental demand, specifically the following pair *NoPrev-SameEnv>NoPrev-DiffEnv* Complete statistical results for all task load measures are provided in Table 4, with corresponding box plots in Figure 4(c).

Table 4: Statistical test results for participants' subjective task load from the Raw-TLX scale. R-TLX provides average task load along with six other dimensions: performance, effort, frustration, mental demand, temporal demand, and physical demand.

Measure	**Factor**	$F(1,26) =$	p	η_p^2
Average Task Load	*Previews*	0.16	0.696	0
	Env Change	0.80	0.378	0.03
	*Previews*Env*	1.46	0.238	0.05
Performance	*Previews*	0.73	0.401	0.03
	Env Change	15.17	<**0.005**	0.37
	*Previews*Env*	2.49	0.126	0.09
Frustration	*Previews*	0.46	0.503	0.02
	Env Change	4.88	**0.036**	0.16
	*Previews*Env*	0	1	0
Effort	*Previews*	0.98	0.331	0.04
	Env Change	8.95	**0.001**	0.26
	*Previews*Env*	2.08	0.161	0.07
Mental Demand	*Previews*	0.06	0.458	0.02
	Env Change	1	0.062	0.13
	*Previews*Env*	0.68	**0.006**	0.25
Physical Demand	*Previews*	0.21	0.813	0
	Env Change	0.20	0.33	0.04
	*Previews*Env*	2.74	0.415	0.03
Temporal Demand	*Previews*	0.57	0.649	0.01
	Env Change	3.79	0.656	0.01
	*Previews*Env*	8.77	0.109	0.1

5 Discussions

Our experiment reveals that the changing environments and using previews when teleporting between VEs can have an impact on users' visual recognition memory performance. To summarize our main findings from Section 4: (1) teleporting between distinct VEs led to poorer memory performance without previews (*NoPrev-SameEnv>NoPrev-DiffEnv*), (2) teleporting between distinct VEs with previews improved memory performance (*Prev-DiffEnv>NoPrev-DiffEnv*), and (3) subjective measurements of confidence and some task load dimensions were affected by changing VEs. We discuss our main findings and hypotheses (Section 5.1), followed by discussions about participants' perception of their own performance (Section 5.2), and then address the limitations Section 5.3.

5.1 Memory Effects

Our primary investigation concerned how VR teleportation design influences recognition memory, guided by the hypotheses in Section 3.5.1. As outlined in the Introduction (Section 1), EST describes how transitions of varying predictability and magnitude influence the stability of event models in working memory. In brief, predictable and coherent transitions tend to preserve recently encoded information, whereas salient disruptions increase the likelihood of event-model updating, which can reduce access to prior content. Prior findings on the Doorway Effect and other context-shift paradigms support this view across a range of perceptual and narrative domains [18, 37, 38, 41]. Our study extends these ideas into immersive VR by examining whether teleportation previews and environmental change modulate memory performance during scene transitions.

Building on these expectations, we hypothesized that spatial transitions across VEs would produce memory differences depending on both preview availability and the magnitude of environmental change. Firstly, our experiment provided users with previews, a glimpse of the destination environment, before teleportation, increasing the predictability of upcoming transitions. Consistent with this expectation, our results (Section 4.1) showed that participants performed better with previews than without when transitioning into distinct environments, supporting **H1**. In our implementation, previews were presented through a portal that displayed a 2D live feed of the next environment, combined with a six-second fade-in/fade-out animation. However, previews can be designed in many other ways that may differentially influence memory. Visual previews may range from simple static snapshots (e.g., thumbnails or minimaps) to richer, continuous glimpses into the destination [20]. Auditory cues—such as environmental soundscapes or spoken descriptions—may likewise support anticipation. Previews may also be interactive; for instance, SliVR by Linne et al. [27] allows users to examine and select among multiple destinations, each accompanied by visual information. These variations differ in the level of predictability they provide, the degree of immersion they evoke, and the extent to which they engage working memory resources. Although we did not test these alternatives, our findings indicate that preview design is a promising dimension for future investigation.

