Scene Memory is Better for Dynamic Versus Static Experiences in Immersive Virtual Reality

by

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Abstract

Everyday events are formed in immersive 360-degree 3D settings, but little is known regarding how the dynamic aspect of such experiences influences memories. Dynamism can signal a meaningful change during everyday life that creates more distinctive events from our continuous experiences of the world. Memory for distinct events requires retrieval from a specific perspective and construction of the layout, and these characteristics make up scene memory. Across two studies, we explored the prediction that dynamism preferentially affects scene-related aspects of memory. In immersive 3D 360-degree virtual reality, participants experienced immersive events (e.g., a hiking trail). Half of the immersive experiences included a dynamic object in the scene (e.g., jumping rabbits), whereas the other half included a static version of a semantically similar object (e.g., sitting rabbit). Study 1 was an incidental encoding task (i.e., no purposeful encoding of the event) with semantically congruent sounds (i.e., sounds that matched the event) for the dynamic condition. In Study 2 the sounds were removed, and encoding was made intentional. The changes from Study 1 to Study 2 ensured that our results were due to the manipulation of dynamism and to improve overall memory performance. After encoding, an *Old*/*New* recognition memory test followed, in which participants were cued by the dynamically manipulated object (e.g., rabbit). *Old* responses were then followed by additional questions assessing scene (setting name and object location) and content (recall two additional objects from the event) memory. The results indicated better recognition memory in the dynamic than static condition. Moreover, dynamic experiences were also associated with better scene memory than static experiences, however, there were no differences in content memory. These results were replicated in Study 2. Together these findings reveal that dynamic experiences contribute to better scene-related aspects of memories. More broadly, our findings exemplify how we can use

immersive 360-degree experiences to manipulate the dynamic nature of the real world to investigate how we form and remember events.

Preface

This thesis is an original work by Anna Sophia Romero. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name “360-Degree Video Study”, Pro00116352, March 11, 2022. This work was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) Canada Graduate Scholarship – Master’s, University of Alberta’s Walter H. John’s Fellowship, University of Alberta’s Alberta Graduate Recruitment Scholarship, and the Alberta Graduate Excellence Scholarship.

Table of Contents

List of Tables

List of Figures

Introduction

Events in everyday life have movement not merely static tableaus. An event with more movement compared to little movement may be more memorable for us. For example, if you are belaying a friend while they climb, the moment they fall is more memorable than when they take a break at the same spot. The fall is a sudden change, where the belayer has to act accordingly. The fall is a mini-event within the larger event of climbing that route, where each has a beginning, middle, and end.

Dynamism is an important aspect of real-world events (Radvansky & Zacks, 2011), but how it impacts memory for experiences is not well understood. Dynamism can refer to the movement of a person within the world, for example, interacting with objects, or dynamism can refer to the movement of the objects in the world, for example, a puck gliding across the ice. The current study focused on the latter. According to the "dynamic superiority effect" (Goldstein et al., 1982), we remember dynamic stimuli better than static stimuli. However, prior research investigating the dynamic superiority effect has primarily used dynamic videos versus static images of films (Buratto et al., 2009; Goldstein et al., 1982; Matthews et al., 2007, 2010), which may not capture important properties of episodic memories. Episodic memory contains "personal, temporally dated, and self-relevant" (Tulving, 1989, p. 361) and involves being "consciously aware of having witnessed or participated in events and happenings" (Tulving, 1989, p. 362). Film stimuli, do not have the participant embedded in the film's events. However, recent advances in virtual reality (VR) and 360-3D video technologies allow us to create first-person immersive events that people experience as participants rather than merely watching. Simultaneously, this medium allows us to manipulate dynamism and control what all participants experience. The current research aims to investigate how dynamism influences episodic memory for immersive VR events.

Dynamism increases immersion in VR experiences and can influence participants' subjective sense of presence and emotionality for the event (Smith, 2019). Dynamism can be considered a manipulation of immersion since these are objective changes that contribute to "shut[ting] out sensations from the 'real world'" (Slater, 1999, p. 1). Motion over a static tableau creates an insular reality unlike the participants' own, and motion provides the potential for participation (Slater & Wilbur, 1997). Removing the participant from their external world can increase sense of presence in the virtual experience (Slater & Wilbur, 1997). Sense of presence is the extent to which participants are "mentally transported into the virtual environment" (Smith, 2019, p. 1228). The subjective judgement that the person has visited the place being projected, rather than having watched images on a screen is important to the sense of presence (Slater & Wilbur, 1997). Sense of presence is important to measure because this is a prerequisite to being consciously aware of participating in the event, a defining characteristic of episodic memory (Tulving, 1989). Emotionality is another property of episodic memory that can be manipulated and measured in VR experiences. Emotionality and sense of presence are orthogonal (Slater, 2003), therefore their contribution to memory are separate. Prior literature has separately manipulated sense of presence and emotionality with immersive display and narrative instruction, respectively, and found that to trigger a physiological response with increased heart rate required both increased immersion and a narrative (Gorini et al., 2011). Other literature has also found that sense of presence correlated with memory scores beyond emotionality (Makowski et al., 2017). Makowski and colleagues (2017) manipulated the immersion of *Avengers: Age of Ultron* (Whedon, 2015) as either a 2D or 3D movie. The authors then tested the participants' factual memory of the film with 27 multiple-choice questions about the movie and the temporal order of 10 important scenes from the film. In addition to the memory tasks, participants completed questions about their sense of presence and emotional experience watching the film. Makowski and colleagues (2017) found that sense of presence correlated with participants' emotional experience and factual memory scores. Also, emotional experience correlated with factual memory score, but even presence explained this correlation. Overall, prior research indicates an interactive influence between emotional valence and dynamism on memory.

The immersion and control of VR allow us to test specific aspects of episodic memory that have been robustly found in cognitive literature, like the dynamic superiority effect (Goldstein et al., 1982). Matthews and colleagues (2007) manipulated dynamism by creating a stimulus set with still images and sound-absent moving clips of unknown films. The participants watched both the moving clips and the still images, then after two retention intervals (7-days later and 28-days later) they tested their participants' memory. The participants' recognition accuracy was higher for the moving clips than the static images. Buratto and colleagues (2009) replicated this effect but found that the dynamic superiority effect could be removed if dynamism did not match between study and test. Nevertheless, these studies show that with more realistic stimuli, movement aids memory.

One possible reason as to why movement aids memory may be because humans tend to create meaning out of dynamism. People will perceive a rotating 2D shadow of the wire to be 3D because it is moving, this is known as the kinetic depth effect (Wallach & O'Connell, 1953). Beyond perceiving a three-dimensional form, is that people will perceive several moving lights as moving human beings (Johansson, 1973). People also interpret stories and motives based on the movement of 2D geometric objects (Heider & Simmel, 1944). More naturally, people also perceive many identifiers on a face based on its movement, which include head movements, and non-rigid movements such as facial expression, eye gazes, and speech production (O'Toole et al., 2002). Therefore, with more complexity in VR experiences, dynamism can create meaning through event formation (Zacks, 2004). Radvansky and Zacks (2011) label a static tableau as the "state-of-affairs", in that the tableau is constrained in a specific time and place, but nothing is happening across time. Meanwhile, an event is dynamic with actions unfolding across time in a specific place (Radvansky & Zacks, 2011). Therefore, the lack of action in a static tableau may not show an event and evoke meaning as strongly as a dynamic presentation. To create a representation of an event, spatial information is important (Radvansky & Zacks, 2011). An aspect of spatial information is a spatial label which is the label that defines the location where the event is taking place (Radvansky & Zacks, 2011). Another aspect of spatial information is spatial relations between entities of an event, in other words, the layout of entities in the event (Radvansky & Zacks, 2011). Spatial relations between entities, however, do not mean that all entities and all features of each entity are stored nor remembered (Radvansky & Zacks, 2011). Altogether, a dynamic object creates an event unfolding across time and understanding events requires spatial and temporal information. The current study is interested in spatial information. As stated earlier spatial information includes a spatial label or setting, and the spatial relationship between entities. Entities are objects that may or may not be involved in the unfolding event. The authors state that entities and certain properties of these entities that are relevant to the causal relationship in the event are more likely to be remembered than those not causally relevant. An idea of selective attention supports that certain entities and properties of entities are perceived and others ignored if it is not needed since perception needs to be quick (Gibson, 1966).

Therefore, not all entities nor features of entities are stored or recalled if they do not aid in understanding the unfolding experience. Entities not involved in the causal relation may not contribute to event understanding and not all properties of the entity are stored. The separation between spatial information and entities in understanding an event has also been hypothesized in recent neuroscience literature. It has been hypothesized that we have two separate systems in the brain that work together, particularly the posterior temporal (PT) system and the anterior temporal (AT) system (Ranganath & Ritchey, 2012). The PT system contributes to creating situation models that include the spatial, temporal, and causal context of what is happening in the event. The AT system, on the other hand, is for recognizing objects and their associated concepts. According to Ranganath and Ritchey (2012), the AT system may also be involved in learning about the importance of the object to the event. Overall, this literature emphasizes the importance of spatial information and causal relationships in understanding events, but less relevant entities are not as important and therefore not easily recalled.

Spatiotemporal information is required for episodic memory retrieval. In episodic memory, scenes are reconstructed with the multi-modal components of the event (Hassabis & Maguire, 2007) and arranged in a specific spatial layout (Rubin & Umanath, 2015). Also, scenes for real-world events are inherently immersive, in that when we perceive our world, we are embedded within it and not limited to viewing our world within a boundary, such as the four sides of a frame (Intraub, 2010). During memory retrieval, we are also embedded within the scene but viewing the unfolding action with a specific perspective (Rubin & Umanath, 2015). This scene information is independent of the objects and characters involved in the event (Rubin, 2020; Rubin et al., 2019). For example, Rubin and colleagues (2019) asked participants to recall autobiographical memories and rate them on scene layout, content, and phenomenological properties of autobiographical memories like vividness. They found that participants' ratings of scene layout were correlated with ratings of phenomenological properties of autobiographical memories like vividness above and beyond their ratings for memory content. These correlations were maintained, even when participants rated these scene measures for different memories (Rubin, 2020). Therefore, retrieval of scene layout and memory content like specific entities and their details are independent of each other. This dissociation between scene and content is also reflected in the brain, with scenes and spatial layout being associated with the parahippocampal cortex while memory contents such as objects are associated with the perirhinal cortex for both encoding and retrieval (Davachi, 2006; Graham et al., 2010). Overall, there seem to be parallels between how events are perceived and remembered with the separation of scene and content information.

In the current study, we investigated how dynamism differentially influences scene and content memory for events. We created 3D 360-degree immersive VR experiences with a unique spatial setting and multiple 3D objects. Dynamism was manipulated by having one of the objects either move (dynamic) or not (static). After each immersive experience, participants rated it on pleasantness, emotional intensity, and sense of presence. After participants watched all 48 immersive experiences, they completed an "Old" / "New" recognition task. Participants were presented with an object from each of the experiences as well as 48 lures. If they judged the object as "old", they completed a cued recall task measuring both scene and content memory. Afterwards, they also subjectively rated their scene memory and vividness. We predicted that the sense of presence would be greater for dynamic experiences than static ones due to the increased immersion (Smith, 2019) that dynamism provides. Despite emotionality and the sense of presence not necessarily being correlated, increased immersion and emotionality may have an interactive effect. Therefore, we predicted that dynamism especially in certain experiences would increase their emotional intensity more than static experiences. Also, due to the robust dynamic superiority effect (Buratto et al., 2009; Goldstein et al., 1982; Matthews et al., 2007, 2010), we predicted that recognition accuracy would be greater for the dynamic condition than the static condition. Furthermore, dynamic experiences are perceived as more of an event rather than a "state-of-affairs" compared to static experiences, (Radvansky & Zacks, 2011) and event retrieval requires scene retrieval (Rubin, 2020; Rubin et al., 2019; Rubin & Umanath, 2015). Therefore, we predicted that scene memory for dynamic experiences would be better than for static experiences. However, other entities in either dynamic or static experiences that are not involved in the causal relationship of the event may not be important to understanding the event unlike the scene therefore, we predicted that there would be no difference in recall of content between dynamic and static conditions. Finally, we predicted that vividness would be greater for dynamic events than static tableaus, due to scene-related aspects being a defining characteristic of episodic memory (Hassabis & Maguire, 2007) and correlating with phenomenological properties of episodic memory like vividness (Rubin, 2020; Rubin et al., 2019).