Secondly, we tested whether teleporting within the same VE versus into a perceptually distinct VE would destabilize event models sufficiently to impair recognition (**H2**). Although this effect has not been explicitly demonstrated in VR, EST predicts that larger disruptions increase the likelihood of memory impairment. Our findings support this prediction: in the absence of previews, participants' recognition performance declined when transitioning into a distinct VE compared to remaining in the same one. This manipulation was achieved by varying spatial, visual, and auditory properties of the environments (see Section 3.2). Interestingly, prior VR studies of the doorway effect [30, 52] did not observe such memory effects. Those experiments employed relatively similar environments, with doorways serving as the only cue for change, following the original desktop paradigm [38]. It is possible that these manipulations were not perceptually disruptive enough to produce memory decline. While such studies aimed to replicate the original effect in VR, their mixed outcomes raise the question of whether transitions in immersive VR are perceived differently from those in other mediums, such as desktop settings or the real world.

Considering our two main findings, previews increased predictability (**H1**), whereas transitioning into a distinct VE reduced it (**H2**). However, when previews were provided for same-environment transitions, they offered no measurable benefit in this study. This outcome is consistent with EST: since transitions within the same VE are relatively stable and do not strongly destabilize the event model, there is little need for additional predictive cues. Previews become meaningful only when an upcoming change threatens to disrupt the current model, such as during transitions into distinct environments. Thus, our results support Hypothesis **H3**, clarifying that the effectiveness of previews depends on the degree of disruption introduced by the transition, however more research is required to accept the absence of the effect.

In our experiment, we focused on two transition design variables, each with two levels: the availability of previews and environmental change, but other variables may also influence how memory is organized during VR transitions. For instance, our previews can be designed uniquely, such as richness of preview (2d, 3d, interactive), and preview modality (visual, audio). Another important factor is the transition animation style. We implemented the popular fade-in/fade-out sequence over six seconds, but sharper animations such as snap/cut teleport [12] may be more disruptive, potentially destabilizing memory representations. Conversely, more gradual transitions [45] may create a smoother, more continuous experience. Locomotion technique is another promising dimension [2, 7]. Our experiment focused on teleportation, which is common in commercial VR, yet alternatives such as natural walking may have very different cognitive consequences. Walking unfolds gradually, providing continuous sensory input and affording users a high degree of agency over movement [34]. Future work should systematically examine how these transition design factors, individually and in combination, can shape memory organization in VR.

Beyond design considerations, it is also important to reflect on the functional role of memory changes during transitions. Here we provide evidence on why both memory retention and memory impairment can be important in different scenarios. Impaired memory poses clear costs in scenarios where recently learned information should be preserved, for example, a student in a VR classroom may forget material just introduced when transitioning into a new environment. In other situations, however, forgetting can be adaptive. Releasing information may prepare users for a new context where the previous content is no longer relevant, freeing cognitive resources for upcoming tasks [10, 33]. Furthermore, some research has shown that large updates triggered by disruptions can enhance memory for information surrounding the disruption, even up to a month later [13]. Based on them, such disruptions may impair recall of just-learned material but strengthen memory for the disruptive event itself, leaving a more vivid and durable trace in long-term memory.

5.2 Participants' Perception of their Own Performance

Our findings demonstrate objective memory effects due to teleportation across VEs, but we also examined participants' subjective experience through confidence ratings and the R-TLX. From the confidence scores (see Section 4.2), we found a main effect of environmental change but not previews: as shown in Figure 4(b), confidence declined when participants transitioned into a distinct environment. Similarly, the R-TLX results (Section 4.3) revealed lower perceived performance, higher frustration, and greater effort in these conditions. Taken together, these findings suggest that the disruption caused by environmental change was subjectively felt by participants. By contrast, previews — though they improved recognition performance in distinct environments — did not translate into higher confidence ratings or reduced task load. In the post-experiment questionnaire, when asked *"Did you feel any memory performance difference among the four conditions?"*, several participants reported that changes in environment felt distracting and may have reduced their memory performance. Some, however, described the previews themselves as distracting.

Overall, these results suggest that while participants were sensitive to the disruptive nature of environmental change, they were largely unaware of the protective effect of previews on memory. This discrepancy highlights a potential gap between objective performance and subjective perception in VR transition design.

5.3 Limitations

This experiment examined how spatial transitions and teleportation design factors affect memory in VR. While our results align with our hypotheses (refer Section 3.5.1), we caution against interpreting the observed patterns as definitive. The controlled laboratory environment was essential for isolating variables of interest, but it also constrains ecological validity. Our transitions were created with specific VEs and a particular teleportation design, which ties our findings to this scenario. To improve generalizability, future work should consider the following limitations.

First, the design space for VR transitions is large, yet we examined only two factors (preview availability and environmental change) each with two levels. Other factors such as preview richness (e.g., 2D, 3D, interactive), modality (visual, audio), animation style (fade versus snap teleport), and locomotion technique (teleportation versus natural walking) may significantly influence memory organization. Future studies should explore these dimensions individually and in combination to understand their cognitive impact.

Second, based on prior research on VR transitions, it is known that spatial transitions can influence spatial memory [15, 42], primarily because the nature of movement directly affects how spatial representations are formed. Our study, however, tested recognition memory using visual probes (3D objects), which differs from spatial memory. This choice was informed by prior doorway effect experiments [38,40,41], but memory is multifaceted. Different probe types(verbal stimuli, auditory cues, or complex visual scenes) engage different cognitive processes. It remains an open question whether the effects observed here extend across these modalities.

Third, we used a simplified 1–7 RAW-TLX rating scale rather than the standard NASA-TLX 0–100 scale. While task load was not a primary measure in this study, this choice may limit comparability with prior VR workload research.

Finally, our participant pool was limited in terms of age (mean age 26.4 years, $SD = 3.8$), gender (15 male, 10 female, 2 non-binary) and educational background (all were from our university community). Memory performance can vary with age, and prior research indicates gender-related differences in specific domains. For example, males often show advantages in visuospatial memory [53], whereas females tend to excel in semantic memory [19]. Furthermore, because our sample consists entirely of university-affiliated individuals, our results may be influenced by the use of advanced mnemonic strategies. Consequently, these findings may not represent the memory capabilities of the general population. Future work should prioritize recruiting larger and more diverse participant pools, encompassing variations in age, gender, and educational background, along with other human factors such as cultural background.

6 Conclusions

In this paper, we presented a human-subjects experiment examining how two teleportation transition factors, preview availability and environmental change, affect memory for information encountered just before a spatial transition. Our findings reveal two key results. First, recognition performance was significantly higher when participants teleported into a distinct environment with a preview of the destination compared to without one. Second, in the absence of previews, recognition performance dropped when participants transitioned into a distinct environment relative to remaining in the same environment. We attribute these results to the disruptive nature of transitions. Event Segmentation Theory (EST) suggests that salient changes prompt working memory to update, replacing previously encoded information and thereby reducing its accessibility. Transitions into perceptually distinct environments appear more disruptive than those within the same environment. Providing previews, however, gives users a glimpse of the upcoming context, allowing them to anticipate the change and reducing its disruptive impact. These findings have two practical implications. If the goal is to support memory retention, for example, in educational or training contexts, designers should minimize distinct environment transitions, or if unavoidable, include previews to mitigate memory impairment. Conversely, if the goal is to encourage the release of outdated or irrelevant information, more distinct transitions without previews may be preferable. Overall, this study highlights how teleportation design can shape cognitive outcomes in VR. By connecting design choices to EST, we provide both a theoretical account of memory effects during VR transitions and practical guidance for building transitions that better align with application goals.

Acknowledgments

This material includes work supported in part by the National Science Foundation under Award Number 2235066 (Dr. Han-Wei Shen, IIS); the Office of Naval Research under Award Numbers N00014-21-1-2578 and N00014-21-1-2882 (Dr. Peter Squire, Code 34); the AdventHealth Endowed Chair in Healthcare Simulation (Prof. Welch) and the Chateaubriand Fellowship 2024-2025 (Zubin Datta Choudhary).