Methods: Study 1

Participants

There were 60 participants who consented to the study. We excluded six participants who could not complete the encoding task due to VR motion sickness (three participants) and participants who did not complete the retrieval task (three participants). The final sample included 54 participants (34 female, 1 genderfluid), between the ages of 18 - 25 years old (M = 9.74, SD = 1.79). All participants had normal or corrected-to-normal vision. The final sample size was based on a simulation power analysis conducted with the Superpower Shiny app for

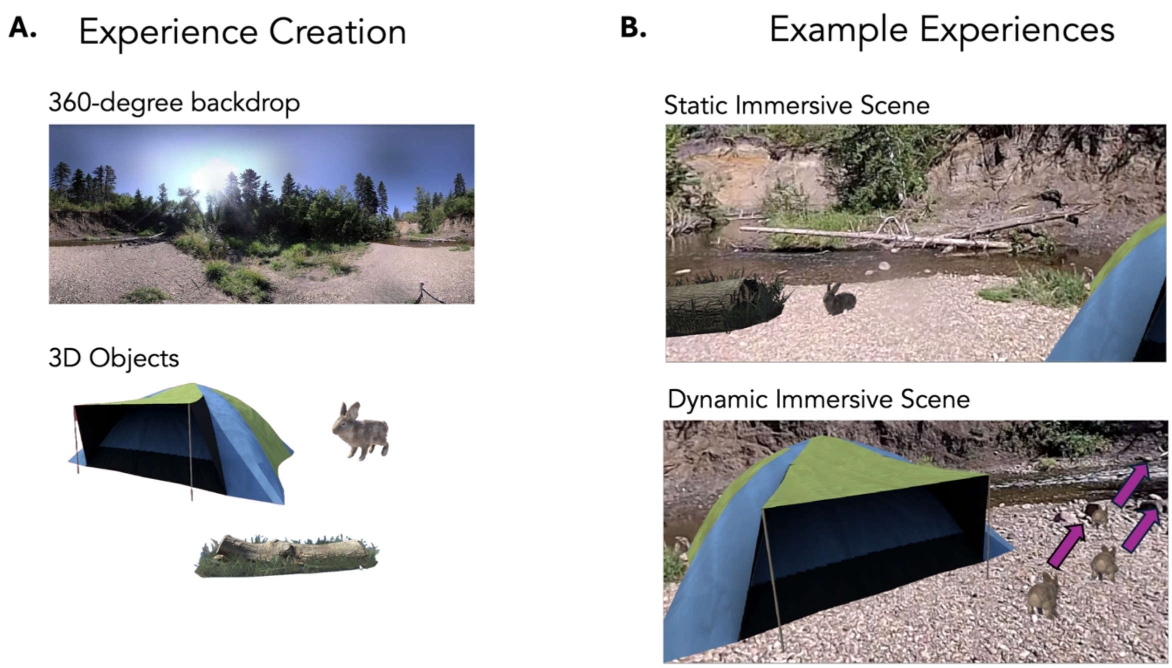
ANOVA (Lakens & Caldwell, 2021). We defined a 2 (dynamism: dynamic, static) x 3 (valence: negative, neutral, positive) repeated-measures ANOVA. We used mean difference estimates based on finding a small main effect of dynamism on our subjective ratings. The app confirmed statistical reliability with a sample size of 45 subjects (statistical power = 82.65%; medium Cohen's F effect size = 0.18; significance level = 0.05) for testing the main effect of dynamism on subjective ratings of scene memory. All participants were undergraduate students at the University of Alberta and were given class credit for their participation. The study was approved by the University of Alberta Research Ethics Office.

Material

We created immersive emotional events by combining 3D 360-degree videos with 3D models of semantically congruent objects (see Figure 1). The 3D 360-degree videos comprised neutral settings that were free from other movement or actions (e.g., a parking lot, an empty field). Videos were selected from the Library for Universal Virtual Reality Experiments (luVRe, Schöne et al., 2023) which were filmed using an Insta360 VR camera (https://www.insta360.com/) with 4k resolution and in a 3D format. Additional videos were created in-house using the VUZE+ VR camera (https://vuze.camera/camera/vuze-plus-camera) with 4K resolution in a 3D format. Videos were filmed between 150 - 163 cm height, which is the optimal height for balancing individual height differences with the realism of the VR experience (Keskinen et al., 2019). In total 48 videos were included, 30 from the luVRe database and 18 in-house videos. Half of the videos depicted indoor locations and the remaining half depicted outdoor locations.

Figure 1

Stimulus Creation



Note. (A) To create the immersive experiences, we employed 360-degree backdrops of real-world settings and added 3D Objects from the Unity Asset Store using the Unity Game Engine. (B) Dynamism was manipulated by having all objects not move in the static immersive experience, or one object move in the dynamic immersive experience.

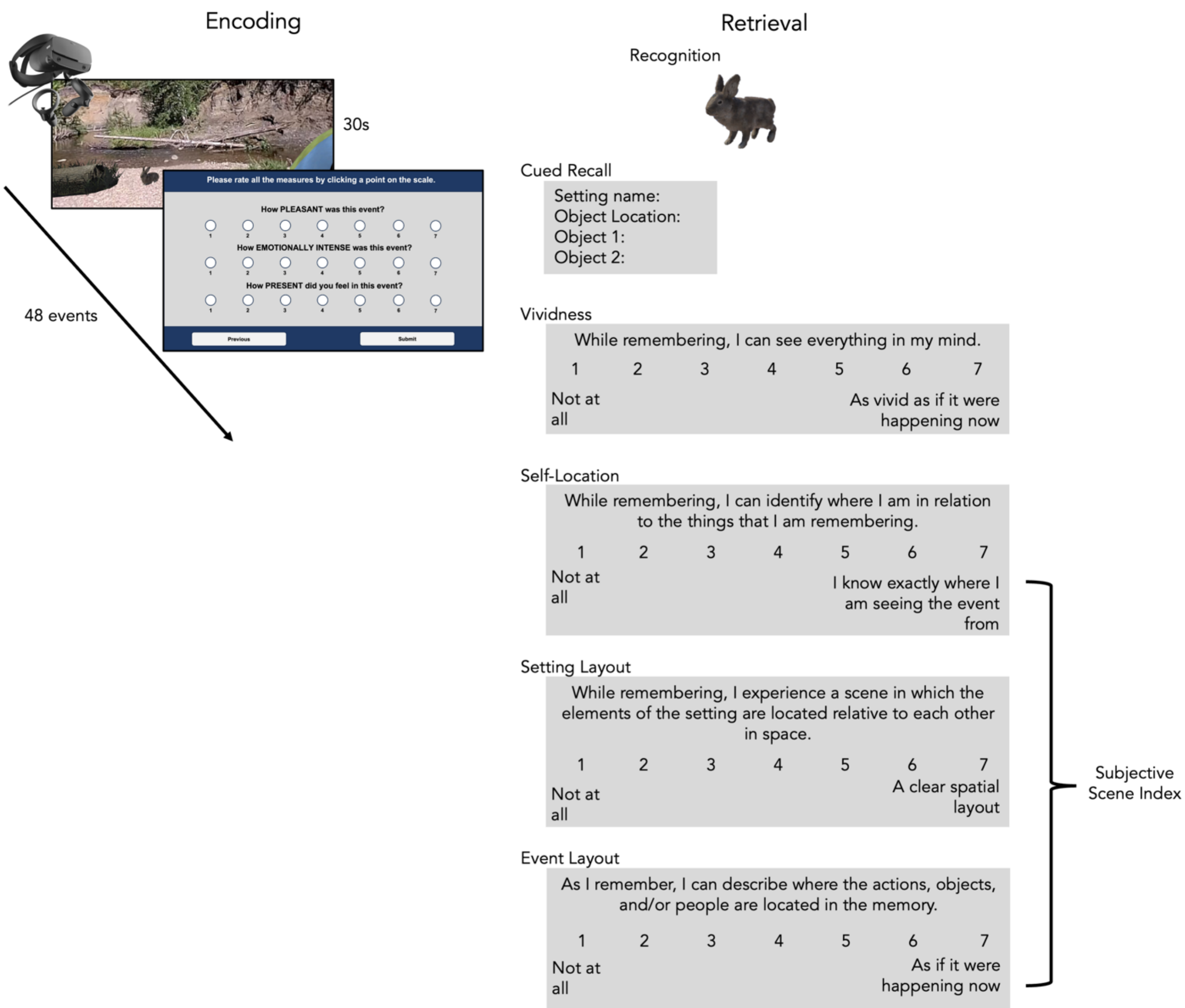
Unity (2020.3.1.14f1) was used to add three objects from the Unity Asset Store in each video to create an emotional scene involving a setting and foreground objects (see Figure 1). There were 16 video events for each valence (positive, negative, neutral). Each immersive experience had a unique, neutral location as the backdrop and semantically congruent foreground objects were added to create valenced narratives. Each immersive experience included objects with a variety of sizes relative to each other. The objects were placed approximately at equal distances within a 120-degree field of view such that all three objects could be viewed with minimal head movement. We created dynamic and static versions of each video event to manipulate dynamism. In the static version, all 3D objects in the video had no movement. In the dynamic version, one of the objects moved and included audio to match the movement. Dynamic elements included limb movements (e.g., a gorilla standing up and hitting its chest), particle effects (e.g., fire, smoke, running water), and small translational movements (e.g., a car or ball moving across the screen). Each video event lasted 30 seconds (e.g., the rabbit hops across riverbank from left to right for 30 seconds). Please see Appendix A for the stimuli and Appendix B for the stimuli's valence ratings.

Procedure

Participants experienced immersive scenes presented in Unity while wearing an Oculus Rift S headset (see Figure 2). Interpupillary distance for each participant was measured and adjusted in the headset to maximize the 3D nature of the experiences. Participants were instructed to stand in one spot and to look carefully around the scene by moving their heads only. We restricted movement within the 360-degree video to ensure that all participants would focus on the 3D objects placed in the event. After each immersive scene, participants were asked to rate the pleasantness from 1 (extremely unpleasant) to 7 (extremely pleasant), emotional intensity from 1 (not at all intense) to 7 (extremely intense), and the sense of presence (i.e., the extent that the participant could reach out to touch things or the objects could touch the participant) from 1 (not at all present) to 7 (extremely present). The questionnaire was presented by adapting the VR Questionnaire toolkit (Feick et al., 2020) and participants made their self-paced responses using an Oculus Rift S controller. Video events were randomly assigned to 24 dynamic and 24 static conditions equally for positive, negative and neutral events for a total of 48 videos. The order of the video presentation was also randomized for each participant. Before starting the task, participants experienced a practice video with no objects to familiarize them with the VR environment and use of the controllers.

Figure 2

Study Design



Note. During encoding, participants viewed 48 3D 360-degree immersive experiences in virtual reality. Participants wore the Oculus Rift S to view the events for 30 seconds. After each event, participants rated the experience on pleasantness, emotional intensity, and sense of presence. After encoding, participants completed the retrieval task. Participants saw a 2D static image of an object from each of the 48 events along with 48 lures and had to complete a recognition task. If the object was recognized, participants completed a cued recall task, where they recalled the setting name, object location, and named two other objects from the same event as the cued object. Participants then completed subjective ratings on their memory for the event including vividness, self-location, setting layout, and event layout. Self-location, setting layout, and event layout scores were averaged to create a subjective scene index.

Immediately following the presentation of all the events, the retrieval task was administered in PsychoPy (2022.2.5) on a desktop computer (see Figure 2). Participants were shown 2D images of the 3D objects on a computer screen and asked to indicate *yes* or *no* whether the object was from one of the immersive scenes they experienced. A total of 96 objects were presented in the recognition memory task, such that half were targets and the other half were lures. Target objects consisted of the 3D object in which dynamism was manipulated (i.e., the static 3D object from the static condition or a still shot of the dynamic 3D object in the dynamic condition). Lure objects were created by selecting 3D objects from the Unity Asset Store and were not semantically related to target objects. For trials in which participants indicated *yes* that the target was from an immersive scene they had experienced, they were asked several additional questions. Participants were asked to identify the setting name of the immersive experience while being as specific as possible. Participants named the setting of each event on their own, they were not presented with a setting name during encoding (see Appendix C for coding procedure). Next, they were asked to describe the target object's location in the event providing sufficient detail for another person to place it in the scene (see Appendix D for coding procedure). Then, they were asked to describe two other objects from the same event and provide sufficient detail to emphasize each object's uniqueness to the event (see Appendix E for coding procedure). Finally, participants were asked to provide subjective ratings of vividness, *while remembering, I can see everything in my mind (*1-*not at all* to 7-*as vivid as if it were happening now),* self-location, *while remembering, I can identify where I am in relation to the things that I am remembering (*1-*not at all* to 7-*I know exactly where I am seeing the event from),* setting layout, *while remembering, I experience a scene in which the elements of the setting are* *located relative to each other in space (*1-*not at all spatially organized* to 7-*a clear spatial layout),* and event layout, *as I remember, I can describe where the actions, objects, and/or people are located in the memory (*1-*not at all spatially organized* to 7-*as if it were happening now).* Setting layout and event layout are both measures of layout in Rubin and colleagues' (2019) autobiographical memory questionnaire and are correlated. Setting layout asks about elements of the scene, while event layout asks about locations of actions and actors in the memory. Rubin and colleagues (2019) judged the setting layout question to be less related to the concept of layout than the event layout question. We decided to keep both questions because there might be a difference in how these two questions are answered once an action is present (i.e., dynamic condition) versus when an action is not present (i.e., static condition). However, we did not find this to be the case. All questions were self-paced. Following the memory test, participants completed a demographic questionnaire indicating their age, gender identity, years of education, and past VR experience.