References

[1] N. H. Bakker, P. O. Passenier, and P. J. Werkhoven. Effects of head-slaved navigation and the use of teleports on spatial orientation in virtual environments. *Human factors*, 45(1):160–169, 2003. 1

[2] C. Boletsis. The new era of virtual reality locomotion: A systematic literature review of techniques and a proposed typology. *Multimodal Technologies and Interaction*, 1(4):24, 2017. 2, 7

[3] D. A. Bowman, D. Koller, and L. F. Hodges. Travel in immersive virtual environments: An evaluation of viewpoint motion control techniques. In *Proceedings of IEEE 1997 Annual International Symposium on Virtual Reality*, pp. 45–52. IEEE, 1997. 1

[4] G. Bruder, P. Lubos, and F. Steinicke. Cognitive resource demands of redirected walking. *IEEE Transactions on Visualization and Computer Graphics*, 21(4):539–544, 2015. doi: 10.1109/TVCG.2015.2391864 2

[5] M. G. Buckley, L. A. Myles, A. Easton, and A. McGregor. The spatial layout of doorways and environmental boundaries shape the content of event memories. *Cognition*, 225:105091, 2022. 2, 3

[6] F. Chiossi, L. Haliburton, C. Ou, A. M. Butz, and A. Schmidt. Short-form videos degrade our capacity to retain intentions: Effect of context switching on prospective memory. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, CHI '23. Association for Computing Machinery, New York, NY, USA, 2023. doi: 10.1145/3544548.3580778 1

[7] Z. D. Choudhary, L. Battiste, R. Syamil, H. Furuya, F. Argelaguet, G. Bruder, and G. Welch. Examining the effects of teleportation on semantic memory of a virtual museum compared to natural walking. In *International Conference on Artificial Reality and Telexistence & Eurographics Symposium on Virtual Environments (ICAT-EGVE)*, pp. 1–10, 2024. 7

[8] C. G. Christou and P. Aristidou. Steering versus teleport locomotion for head mounted displays. In *Augmented Reality, Virtual Reality, and Computer Graphics: 4th International Conference, AVR 2017, Ugento, Italy, June 12-15, 2017, Proceedings, Part II 4*, pp. 431–446. Springer, 2017. 2

[9] J. Cohen. Quantitative methods in psychology: A power primer. *Psychol. Bull.*, 112:1155–1159, 1992. 5

[10] S. DuBrow and L. Davachi. The influence of context boundaries on memory for the sequential order of events. *Journal of Experimental Psychology: General*, 142(4):1277, 2013. 7

[11] Y. Farmani and R. J. Teather. Evaluating discrete viewpoint control to reduce cybersickness in virtual reality. *Virtual Reality*, 24:645–664, 2020. 2

[12] N. Feld, P. Bimberg, B. Weyers, and D. Zielasko. Keep it simple? evaluation of transitions in virtual reality. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems*, pp. 1–7, 2023. 2, 7

[13] S. Flores, H. R. Bailey, M. L. Eisenberg, and J. M. Zacks. Event segmentation improves event memory up to one month later. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 43(8):1183, 2017. 7

[14] K. T. Gagnon, B. J. Thomas, A. Munion, S. H. Creem-Regehr, E. A. Cashdan, and J. K. Stefanucci. Not all those who wander are lost: Spatial exploration patterns and their relationship to gender and spatial memory. *Cognition*, 180:108–117, 2018. 2

[15] M. Gottsacker, H. Furuya, L. Battistel, C. P. Jimenez, N. LaMontagna, G. Bruder, and G. F. Welch. Exploring spatial cognitive residue and methods to clear users' minds when transitioning between virtual environments. In *2024 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 1000–1009. IEEE, 2024. 1, 2, 8

[16] S. G. Hart. Nasa-task load index (nasa-tlx); 20 years later. In *Proceedings of the human factors and ergonomics society annual meeting*, vol. 50, pp. 904–908. Sage publications Sage CA: Los Angeles, CA, 2006. 4

[17] Q. He, T. P. McNamara, B. Bodenheimer, and A. Klippel. Acquisition and transfer of spatial knowledge during wayfinding. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 45(8):1364, 2019. 2

[18] A. C. Heusser, Y. Ezzyat, I. Shiff, and L. Davachi. Perceptual boundaries cause mnemonic trade-offs between local boundary processing and across-trial associative binding. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 44(7):1075, 2018. 2, 7

[19] M. Hirnstein, J. Stuebs, A. Moè, and M. Hausmann. Sex/gender differences in verbal fluency and verbal-episodic memory: a meta-analysis. *Perspectives on Psychological Science*, 18(1):67–90, 2023. 8

[20] Y.-M. Huang, T.-W. Mi, and L. Chan. Preview teleport: An occlusion-free point-and-teleport technique enhanced with an augmented preview. *IEEE Transactions on Visualization and Computer Graphics*, 2025. 1, 2, 7

[21] R. Kazemi, N. Kumar, and S. C. Lee. Comparative analysis of teleportation and joystick locomotion in virtual reality navigation with different postures: A comprehensive examination of mental workload. *International Journal of Human–Computer Interaction*, pp. 1–12, 2024. 1, 2

[22] B. Keshavarz, B. E. Riecke, L. J. Hettinger, and J. L. Campos. Vection and visually induced motion sickness: how are they related? *Frontiers in psychology*, 6:472, 2015. 2

[23] C. Lai, X. Hu, A. A. Aiyaz, A. Segismundo, A. Phadke, and R. P. McMahan. The cognitive loads and usability of target-based and steering-based travel techniques. *IEEE Transactions on Visualization and Computer Graphics*, 27(11):4289–4299, 2021. 1, 2

[24] E. Langbehn, P. Lubos, and F. Steinicke. Evaluation of locomotion techniques for room-scale vr: Joystick, teleportation, and redirected walking. In *Proceedings of the Virtual Reality International Conference - Laval Virtual*, VRIC '18. Association for Computing Machinery, New York, NY, USA, 2018. doi: 10.1145/3234253.3234291 2

[25] J. J. LaViola Jr, E. Kruijff, R. P. McMahan, D. Bowman, and I. P. Poupyrev. *3D user interfaces: theory and practice*. Addison-Wesley Professional, 2017. 2

[26] Z. Lawrence and D. Peterson. Mentally walking through doorways causes forgetting: The location updating effect and imagination. *Memory*, 24(1):12–20, 2016. 1

[27] K. Linne, S. Thomas, J. Roth, and M. Weigel. Slivr: A 360 vr-hub for fast selections in multiple virtual environments. 2, 7

[28] J. P. Magliano and J. M. Zacks. The impact of continuity editing in narrative film on event segmentation. *Cognitive science*, 35(8):1489–1517, 2011. 1

[29] E. S. Martinez, A. S. Wu, and R. P. McMahan. Research trends in virtual reality locomotion techniques. In *2022 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 270–280. IEEE, 2022. 1, 2

[30] J. McFadyen, C. Nolan, E. Pinocy, D. Buteri, and O. Baumann. Doorways do not always cause forgetting: a multimodal investigation. *BMC psychology*, 9:1–13, 2021. 1, 3, 7

[31] Meta Developers. *Unity ISDK Teleport Interaction*, 2024. Accessed: 2024-05-20. 3

[32] Meta Platforms, Inc. Meta quest 3, 2024. Accessed: 2024-05-20. 3

[33] T. Mizuho, T. Narumi, and H. Kuzuoka. Reduction of forgetting by contextual variation during encoding using 360-degree video-based immersive virtual environments. *IEEE Transactions on Visualization and Computer Graphics*, 2024. 7