Statistical Analyses

The main goal was to investigate the effect of dynamism on object and scene memory. Unless indicated below, we conducted separate 2 (dynamism: dynamic, static) x 3 (valence: negative, neutral, positive) repeated-measures ANOVAs on each of the dependent variables. We created two indices. First, we calculated the average correct response for naming the two objects from each event. These two objects were the objects recalled after judging the cue object as old in the recognition task. The average kept the scale between 0 and 1, like the other cued-recall measures (i.e., setting name and object location), while maintaining the information of the number of objects correctly recalled (i.e., content memory index). Second, we created a composite score of the subjective scene measures by averaging the self-location, setting layout, and event layout ratings. These three questions were from Rubin and colleagues' (2019) measures of scene memory that correlated with phenomenological properties of autobiographical memory and they also showed similar patterns of results in our study, therefore indexing them into a composite score (i.e., subjective scene index) allowed for a singular, holistic scene variable for our results. Please see Appendix F for a list of independent and dependent variables. Holm-Bonferroni's correction was applied in all follow-up analyses (p_{adj}). All analyses were run on Jamovi (2.3.28.0). To identify outliers we used the quartiles of the interquartile range (IQR). Data points greater than 1.5*IQR of the third quartile and less than 1.5*IQR of the first quartile were considered outliers. We analyzed the data with and without outliers and both had similar results, therefore, for completeness, all data points were kept.

Results: Study 1

Encoding

We examined whether there were differences in the subjective experience associated with dynamic and static conditions (for means and SD see Table 1). For pleasantness ratings, there was a main effect of valence $F(2, 106) = 171.37$, $p < .001$, $\eta_p^2 = .76$. As expected, post-hoc analyses indicated that positive videos were rated more pleasantly ($M = 4.76$, $SD = 0.80$) than negative ($M = 2.99$, $SD = 0.79$) and neutral ($M = 4.31$, $SD = 0.74$) videos, both $p_{adj} < .001$, and neutral videos were rated more pleasantly than negative videos ($p_{adj} < .001$). However, there was no main effect of dynamism $F(1, 53) = .99$, $p = .32$, $\eta_p^2 = .02$, nor an interaction between dynamism and valence $F(2, 106) = 1.99$, $p = .14$, $\eta_p^2 = .04$.

For emotional intensity ratings, there was a main effect of valence $F(2, 106) = 74.97$, $p < .001$, $\eta_p^2 = .59$. Post-hoc analyses indicated higher emotional intensity ratings for negative ($M = 3.62$, $SD = 1.27$) and positive ($M = 2.63$, $SD = 1.15$) videos when compared to neutral videos (M

= 2.49, *SD* = 1.12), $p_{adj} < .001$ and $p_{adj} = .002$, respectively. Additionally, negative videos were also rated as more emotionally intense than positive videos, $p_{adj} < .001$. There was also a main effect of dynamism $F(1, 53) = 47.94$, $p < .001$, $\eta_p^2 = .48$, reflecting higher emotional intensity in the dynamic (*M* = 3.09, *SD* = 1.11) than the static (*M* = 2.74, *SD* = 1.12) condition (see Figure 3a). However, these main effects were qualified by an interaction between dynamism and valence $F(2, 106) = 3.72$, $p = .027$, $\eta_p^2 = .07$. Simple main effect analyses indicated that the dynamic condition had greater emotional intensity than the static condition for negative, neutral, and positive videos, $p < .001$, $p = .023$, $p < .001$, respectively.

Finally, for sense of presence there was no main effect of valence, $F(2, 106) = 1.06$, $p = .35$, $\eta_p^2 = .02$. However, there was a main effect of dynamism $F(1, 53) = 8.87$, $p = .004$, $\eta_p^2 = .14$ (see Figure 3b), such that the dynamic condition (*M* = 4.70, *SD* = 0.93) had higher presence ratings than the static condition (*M* = 4.47, *SD* = 1.07). There was no interaction between dynamism and valence $F(2, 106) = .68$, $p = .508$, $\eta_p^2 = .01$.

In sum, dynamism changed the way participants experienced the events. Motion in an event contributed to a stronger feeling of being present and heightened the emotional intensity of these experiences. Next, we examined how these effects on subjective experience influenced memory.

Table 1

Subjective Encoding Ratings

		Study 1			Study 2		
		Negative	Neutral	Positive	Negative	Neutral	Positive
Static	Pleasantness	3.01 (0.80)	4.31 (0.85)	4.67 (0.91)	2.78 (0.79)	4.25 (0.76)	4.62 (0.71)
	Emotional Intensity	3.38 (1.35)	2.40 (1.15)	2.44 (1.16)	3.57 (1.12)	2.36 (0.96)	2.56 (1.04)
	Presence	4.4 (1.18)	4.45 (1.10)	4.55 (1.14)	4.18 (1.10)	4.24 (1.01)	4.39 (0.98)
Dynamic	Pleasantness	2.98 (0.90)	4.32 (0.75)	4.85 (0.79)	2.71 (0.85)	4.19 (0.92)	4.74 (0.90)
	Emotional Intensity	3.87 (1.27)	2.58 (1.16)	2.81 (1.22)	3.97 (1.18)	2.53 (0.99)	2.69 (1.04)
	Presence	4.71 (1.08)	4.64 (1.07)	4.74 (0.93)	4.32 (1.17)	4.35 (1.01)	4.39 (0.98)

Note. Mean (SD).

Retrieval

We first examined the effects of dynamism on recognition memory accuracy (for means and SD see Table 2). There was a main effect of valence $F(2, 106) = 28.55$, $p < .001$, $\eta_p^2 = .35$, reflecting greater accuracy for negative ($M = .67$, $SD = .15$) than both neutral ($M = .52$, $SD = .19$) and positive ($M = .56$, $SD = .20$) videos, both $p_{adj} < .001$. However, there was no difference in recognition between the neutral and positive videos ($p_{adj} = .089$). As predicted, there was also a main effect of dynamism $F(1, 53) = 180.88$, $p < .001$, $\eta_p^2 = .77$ (see Figure 4a), such that recognition accuracy was greater in the dynamic ($M = .69$, $SD = .17$) than static ($M = .48$, $SD = .16$) condition. However, there was no statistically significant interaction for recognition $F(2, 106) = 2.82$, $p = .064$, $\eta_p^2 = .05$. Thus, dynamism influenced correct recognition of the target object in the event.

To understand the effect of dynamism on scene memory we examined recall of setting name and object location, as well as the subjective scene index. First, for setting name there was no main effect of valence $F(2, 98) = 2.72$, $p = .071$, $\eta_p^2 = .05$. There was a main effect of dynamism $F(1, 49) = 8.66$, $p = .005$, $\eta_p^2 = .15$ (see Figure 4c), such that participants were better able to recall the correct setting of the object in the dynamic ($M = .88$, $SD = .16$) than static ($M =$

.79, *SD* = .24) condition. However, this was qualified by an interaction between dynamism and valence $F(2, 98) = 4.35$, $p = .015$, $\eta_p^2 = .08$. Simple main effect analyses indicated that the dynamic condition had more accurate responses for neutral and positive videos than the static condition, $p = .034$ and $p < .001$ respectively. However, there was no difference in setting name accuracy between the dynamic and static conditions for the negative videos, $p = .740$.

Second, for object location scores there was a main effect of valence $F(2, 98) = 4.72$, $p = .011$, $\eta_p^2 = .09$. However, the post-hoc analyses did not meet our threshold for significance following correction for multiple comparisons, range of $p_{adj} = .053$ to $p_{adj} = .93$. We found a main effect of dynamism $F(1, 49) = 18.78$, $p < .001$, $\eta_p^2 = .28$ (see Figure 4d), such that object location scores were higher in the dynamic (*M* = .76, *SD* = .26) than the static (*M* = .66, *SD* = .29) condition. There was no interaction between dynamism and valence $F(2, 98) = 2.82$, $p = .065$, $\eta_p^2 = .05$.

Finally, for the subjective scene index, there was a main effect of valence $F(2, 98) = 6.63$, $p = .002$, $\eta_p^2 = .12$, reflecting higher ratings for negative (*M* = 4.87, *SD* = 0.92) than both neutral (*M* = 4.62, *SD* = 0.96) and positive (*M* = 4.61, *SD* = 0.97) videos, both $p_{adj} = .006$. There were no differences in scene ratings between neutral and positive videos, $p_{adj} = .920$. There was also a main effect of dynamism $F(1, 49) = 6.81$, $p = .012$, $\eta_p^2 = .12$ (see Figure 4b), which was reflected by higher scene ratings for dynamic (*M* = 4.81, *SD* = 0.89) than static (*M* = 4.59, *SD* = 0.99) videos. However, there was no interaction between dynamism and valence.

In sum, participants subjectively remembered a more coherent scene in the dynamic than in the static condition. Overall, these results indicate that the presence of a dynamic object leads to a more accurate scene representation. However, dynamism's influence on the scene memory does not similarly influence other objects in the event.

To investigate the influence of dynamism on object memory we used our index of memory content. We found no main effect of dynamism $F(1, 49) = 3.18$, $p < .081$, $\eta_p^2 = .06$ (see Figure 5a). However, there was a main effect of valence $F(2, 98) = 10.601$, $p < .001$, $\eta_p^2 = .18$. Negative videos ($M = .57$, $SD = .23$) had higher memory content scores than neutral videos ($M = .47$, $SD = .26$), $p_{adj} < .001$ and positive videos ($M = .51$, $SD = .25$), $p_{adj} = .027$. Neutral and positive videos had similar other object scores. There was no interaction between dynamism and valence $F(2, 98) = 0.34$, $p = .712$, $\eta_p^2 = .01$. Therefore, the presence of the dynamic object does not lead to better memory for other unique entities in the experience.

Nevertheless, subjective memory quality showed an effect of dynamism. For vividness, there was a main effect of dynamism $F(1, 49) = 8.93$, $p = .004$, $\eta_p^2 = .15$ (see Figure 6a), where dynamic videos ($M = 4.72$, $SD = 1.06$) were more vivid than static videos ($M = 4.44$, $SD = 1.04$). There was also a main effect of valence $F(2, 98) = 8.07$, $p < .001$, $\eta_p^2 = .14$. Negative videos ($M = 4.78$, $SD = 1.03$) had higher vividness ratings than both neutral ($M = 4.49$, $SD = 1.03$) and positive videos ($M = 4.47$, $SD = 1.10$), both $p_{adj} = .004$. Neutral and positive videos were similarly rated in vividness. There was no interaction between dynamism and valence $F(2, 98) = 1.97$, $p = .145$, $\eta_p^2 = .04$.

In sum, objects were more accurately recognized when presented dynamically. Dynamism also led to a more accurate and richer scene representation but did not aid or worsen the recall of other objects (i.e., memory content) in the scene. However, this inability to improve memory content did not hinder the vividness of the experience, since dynamic events were still more vividly remembered than static events.

Table 2

Retrieval Means for Recognition, Scene, and Content Measures

		Study 1			Study 2		
		Negative	Neutral	Positive	Negative	Neutral	Positive
Static	Hits	0.58 (0.20)	0.39 (0.20)	0.47 (0.22)	0.59 (0.20)	0.49 (0.21)	0.52 (0.22)
	Setting Name	0.84 (0.24)	0.81 (0.30)	0.73 (0.33)	0.85 (0.21)	0.84 (0.21)	0.79 (0.27)
	Object Location	0.70 (0.31)	0.71 (0.33)	0.60 (0.38)	0.74 (0.29)	0.79 (0.24)	0.72 (0.31)
	Subjective Scene Index	4.82 (0.27)	4.55 (0.30)	4.39 (0.32)	5.05 (1.27)	4.61 (1.12)	4.64 (1.20)
	Other Objects	0.56 (0.27)	0.45 (0.30)	0.48 (0.32)	0.6 (0.28)	0.51 (0.25)	0.54 (0.30)
	Vividness	4.71 (1.09)	4.37 (1.20)	4.23 (1.30)	4.94 (1.36)	4.56 (1.14)	4.64 (1.31)
Dynamic	Hits	0.76 (0.17)	0.66 (0.22)	0.65 (0.23)	0.78 (0.15)	0.64 (0.19)	0.75 (0.20)
	Setting Name	0.83 (0.22)	0.91 (0.20)	0.88 (0.18)	0.89 (0.14)	0.91 (0.16)	0.86 (0.18)
	Object Location	0.77 (0.29)	0.77 (0.28)	0.75 (0.29)	0.85 (0.19)	0.86 (0.19)	0.81 (0.27)
	Subjective Scene Index	4.92 (0.25)	4.69 (0.27)	4.83 (0.26)	5.18 (0.93)	4.91 (1.06)	4.82 (1.03)
	Other Objects	0.58 (0.25)	0.48 (0.27)	0.54 (0.26)	0.61 (0.24)	0.53 (0.29)	0.54 (0.23)
	Vividness	4.84 (1.11)	4.60 (1.10)	4.72 (1.19)	5.17 (1.01)	4.84 (1.10)	4.82 (1.08)

Note. Mean (SD)

Discussion: Study 1

Overall, our results showed that dynamic experiences led to stronger emotional responses and greater feelings of presence than static experiences. Dynamism also influenced recognition memory, replicating previous research on the dynamic superiority effect (Buratto et al., 2019; Goldstein et al., 1982; Matthews et al., 2007, 2010). We found that measures of scene memory (setting name, object location, and subjective scene ratings) were also greater for the dynamic condition than the static condition, suggesting that dynamism improved scene-related aspects of memory. In contrast, we found no effect of dynamism on content memory. These results are consistent with Rubin and Umanath's (2015) theory of event memory indicating a separation between scene memory and memory content.

One potential limitation was that recognition memory in the static condition was below chance. Below chance performance might indicate that participants failed to encode the experiences and were merely guessing during the recognition task. If participants were guessing for the static condition, their cued and subjective recall scores would not be representative of memory for static experiences, since they did not have a memory for these experiences in the first place. Therefore, our results would not be comparing memory for dynamic experiences and static experiences, but rather memory for dynamic experiences and lack of memory. Additionally, the dynamic condition included additional semantically congruent audio information (e.g., the sound of a stream in the hiking trail experience). Including sounds, especially for just one condition can confound the effects of dynamism. Sounds in the dynamic condition could change the encoding experience and boost memory beyond what dynamic movement alone would boost, therefore we are unsure of the extent to which dynamism and sound affected encoding and retrieval. To address these potential issues, we conducted a second study. In Study 2, we changed the encoding task from an incidental to an intentional task, by telling participants that we would be testing their memory. Prior literature has shown that intentionality is not required for remembering scene information (Castelhano & Henderson, 2005). However, the depth of processing during encoding can improve retrieval accuracy (Craik & Tulving, 1975). An intentional encoding instruction can increase the depth of processing during encoding and lead to improved overall memory. Additionally, we removed all audio associated with the dynamic object to disentangle the role of movement and sound in the dynamic condition.

Methods: Study 2

Preregistration

The sample size, hypotheses, variables, and planned analyses were preregistered on Open Science Framework (https://osf.io/dtc3x) before any were collected.

Participants

There were 81 participants who consented to the study. We excluded five participants who could not complete the encoding task due to VR motion sickness. The final sample was 76 participants (39 female, 1 preferred not to say) between 18 - 25 years old (M = 19.36, SD = 1.87). The final sample size was based on a simulation power analysis conducted with the Superpower Shiny app for ANOVA (Lakens & Caldwell, 2021). The app confirmed statistical reliability with a sample size of 72 subjects (statistical power = 81.75%; medium Cohen's F effect size = 0.13; significance level = 0.05), for the main effect of dynamism specifically for the subjective scene index ratings from Study 1. All participants were undergraduate students at the University of Alberta and were given class credit for their participation. The study was approved by the University of Alberta Research Ethics Office.

Material

The materials used in Study 2 were identical to Study 1, except that the sound in the dynamic videos was removed.

Procedure

The procedure in Study 2 was identical to Study 1, except that the encoding task was made intentional. Participants were told in the instructions that "later, you will be asked to recall details about the events you just watched."

Results: Study 2

Encoding

The effect of dynamism on the subjective experience of events was replicated in Study 2 (for means and SD see Table 1). For pleasantness ratings, $F(2, 150) = 272.57$, $p < .001$, $\eta_p^2 = .78$, like Study 1, positive videos were rated more pleasantly (M = 4.68, SD = 0.77) than negative (M

= 2.75, SD = 0.76) and neutral (M = 4.22, SD = 0.79) videos, both $p_{adj} < .001$, and neutral videos were rated more pleasantly than negative videos ($p_{adj} < .001$). There was no main effect of dynamism $F(1, 75) = .02$, $p = .887$, $\eta_p^2 = 0.00$, replicating Study 1. Also, there was no interaction between dynamism and valence $F(2, 150) = 2.43$, $p = .091$, $\eta_p^2 = .031$.

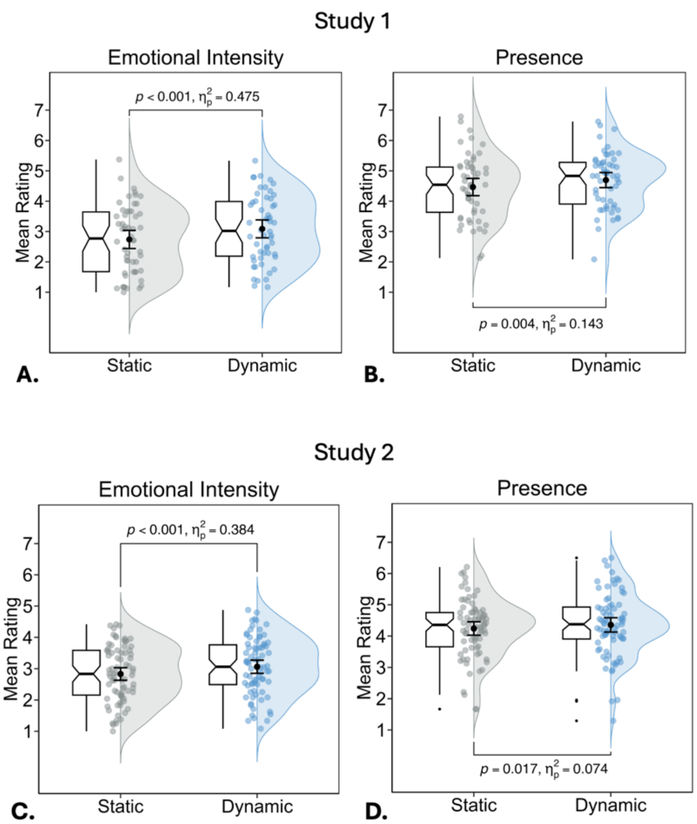
For emotional intensity, the main effect of valence was once again present $F(2, 150) = 117.07$, $p < .001$, $\eta_p^2 = .61$. Post-hoc analyses indicated that emotional intensity ratings were higher in negative videos (M = 3.77, SD = 1.12) than either positive (M = 2.62, SD = 0.99) and neutral videos (M = 2.44, SD = 0.95), both $p_{adj} < .001$. Additionally, positive videos were rated as more emotionally intense than neutral videos, $p_{adj} < .001$. There was also a main effect of dynamism $F(1, 75) = 46.75$, $p < .001$, $\eta_p^2 = .38$, reflecting higher emotional intensity in the dynamic (M = 3.06, SD = 0.93) than the static (M = 2.83, SD = 0.90) condition (see Figure 3c). These main effects were qualified by an interaction between dynamism and valence $F(2, 150) = 5.41$, $p = .005$, $\eta_p^2 = .07$. Simple main effect analyses indicated that the dynamic condition had greater emotional intensity than the static condition for negative, neutral, and positive videos, $p < .001$, $p = .002$, $p = .046$, respectively.

Finally, for sense of presence, there was no main effect of valence $F(2, 150) = 0.97$, $p = .383$, $\eta_p^2 = .01$. However, there was a main effect of dynamism $F(1, 75) = 5.97$, $p = .017$, $\eta_p^2 = .07$ (see Figure 3d), such that the dynamic condition (M = 4.36, SD = 1.02) had higher presence ratings than the static condition (M = 4.24, SD = 0.95). There was no interaction between dynamism and valence $F(2, 150) = .141$, $p = .868$, $\eta_p^2 = .002$.

In sum, we replicated the findings from Study 1, such that dynamic events were experienced with greater emotional intensity and sense of presence.

Figure 3

Effect of Dynamism on Encoding



Note. The dynamic condition compared to the static condition had higher emotional intensity ratings in both Study 1 (A) and Study 2 (C). There was higher sense of presence in the dynamic condition compared to the static condition for both Study 1 (B) and Study 2 (D). The dots are averaged ratings for each participant. The grey dots are the average ratings for the static condition. The blue dots are the average ratings for the dynamic condition. On top of the dots are half violin plots that show the distribution of the ratings for each condition. There is also a black dot on top of the other dots to indicate the mean and bars on top and below of this black dot to indicate the standard error of the mean. To the left of the dots are boxplots also indicating the spread of the data.

Retrieval

We first examined the effects of dynamism on recognition memory accuracy (for means and SD see Table 2). There was also a main effect of valence $F(2, 150) = 22.08$, $p < .001$, $\eta_p^2 = .23$. Negative events ($M = .67$, $SD = .14$) had greater recognition accuracy than neutral ($M = .56$,

SD = .16) and positive events (M = .63, SD = .17), $p_{adj} < .001$ and $p_{adj} = .013$, respectively. Also, positive events had higher recognition accuracy than neutral events (p = .001). There was a main effect of dynamism $F(1, 75) = 133.79$, $p < .001$, $\eta_p2 = .64$ (see Figure 4e), reflecting greater accuracy for the dynamic condition (M = .71, SD = .14) than the static condition (M = .53, SD = .16). However, a two-tailed, paired t-test showed that the proportion of hits in the static condition was not significantly better than chance (M = 0.5), $t(150) = 1.71$, p = .08. In the ANOVA, there was no statistically significant interaction between dynamism and valence for recognition $F(2, 150) = 2.72$, p = .069, $\eta_p^2 = .04$.

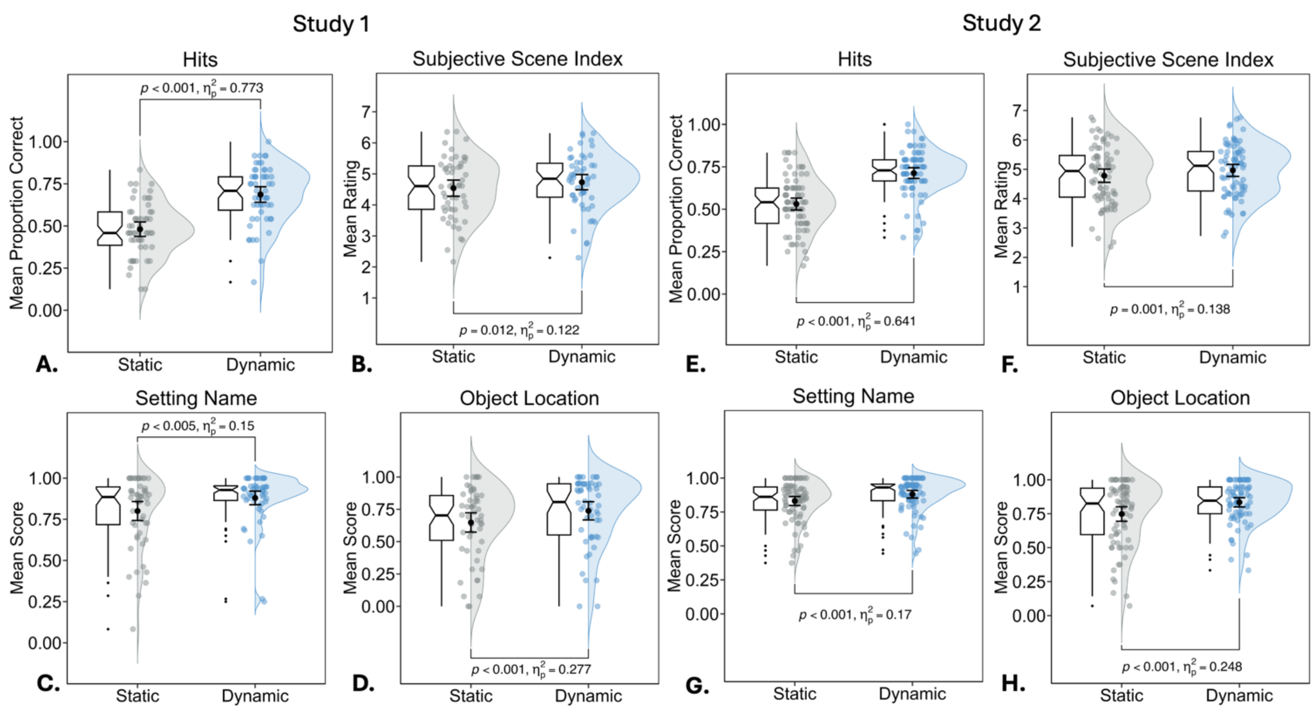
We also replicated the findings from Study 1 for scene memory. First, for setting name there was a main effect of valence $F(2, 144) = 3.22$, p = .043, $\eta_p^2 = .04$. However, post-hoc analyses showed no significant difference in setting name scores between valences. There was no difference between negative (M = .87, SD = .14) and neutral (M = .88, SD = .15), $p_{adj} = .807$ or positive videos (M = .83, SD = .18), $p_{adj} = .104$, nor between neutral and positive videos $p_{adj} = .104$. There was a main effect of dynamism $F(1, 72) = 14.74$, $p < .001$, $\eta_p^2 = .170$ (see Figure 4g), such that participants were better able to recall the correct setting of the object in the dynamic (M = .88, SD = .12) than static condition (M = .83, SD = .15). In addition, there was no interaction between dynamism and valence $F(2, 144) = .26$, p = .770, $\eta_p^2 = .004$.