[34] N. C. Nilsson, S. Serafin, F. Steinicke, and R. Nordahl. Natural walking in virtual reality: A review. *Computers in Entertainment (CIE)*, 16(2):1–22, 2018. 2, 7

[35] S. Nolden, G. Turan, B. Güler, and E. Günseli. Prediction error and event segmentation in episodic memory. *Neuroscience & Biobehavioral Reviews*, 157:105533, 2024. 1, 2

[36] R. Paris, M. Joshi, Q. He, G. Narasimham, T. P. McNamara, and B. Bodenheimer. Acquisition of survey knowledge using walking in place and resetting methods in immersive virtual environments. In *Proceedings of the ACM symposium on applied perception*, pp. 1–8, 2017. 2

[37] O. Raccah, K. B. Doelling, L. Davachi, and D. Poeppel. Acoustic features drive event segmentation in speech. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 49(9):1494, 2023. 2, 7

[38] G. A. Radvansky and D. E. Copeland. Walking through doorways causes forgetting: Situation models and experienced space. *Memory & cognition*, 34:1150–1156, 2006. 1, 2, 4, 7, 8

[39] G. A. Radvansky, N. Crockett, D. Parra, and A. Doolen. Walking through doorways causes forgetting but it may help understanding. *Available at SSRN 5063124*, 2025. 1

[40] G. A. Radvansky, S. A. Krawietz, and A. K. Tamplin. Walking through doorways causes forgetting: Further explorations. *Quarterly journal of experimental psychology*, 64(8):1632–1645, 2011. 1, 2, 3, 8

[41] G. A. Radvansky, K. A. Pettijohn, and J. Kim. Walking through doorways causes forgetting: Younger and older adults. *Psychology and Aging*, 30(2):259, 2015. 2, 3, 7, 8

[42] K. Rahimi, C. Banigan, and E. D. Ragan. Scene transitions and teleportation in virtual reality and the implications for spatial awareness and sickness. *IEEE transactions on visualization and computer graphics*, 26(6):2273–2287, 2018. 1, 2, 8

[43] B. E. Riecke, M. V. D. Heyde, and H. H. Bülthoff. Visual cues can be sufficient for triggering automatic, reflexlike spatial updating. *ACM Transactions on Applied Perception (TAP)*, 2(3):183–215, 2005. 2

[44] K. M. Swallow, J. M. Zacks, and R. A. Abrams. Event boundaries in perception affect memory encoding and updating. *Journal of Experimental Psychology: General*, 138(2):236, 2009. 1

[45] E. K. Tütüncü and M. Slater. Perception in flux: Investigating memory and attention during gradual environmental transformations in virtual reality. In *2025 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, pp. 1166–1169. IEEE, 2025. 7

[46] Unity Asset Store. 3d free modular kit, 2022. Accessed: 2024-05-20. 3

[47] Unity Asset Store. Old sea port, 2022. Accessed: 2024-05-20. 3

[48] Unity Asset Store. Coffee shop environment, 2023. Accessed: 2024-05-20. 3

[49] Unity Asset Store. Interior house assets - urp, 2023. Accessed: 2024-05-20. 3

[50] Unity Asset Store. Urban polygon office building, 2023. Accessed: 2024-05-20. 3

[51] Unity Asset Store. Free medieval room, 2024. Accessed: 2024-05-20. 3

[52] T. Van Gemert, S. Chew, Y. Kalaitzoglou, and J. Bergström. Doorways do not always cause forgetting: Studying the effect of locomotion technique and doorway visualization in virtual reality. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*, pp. 1–13, 2024. 1, 7

[53] D. Voyer, S. D. Voyer, and J. Saint-Aubin. Sex differences in visual-spatial working memory: A meta-analysis. *Psychonomic bulletin & review*, 24:307–334, 2017. 8

[54] P. W. Watson and S. Gaudl. Walking through virtual doors: A study on the effects of virtual location changes on memory. 2021. 1

[55] J. M. Zacks and K. M. Swallow. Event segmentation. *Current directions in psychological science*, 16(2):80–84, 2007. 1, 2