Second, for object location scores, there was a main effect of valence $F(2, 144) = 4.20$, p = .017, $\eta_p^2 = .06$. The post-hoc analyses indicated that there was no difference in object location scores between negative videos (M = .80, SD = .21) and neutral videos (M = .82, SD = .18), $p_{adj} = .217$, nor any difference in object location scores between negative and positive videos (M = .76, SD = .22), $p_{adj} = .151$. We found a main effect of dynamism $F(1, 72) = 23.80$, $p < .001$, $\eta_p^2 = .25$ (see Figure 4h), such that participants were better able to recall the correct location of the object in the dynamic condition (M = .84, SD = .15) than the static condition (M = .75, SD = .23). There was no interaction between dynamism and valence $F(2, 144) = .35$, $p = .703$, $\eta_p^2 = .005$.

Finally, for the subjective scene index, there was a main effect of valence $F(2, 144) = 14.65$, $p < .001$, $\eta_p^2 = .17$ reflecting higher ratings for negative videos (M = 5.11, SD = 1.03) than both neutral (M = 4.76, SD = 1.00) and positive events (M = 4.73, SD = 1.03), both $p_{adj} < .001$. Neutral and positive events had similar subjective scene ratings ($p_{adj} = .762$). We also found a main effect of dynamism, such that dynamic videos M = 4.97, SD = .92) had higher ratings than static videos (M = 4.77, SD = 1.03). There was no interaction between dynamism and valence $F(2, 144) = 0.704$, $p = .496$, $\eta_p^2 = .01$.

Figure 4

Effect of Dynamism on Recognition and Scene Memory

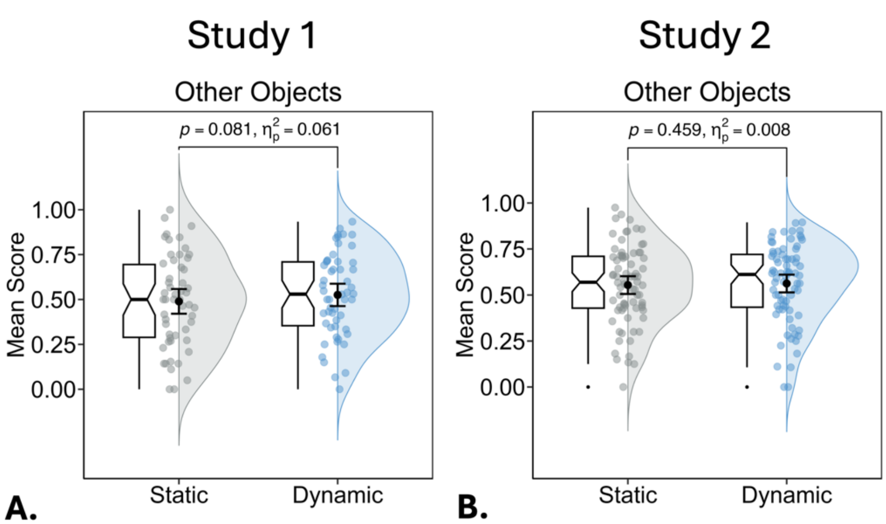


Note. The mean proportion correct for the recognition task was higher in the dynamic condition compared to the static condition in both Study 1 (A) and Study 2 (E). There were also higher ratings in the subjective scene index in the dynamic condition compared to the static condition in both Study 1 (B) and Study 2 (F). Objective measures of scene include setting name and object location. Setting name showed higher scores in the dynamic condition compared to the static condition in both Study 1 (C) and Study 2 (G). There were also higher scores in the dynamic condition compared to the static condition for object location scores for both Study 1 (D) and Study 2 (H). The dots are averaged ratings or score for each participant. The grey dots are the average ratings or score for the static condition. The blue dots are the average ratings or scores for the dynamic condition. On top of the dots are half violin plots that show the distribution of the ratings for each condition. There is also a black dot on top of the other dots to indicate the mean and bars on top and below of this black dot to indicate the standard error of the mean. To the left of the dots are boxplots also indicating the spread of the data.

For content memory, we did not find a main effect of valence $F(2, 144) = 9.14$, $p < .001$, $\eta_p^2 = .11$. Negative videos ($M = .60$, $SD = .23$) had higher total other objects scores than neutral videos ($M = .52$, $SD = .23$), $p_{adj} < .001$ and positive videos ($M = .54$, $SD = .23$), $p_{adj} = .004$. Neutral and positive videos had similar content memory scores ($p_{adj} = .324$). Replicating the findings from Study 1, dynamism did not affect content memory $F(1, 72) = 0.56$, $p = .459$, $\eta_p^2 = .008$ (see Figure 5b). There was no interaction between dynamism and valence $F(2, 144) = 0.14$, $p = .867$, $\eta_p^2 = .002$.

Figure 5

No Effect of Dynamism on Object (Content) Memory

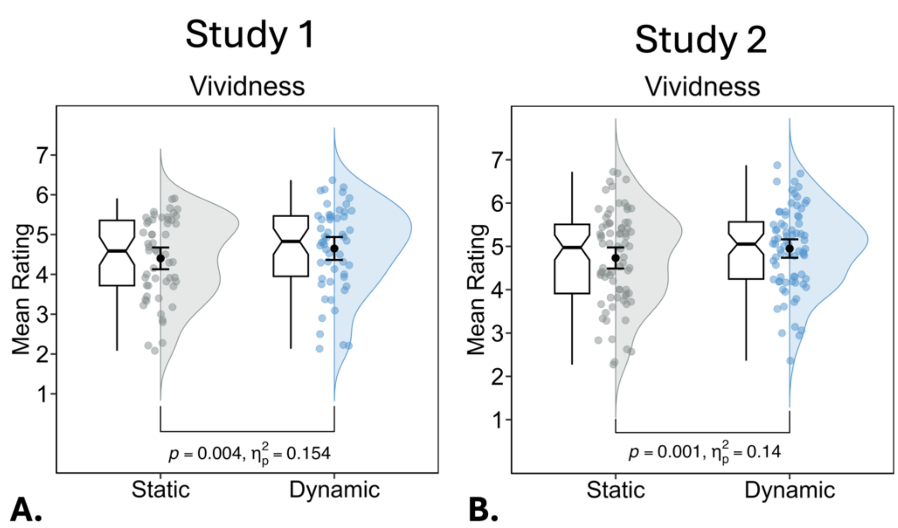


Note. There is no difference between dynamic and static conditions on recalling other objects in the events in both Study 1 (A) and Study 2 (B). The dots are averaged ratings or score for each participant. The grey dots are the average ratings or score for the static condition. The blue dots are the average ratings or scores for the dynamic condition. On top of the dots are half violin plots that show the distribution of the ratings for each condition. There is also a black dot on top of the other dots to indicate the mean and bars on top and below of this black dot to indicate the error of the mean. To the left of the dots are boxplots also indicating the spread of the data.

For vividness, there was a main effect of valence $F(2, 144) = 12.26$, $p < .001$, $\eta_p^2 = .146$. Negative videos ($M = 5.06$, $SD = 1.09$) were rated more vividly than both neutral ($M = 4.70$, $SD = 1.03$) and positive videos ($M = 4.73$, $SD = 1.09$), both $p_{adj} < .001$. Neutral and positive videos were similarly rated in vividness $p_{adj} = .739$. Replicating Study 1, we found a main effect of dynamism $F(1, 72) = 11.76$, $p = .001$, $\eta_p^2 = .14$ (see Figure 6b), reflecting higher vividness for dynamic videos ($M = 4.94$, $SD = 0.96$) than static videos ($M = 4.71$, $SD = 1.11$). There was no interaction between dynamism and valence $F(2, 144) = 0.26$, $p = .769$, $\eta_p^2 = .004$.

Figure 6

Effect of Dynamism on Vividness



Note. There were higher vividness ratings in the dynamic condition compared to the static condition in both Study 1 (A) and Study 2 (B). The dots are averaged ratings for each participant. The grey dots are the average ratings for the static condition. The blue dots are the average ratings or scores for the dynamic condition. On top of the dots are half violin plots that show the distribution of the ratings for each condition. There is also a black dot on top of the other dots to indicate the mean and bars on top and below this black dot to indicate the standard error of the mean. To the left of the dots are boxplots also indicating the spread of the data.

Discussion: Study 2

Overall, the findings from Study 2 replicate Study 1 by demonstrating that dynamism changes the experience of immersive events and influences scene memory but not content memory. We replicated the dynamic superiority effect, such that the dynamic condition had greater recognition accuracy than the static condition. However, we were not able to boost recognition accuracy in the static condition, by changing the instructions from an incidental to an intentional encoding task. One possible explanation is that the object may not be a good cue to retrieve the static experience. Participants may have remembered the static experience, but the object may not be cueing the whole experience, such as other objects or the scene. If we cued participants' recognition memory with the setting, participants may recognize the setting, but may not necessarily recall all the objects, including the object that we used to cue them within our actual task.

Importantly, by removing the audio attached to the dynamic experiences the findings from Study 2 indicate that the effects of dynamism on encoding and retrieval of immersive experiences are independent of semantically congruent sounds. Not only were we able to remove the confound, but we also demonstrated the possibilities within VR to create real-world stimuli to investigate an individual characteristic of the real world. In the real world, when movement is present, an associated sound is usually heard. We are accustomed to a multi-sensory representation of everyday events, therefore, to understand dynamism we had to separate it from the expectation of sound. Furthermore, removing sound may have decreased the importance of the dynamic object and spread the attention towards the other objects in the event. However, not all the sounds were associated with the dynamic object. Nevertheless, removing the sound could have improved memory performance for other objects and both conditions, especially since semantically congruent sounds even if task-irrelevant boosts memory recollection (Duarte et al., 2023).

Dynamism changes how events are experienced, we found that it makes the event more emotionally intense and makes us feel more present. Dynamism also affects our retrieval of the event. We found that dynamism led to a more accurate scene representation and vivid retrieval, even without accurate object content retrieval.

General Discussion

The current study investigated how dynamism influences our subjective experience of an event as well as how it influences scene and content memory. For the first time, we use stimuli that simulate real-world events using 3D 360-degree immersive virtual reality to investigate the dynamic characteristic of episodic memory formation and retrieval. Across two studies we found that dynamic events were experienced with more emotional intensity and sense of presence. Additionally, dynamic objects were more accurately recognized, consistent with the dynamic superiority effect (Buratto et al., 2009; Goldstein et al., 1982; Matthews et al., 2007, 2010). Our findings revealed that dynamism differentially affected scene versus content memory. These findings suggest that dynamism is an important characteristic of everyday life that can impact how people experience and recall events.

A novel aspect of the current study is that we created 3D 360-degree immersive experiences presented in VR. Prior literature on the dynamic superiority effect tried to test the effect realistically, but they used 2D clips of films (Buratto et al., 2009; Matthews et al., 2007, 2010) that lack the self-relevance and immersion of real-life experiences. Other research that looked at the association between scenes and objects used virtual environments with computer-generated scenes presented statically on a screen (Ngo et al., 2016; Spiers et al., 2001). The experience of VR with a head-mounted display as opposed to a computer screen allows people to be embedded into the 360-degree virtual environment. People can turn their heads around naturally and see beyond the boundaries of a screen (Smith, 2019) and this is an important aspect of scene perception and representation (Intraub, 2010). Intraub (2010) emphasized the importance of being able to explore the scene with our full body, not merely looking at a bounded 2D picture of a setting. She also stated that our mental representation of scenes is of our 3D 360-degree world. Our stimuli had realistic 3D 360-degree backdrops and 3D objects added to the events. Furthermore, participants were embedded into the events. This immersion contributes to the self-relevance of the experiences which has been lacking in the current literature (Fan et al., 2023). Dynamism also adds to the visual modality of the sensory experience (Felton & Jackson, 2022) to increase fidelity (Cummings & Bailenson, 2016) and immersion (Smith, 2019). This increased immersion in dynamism supported the higher sense of presence in the dynamic condition compared to the static condition.

Our research on scene memory using real-world stimuli contributes to filling the gap in spatial processing research in episodic memory that is representative of real-life experiences (Fan et al., 2023). Our 3D 360-degree stimuli are representative of everyday life and our mental representation of real-world scenes. We found that dynamism influenced scene memory, which is consistent with event memory theory (Rubin & Umanath, 2015) which states that a scene is required for episodic memory retrieval. With our real-world stimuli, we created unique experiences with unique backdrops and measured setting name and object location recall. We showed that movement in events aids in recall of both setting name and object location. These findings are consistent with findings that found that different subregions of the hippocampus mediate different types of information but work together to retrieve a specific event (Farzanfar et al., 2023; Nadel, 2021). Particularly, the anterior hippocampus is associated with a coarse, global representation of space, similar to our setting name measure, and the posterior hippocampus is associated with geometries of scenes like object position. In addition, we measured participants' subjective scene representation with Rubin and colleagues' (2019) measures of scene. We found that dynamic events had higher ratings for these scene measures than the static tableaus. Therefore, dynamic events have a stronger scene representation than static events during retrieval.

Despite, the boost in scene memory that dynamism provides, our findings show that this is not the case for content memory. We found no difference between dynamic and static conditions in content memory. This is consistent with Rubin and Umanath's (2015) account of event memory, where scene and content information are independent of each other. Content is not required for episodic memory, but a scene representation is (Ranganath & Ritchey, 2012; Rubin, 2020; Rubin et al., 2019). Therefore, people can successfully recollect the experience with the scene without other objects. Furthermore, the spatial relationship between objects may be remembered but not all objects or features of objects will be remembered, particularly if the objects are not causally involved in the event (Radvansky & Zacks, 2011). Static tableaus do not explicitly state a causal relationship between objects across time, this may have made the target object harder to recognize in the static condition than in the dynamic condition. The other objects in the dynamic conditions may not have been causally related to the unfolding event, making them harder to remember. Meanwhile, the other objects in the static condition were equivalent to the target object, and what causal relationship they may have may be unknown to the participant. Therefore, the inability to connect the objects causally may have made it difficult to recall the objects during retrieval.

Manipulating valence also influenced the encoding and retrieval of the immersive experiences. Due to the sense of presence and emotion being orthogonal (Slater, 2003), valence did not affect sense of presence ratings across the two studies. Furthermore, pleasantness ratings did not depend on dynamism but rather on the valence of the video. However, emotional intensity was greater for the dynamic than the static condition, which may be because the event felt more real in the dynamic experience. Across the two studies, recognition accuracy for negative events was greater than for positive and neutral events. Negative events also had greater subjective scene index ratings, greater recall of other objects, and higher vividness ratings, compared to neutral and positive events. Prior literature has shown that emotional memories are usually remembered better than neutral ones (Kensinger, 2009), however, negative stimuli have been found to boost visual details (Kensinger et al., 2007). Furthermore, the negative experiences may also be more novel or have objects in novel contexts that heighten memorability (Ranganath & Rainer, 2003). In our study, visual details such as the scene layout, recall of other objects, and vividness, were better recalled in negative events compared to neutral and positive events.

The current study supports previous accounts of scene-related aspects of memory using novel techniques that simulate real-world events. However, one limitation is that we did not consider whether different types of movement had any effect on perception or memory. Movement could range from stationary to moving across the screen, or it could be a repeated movement or unique across time. Movement of objects of varying sizes and depths from the experiencer have an impact on their perceptual sensitivity (Cutting & Vishton, 1995) and this might influence encoding and retrieval. Perceptual sensitivity might influence whether an object is considered unique to the event or part of the backdrop, even if the object is dynamic. Furthermore, future studies could investigate the impact of dynamic objects on where people look in the scene using eye-tracking and if this influences memory. With eye-tracking we can investigate where people are looking at specific time points. This is important because exploratory eye movements during encoding impacts people's scene representations (Henderson & Castelhano, 2005).

Another possible explanation for better memory performance in the dynamic condition compared to the static condition is attention. In our study, only one object moved in the dynamic condition and this is what we used as our cue in the recognition test. It is possible that participants paid more attention to the dynamic object and not the other objects in the event, which may have influenced the recall of memory content. Therefore, a control condition, where one object drew the participants' attention without moving, would be needed to answer the extent of attention's role in the memory of dynamic events. However, previous research found that full attentional engagement during the encoding of dynamic videos is not required for the dynamic superiority effect during retrieval (Matthews et al., 2010). Matthews and colleagues had participants watch dynamic and static stimuli of hands or faces. They also had a full attention condition and a divided attention condition during encoding. In the full attention condition, participants watched the stimuli, then at the end of each stimulus presentation, they responded *yes* if they saw a face. In the divided attention condition, they listened to tones during stimulus presentation, and at the end, they responded *yes* if they heard three tones of the same frequency. For retrieval, participants completed a recognition task, where they judged a cue on a 6-point scale from *definitely old* to *definitely new*. This experiment found that overall, moving videos during encoding had better memory, demonstrating the dynamic superiority effect. In the divided attention condition, dynamic clips during encoding were still better remembered than static stimuli. Therefore, this study shows that full attention or increased attentional engagement is not required for the dynamic superiority effect to be present. Nevertheless, Matthews and colleagues' (2010) experiment tested recognition memory but did not test the recall of individual objects, where attention may have more influence.

Another possible limitation of the current project is the number of tests run in our multiway repeated-measures ANOVAs. Altogether, each study had nine dependent variables and two independent variables, which resulted in three F-tests (two main effects and one interaction) for each dependent variable. Therefore, altogether we ran 27 F-tests, for each study. This number of tests increases the likelihood of a Type 1 error (Cramer et al., 2016). One of the main issues of running many tests and increasing the chance of Type 1 error, is that the significant results are merely spurious and cannot be replicated again. However, we ran two studies with the same independent and dependent variables, and we were able to replicate our main findings. Our replication provides us with confidence in the true nature of our results.

Our findings revealed that dynamism affects our experience and memory of events. Using novel stimuli, we were able to embed participants into the experience and control a specific component of the real world. We found that dynamism boosted sense of presence and emotional intensity during encoding. With these novel stimuli, we also extended the generalizability of the dynamic superiority effect, with higher recognition accuracy for dynamic events. Dynamism also led to more accurate scene representations but not better content recall. Therefore, we were able to objectively show the independence of scene and content details in episodic memory. Our results demonstrated that dynamic events were retrieved more vividly than static tableaus. Both findings are consistent with event memory theory proposed by Rubin and Umanath (2015). Overall, we demonstrated that dynamism is an important component of how we experience the real world and affects our recollection of these events.

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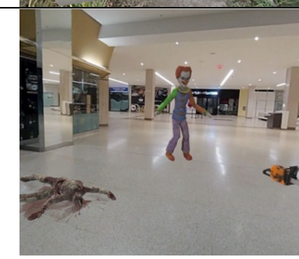
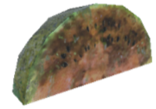
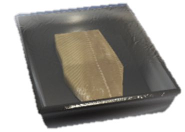
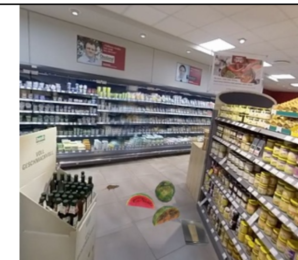
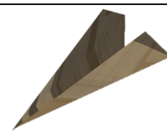
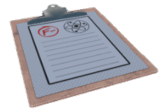
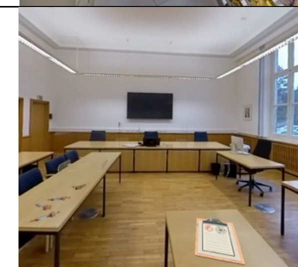
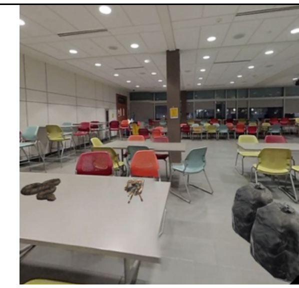
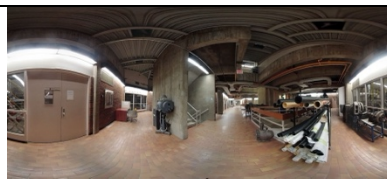
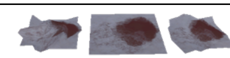
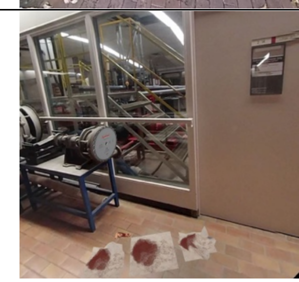
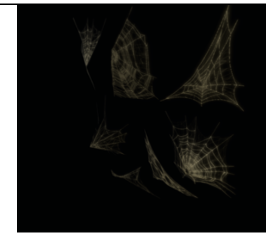
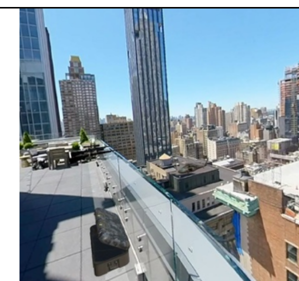
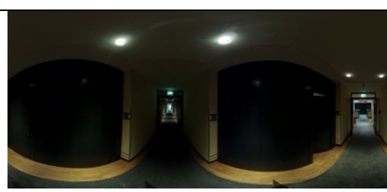
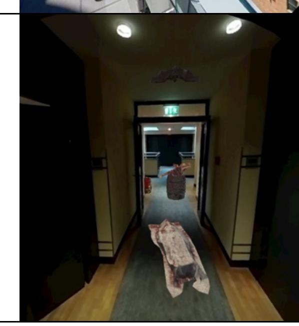
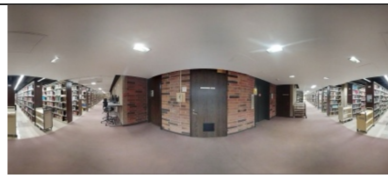
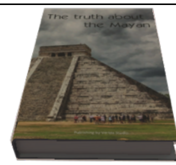
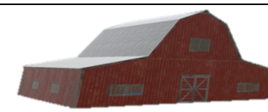
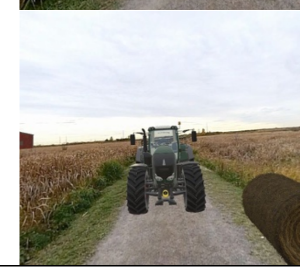
Appendix A: Table of Study 1 and Study 2 Stimuli

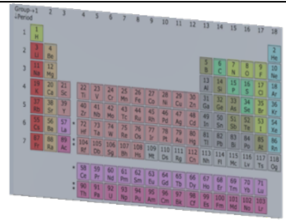
Valence	Backdrop Source	Backdrop	Dynamically Manipulated Object	Object 1	Object 2	Full Experience
Negative	LuVRe		 Falling from the bridge			
Negative	Lab		 Brings arms up and laughs			
Negative	Lab		 Gets on hind legs and roars			

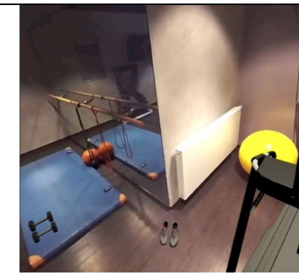
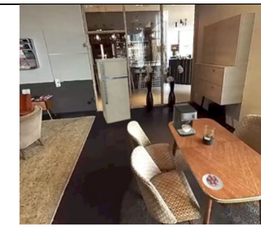
Negative	LuVRe		 Scuttles back and forth in front of cold aisle			
Negative	LuVRe		 Flies around the room			
Negative	Lab		 Drives down the road and hits the deer			
Negative	LuVRe		 Crocodile moves toward the viewer			

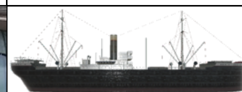
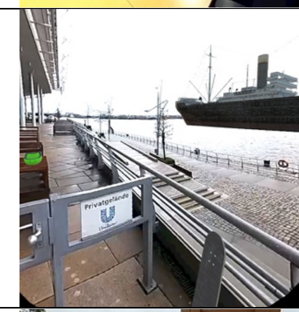
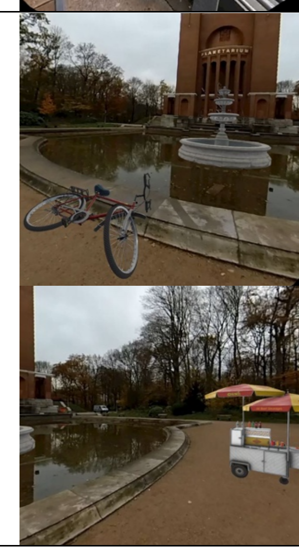
Negative	Lab		 The snake slides across the table			
Negative	LuVRe		 Flies in a swarm flying on top of the poop			
Negative	Lab		 It turns in place			
Negative	LuVRe		 Cranks and release a boulder			

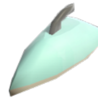
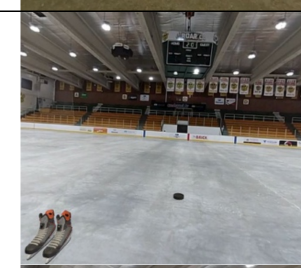
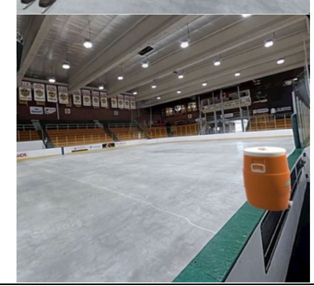
Negative	LuVRe		 Gorilla stands up and pounds it chest			
Negative	LuVRe		 Countdown on the computer screen			
Negative	LuVRe		 It flies across the screen			
Negative	LuVRe		 Flies above the viewer then returns above the doorway			

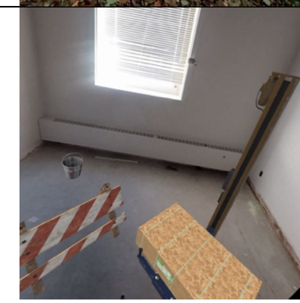
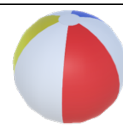
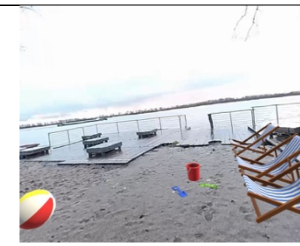
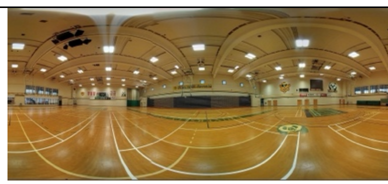
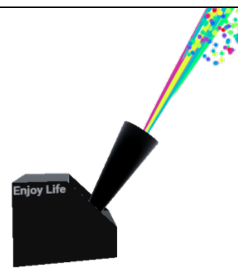
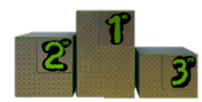
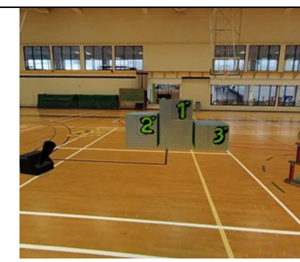
Negative	LuVRe		 Flashing blue and red lights			
Neutral	Lab		 It slides off the cart and land on the ground			
Neutral	LuVRe		 It moves forward away from the viewer			 

Neutral	Lab		 Bubbles fizz out of the flask			 
Neutral	Lab		 Water spraying from the hose			
Neutral	Lab		 The car leaves the parking spot			

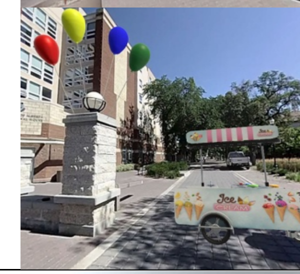
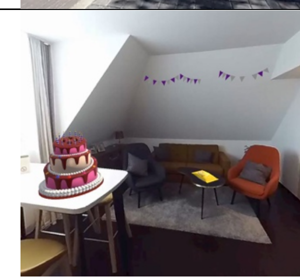
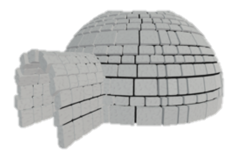
Neutral	LuVRe		 Treadmill belt is running			
Neutral	LuVRe		 The drink is steaming			
Neutral	Lab		 The flames are flickering			

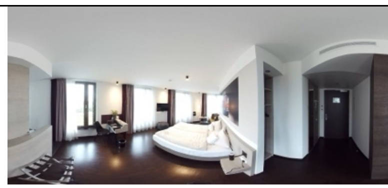
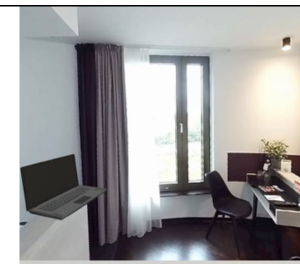
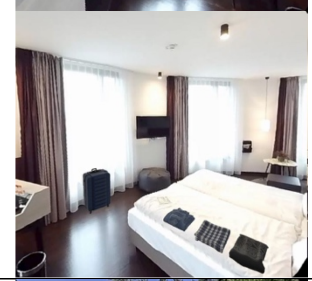
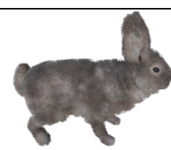
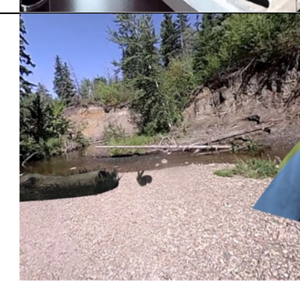
Neutral	LuVRe		 Printed paper sheet comes out of the printer			
Neutral	LuVRe		 Ship slowly moves across the screen			
Neutral	LuVRe		 The front wheel is spinning			

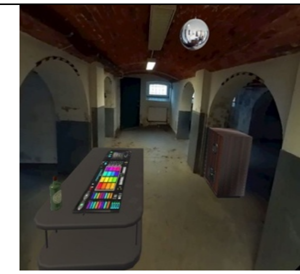
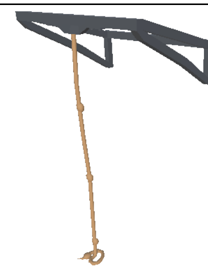
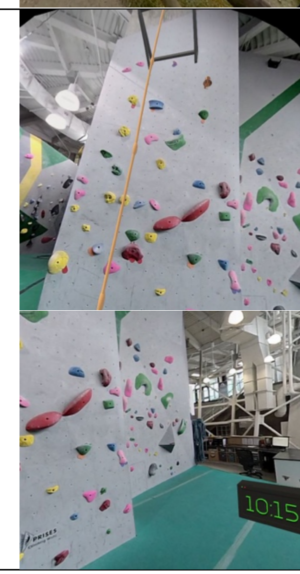
Neutral	LuVRe		 Steam coming out of the iron			
Neutral	LuVRe		 Trumpetting intermittently			 
Neutral	Lab		 Slides across the screen on the ice			 

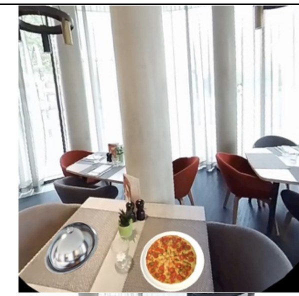
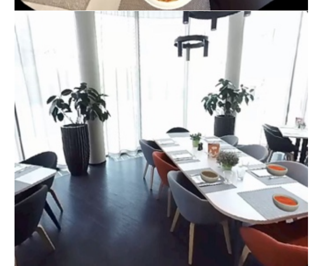
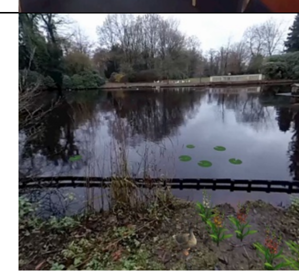
Neutral	LuVRe		 Jumping in the grass intermittently			
Neutral	Lab		 The wood pallet rises			
Positive	LuVRe		 Bounces across the sand			
Positive	Lab		 Confetti explode out of the machine			

Positive	LuVRe		 This bell rings			 
Positive	Lab		 Bounces across the screen towards the towel			 

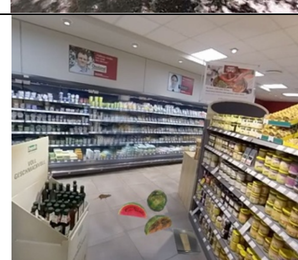
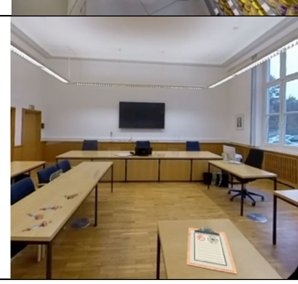
Positive	Lab		 Balloons sway lightly			 
Positive	LuVRe		 Fire on candles sway			
Positive	Lab		 Munching on the snow			 

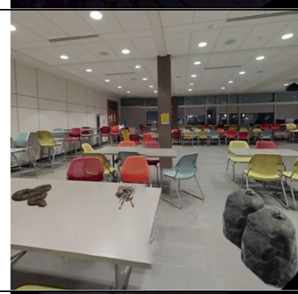
Positive	Lab		 Vault door unlocks and opens			
Positive	LuVRe		 The screen graphics move			 
Positive	Lab		 Moves across the screen			

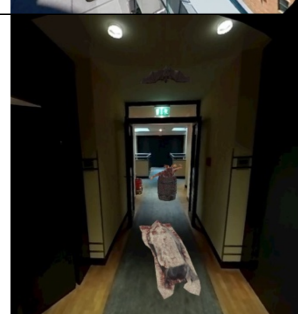
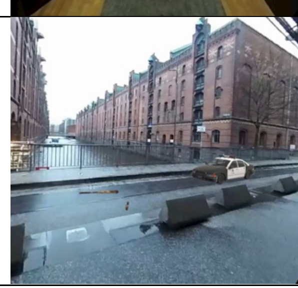
Positive	LuVRe		 Turns in a circle				
Positive	LuVRe		 Scurries on the fence towards the tree				
Positive	Lab		 Bell rings		 	 	

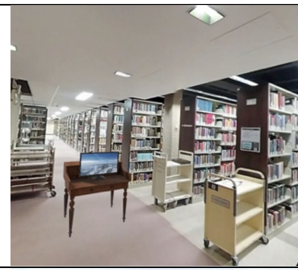
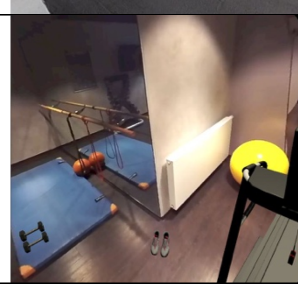
Positive	LuVRe		 Munching on the snow			
Positive	LuVRe		 Light smoke steaming			 
Positive	LuVRe		 Goose honking			

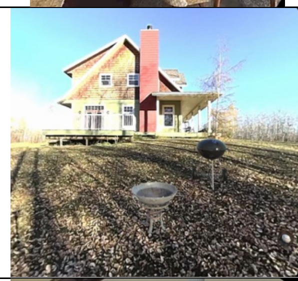
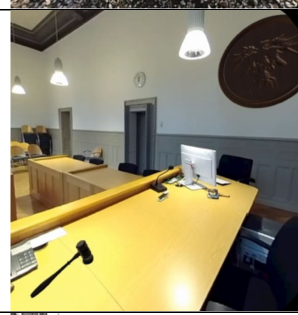
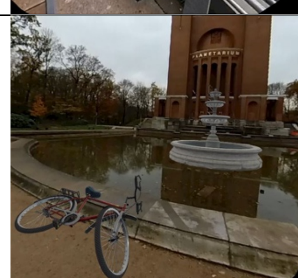
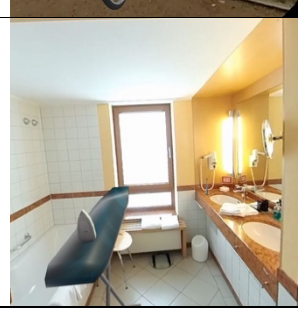
Appendix B: Table of Valence Measures

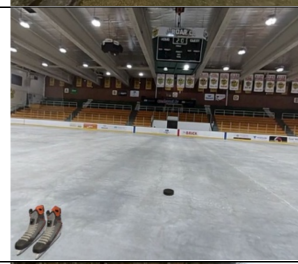
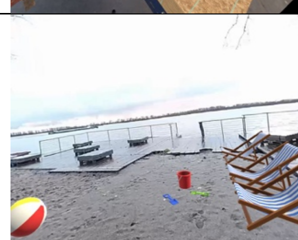
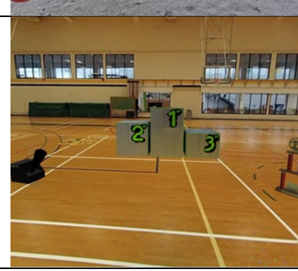
	Average encoding pleasantness rating across trials for each valence Mean (SD)			Average encoding pleasantness rating across participants for each experience Mean (SD)	
Valence	Study 1	Study 2	Experience	Study 1	Study 2
Negative	2.99 (0.48)	2.75 (0.51)		3.07 (1.27)	2.95 (1.21)
				2.44 (1.41)	2.25 (1.41)
				3.00 (1.18)	2.74 (1.19)
				3.24 (1.39)	3.14 (1.03)
				3.31 (1.40)	2.86 (1.30)

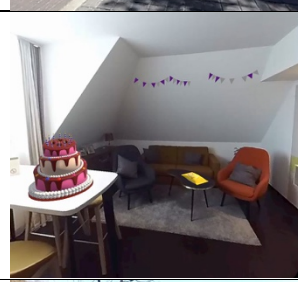
				2.72 (1.14)	2.59 (1.18)
				2.98 (1.42)	2.47 (1.11)
				3.20 (1.32)	2.75 (1.33)
				2.63 (1.28)	2.37 (1.09)
				3.04 (1.50)	2.54 (1.15)
				3.91 (1.34)	3.95 (1.53)

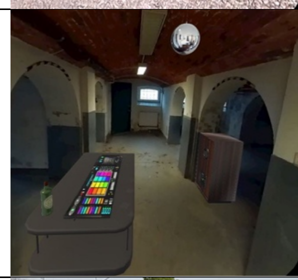
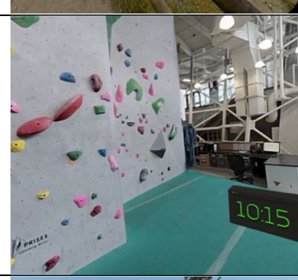
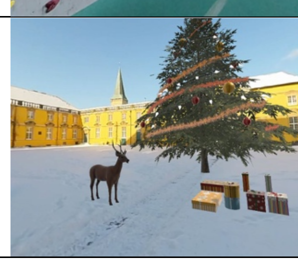
				2.43 (1.38)	2.14 (1.16)
				2.74 (1.14)	2.51 (1.13)
				3.85 (1.42)	3.58 (1.42)
				2.15 (0.98)	2.04 (1.08)
				3.17 (1.33)	3.05 (1.18)

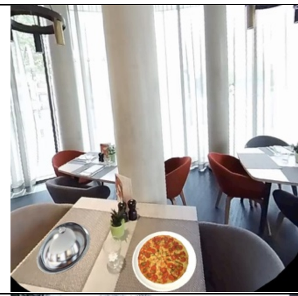
Neutral	4.31 (0.39)	4.22 (0.47)		4.02 (1.28)	4.05 (1.25)
				4.20 (1.28)	4.28 (1.23)
				4.30 (1.22)	3.95 (1.33)
				5.19 (1.21)	5.17 (1.32)
				4.07 (1.24)	3.74 (1.20)
				4.22 (1.19)	4.08 (1.31)

					4.67 (1.36)	4.74 (1.19)
					4.72 (1.20)	4.43 (1.24)
					4.26 (1.47)	4.05 (1.25)
					4.44 (1.08)	4.33 (1.30)
					4.17 (1.09)	4.12 (1.51)
					4.04 (1.23)	3.79 (1.20)

				4.09 (1.17)	4.11 (1.21)
				4.37 (1.34)	4.47 (1.23)
				4.76 (1.37)	4.96 (1.26)
				3.5 (1.02)	3.26 (1.15)
Positive	4.76 (0.41)	4.68 (0.56)		4.98 (1.14)	4.68 (1.09)
				5.11 (1.30)	4.83 (1.37)

				4.30 (1.27)	4.30 (1.23)
				4.70 (1.42)	5.03 (1.25)
				4.70 (1.28)	5.05 (1.20)
				5.07 (1.18)	4.70 (1.32)
				4.35 (1.42)	4.17 (1.33)
				4.31 (1.45)	3.86 (1.49)

				5.13 (1.30)	4.75 (1.33)
				4.35 (1.08)	5.21 (1.25)
				3.74 (1.62)	3.24 (1.33)
				4.94 (1.35)	5.40 (1.23)
				4.52 (1.18)	4.57 (1.12)
				4.94 (1.45)	5.01 (1.13)

				5.28 (1.29)	4.99 (1.22)
				4.98 (1.30)	5.12 (1.40)

Appendix B. We created valenced narratives for our immersive experiences. We did not measure their pleasantness apriori, but we did measure their pleasantness rating during each study. We ran a one-way ANOVA for each study, with the pleasantness rating as the dependent variable, and the grouping variable was the valence we assigned the experiences. For study 1, there was a difference between valences $F(2, 45) = 73.6$, $p < .001$. Negative experiences have the lowest pleasantness ratings ($M = 2.99$, $SD = 0.48$), then neutral experiences ($M = 4.31$, $SD = 0.39$), and positive experiences had the highest pleasantness ratings ($M = 4.76$, $SD = 0.41$). The Tukey post-hoc test showed that negative experiences were significantly less pleasant than neutral ($p < .001$) and positive ($p < .001$) experiences. Neutral experiences were also less pleasant than positive experiences ($p = .014$). These results were also replicated in study 2, where there was a difference in pleasantness ratings between valences $F(2, 45) = 61.9$, $p < .001$. Negative experiences have the lowest pleasantness ratings ($M = 2.75$, $SD = 0.51$), then neutral experiences ($M = 4.22$, $SD = 0.47$), and positive experiences had the highest pleasantness ratings ($M = 4.68$, $SD = 0.56$). The Tukey post-hoc test showed that negative experiences were significantly less pleasant than neutral ($p < .001$) and positive ($p < .001$) experiences. Neutral experiences were also less pleasant than positive experiences ($p = .045$). Therefore, there is a clear difference in valence between our valence categories.

Appendix C: Setting Name Coding Procedure

1. During retrieval, participants were asked to recall the VR video setting where the shown object was involved. They were instructed to be as specific as possible. The experimenter also asked the participants if they understood a "setting". If they did not know, then the experimenter explained where the video took place, and provided an example like "home office".
2. For coding, if participants correctly judged an object to be old, but incorrectly recalled the setting or did not write anything at all, they were given a 0, meanwhile, correct recall of the setting was given a 1.
3. The coder compared the participant's answer to the actual setting. The experimenters did not provide a word for the setting during encoding. Therefore, the coder compared the participants' answers to the visual setting and judged for themselves if the written answer matched the visual setting. The answer was given a 1 if it matched the setting and was specific to that location.
    a. We were also not strict with coding answers as 0. We allowed for the participants' interpretation of the setting since naming the setting by themselves can be based on their own personal knowledge. We only coded answers as 0, if they were completely wrong, they could have mixed up the setting for another experience, or provided no answer.

Below are example scorings for the negative LuVRe experience with the waking gorilla.

Score of 0	Score of 1
"haunted house" - The setting was not a haunted house. But the objects were meant to elicit a negative valence.	"dark place, an abandoned harbor" - The event is taking place on a bridge in a dark place, so it could be taken as a harbor "indoor jungle" - There are lots of plants all around and the walls show that the setting is indoors "Wooden building/walkway in a jungle or zoo" "In a outside resturant with dead skeleton and burnt body"

	- This does seem like it could be inside a Rainforest café, and the participant also stated two other objects that were in the experience

Appendix D: Object Location Coding Procedure

1. During retrieval, the participants were instructed to recall where the object was in the setting, providing sufficient detail that another person could place the object within the experience.
2. For coding, if participants correctly judged an object to be old, but incorrectly recalled the object location or did not write anything at all, they were given a 0, meanwhile, correct recall of the object location was given a 1.
3. The coder compared the participants' answers to the visual location of the object and judged for themselves if the written answer matched the location in the VR experience.
    a. We were also not strict with coding answers as 0. We coded relative to the participant's own descriptions of other objects in the amount of detail they could provide. We gave them the benefit of the doubt, if they added more information/details that showed that they remembered the experience but could not write all the details. We only coded answers as 0, if they were completely wrong, or provided no answer.

Below are example scorings for the negative LuVRe experience with the waking gorilla.

Score of 0	Score of 1
"on the floor/ground" - This is a vague answer. Especially because all the other objects in the experience were on the floor.	"On the ground in the middle of the walkway to the left of viewer" - This is a clear and specific answer "To my left" "To the right of me, starts on the ground then gets up" - The gorilla was to the left of the viewer, but they provided extra information, that ensures me that they know the object the location, but may have just confused left and right. "Next to the skeleton" - They added information about the objects and correctly stated that they are next to each other, just did not specify if left or right

Appendix E: Other Objects (Memory Content) Coding Procedure

1. During retrieval, the participants were instructed to recall two other objects in the same experience as the object being shown. Participants were also instructed to recall each object with sufficient detail to be distinguishable from other objects.
2. For coding, if participants correctly judged an object to be old, but incorrectly recalled another object or did not write anything at all, they were given a 0, meanwhile, the correct recall of each object was given a 1. Each object was scored with a 0 or 1. We averaged this score for analysis.
3. The coder compared the participants' answers to the actual objects in the VR experience, and judged for themselves if the written objects matched the objects in the VR experience.
    a. We were also not strict with coding answers as 0. Any object in the same experience as the shown objects was given a 1. The objects do not have to be the objects that we added. We also coded relative to the participant's descriptions of other objects in the amount of detail they could provide. We gave them the benefit of the doubt if they added more information/details that showed that they remembered the experience but could not write all the details. We only coded answers as 0, if they were completely wrong, or provided no answer.

Below are example scorings for the negative LuVRe experience with the waking gorilla.

Score of 0	Score of 1
"There is another thing in front of me" - Very vague; no object stated	"skeleton" and "dismembered body" - These were the two objects that we added "sign with operation hours"/"sign in foreign language" - An object that is unique to this experience, but not one that we added

Appendix F: List of IVs and DVs

Variable Type	Variable Name	Explanation
Indepdendent	Dynamism: Static, Dynamic	The VR experiences were either presented dynamically or statically. In the dynamic condition one of the added objects moved (more description in Appendix A). In the static condition, none of the added objects moved.
Independent	Valence: Negative, Neutral, Positive	We created the experiences to elicit specific valences (i.e., negative, neutral, and positive), by adding objects that created a narrative that elicited that valence. We did not categorize them according to pleasantness ratings, but we did collect pleasantness ratings during encoding (see Appendix B).
Dependent	Pleasantness	"How pleasant was this event?" 1- Extremely unpleasant 7- Extremely pleasant
Dependent	Emotional Intensity	"How emotionally intense was this event?" 1- Not at all intense 7- Extremely intense
Dependent	Sense of Presence	"How present did you feel in this event?" "Presence refers to how much you feel that you are present in the environment, such that you could reach out to touch things or they could touch you." 1- Not at all present 7- Extremely present
Dependent	Hits	The number of correctly judged old objects in each condition was divided by 24 (there were 24 experiences of each condition that was presented during encoding). This gave us the proportion of hits for each condition, giving us a hit score for dynamic and static condition for each participant.
Dependent	Setting Name	Participants recalled the setting name for an object judged to be old. Please see Appendix C. This was the average score of correct setting name for each condition for each participant.
Dependent	Object Location	Participants recalled the object location for an object judged to be old. Please see Appendix D. This was the average score of correct object location for each condition for each participant.

Dependent	Other Objects (Memory Content Index)	Participants recalled the two other objects in the same experience as the object judged to be old. Please see Appendix E. Participants were instructed to recall two objects for each experience, so this was averaged. Then we averaged this averaged score for each condition for each participant.
Dependent	Vividness	"While remembering, I can see everything in my mind" 1- Not at all 7- as vivid as if it were happening now
Dependent	Subjective Scene Index	This was the average of three questionnaires, that came from Rubin et al., (2019) to measure the scene: Self-location: "While remembering, I can identify where I am in relation to the things that I am remembering. 1- Not at all 7- I know exactly where I am seeing the event from Setting Layout "While remembering, I experience a scene in which the elements of the setting are located relative to each other in space." 1- Not at all spatially organized 7- a clear spatial layout Event layout "As I remember, I can describe where the actions, objects, and/or people are located in the memory." 1- Not at all spatially orgnaized 7- As if it were happening now