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Unintended consequences of spatial presence on learning in virtual reality

Sun Joo (Grace) Ahn [a,*], Kristine L. Nowak [b], Jeremy N. Bailenson [c]

[a] University of Georgia, Grady College of Journalism and Mass Communication, Georgia
[b] University of Connecticut, Department of Communication, USA
[c] Stanford University, Department of Communication, USA

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ABSTRACT

Research on virtual reality (VR) in education and training has found that spatial presence, the perception that the body is inside a mediated environment, increases engagement. However, experiencing spatial presence requires the allocation of limited processing resources, potentially inhibiting the processing of other information. Guided by the frameworks of Limited Capacity Model of Motivated Mediated Message Processing (LC4MP), and the cognitive theory of multimedia learning, two experiments examined the effects of different modalities on spatial presence to test the prediction that spatial presence negatively impacts recall. Study 1 ($N = 100$) found that VR elicited higher spatial presence than video, but that high spatial presence reduced recall. Individual differences (technology apprehension) moderated spatial presence. Study 2 ($N = 260$) found that pre-existing interest in the learning content and aversive responses elicited by the learning content increased spatial presence. However, segmenting the VR content to reduce processing load for participants had little effect on spatial presence or information recall. In sum, modality features and individual differences drove user experiences of spatial presence, which negatively impacted recall, but segmentation of VR content had no effect on learning outcomes.

1. Introduction

Immersive virtual environments, such as virtual reality (VR),[1] engage multiple sensory channels so that users can see, hear, and feel in the mediated world as they would the unmediated world. This facilitates feelings of presence, or the subjective sense of "being there" in the mediated world (Biocca, 1997; Lombard & Ditton, 1997; Slater & Wilbur, 1997). Spatial presence is one dimension of presence, referring to the user sensation that their body is located in a mediated environment where they can interact (Biocca, 1997; Slater & Wilbur, 1997). Earlier research has suggested that spatial presence can enhance learning outcomes, including recall of factual

* Corresponding author. Grady College of Journalism & Mass Communication, University of Georgia, 120 Hooper Street, Athens, GA, 30602-3018, USA.

E-mail address: sjahn@uga.edu (S.J.(G. Ahn).

[1] Immersive virtual environments, popularly known as virtual reality (VR), can be experienced in a variety of forms, ranging from desktop VR systems, projection VR systems such as Cave Automatic Virtual Environments (CAVE), and VR goggles such as head mounted displays (HMD). In recent years, HMD-based VR systems have come to dominate the consumer VR market and recent studies indicate that immersive experiences are in HMDs are more engaging than other forms of VR systems (e.g., Elor et al., 2021). Therefore, the current study focuses on HMD-based systems when we refer to VR.

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knowledge (Mikropoulos & Natsis, 2011) and motivation to learn (Cheng & Tsai, 2019).

People generally report more spatial presence in VR than in less immersive environments (Allcoat et al., 2021; Wu, Yu, & Gu, 2020). Spatial presence can, in turn, increase engagement and enjoyment of mediated content (Shafer, Carbonara, & Popova, 2011; Skalski, Tamborini, Shelton, Buncher, & Lindmark, 2010). Although increased engagement from spatial presence may enhance entertainment, it does not necessarily enhance learning. Based on the cognitive theory of multimedia learning (Mayer, 2014), each separate stream of information taxes the user's processing system. The way VR presents multiple streams of information so that users can see, hear, and feel, can therefore adversely affect recall and learning (Bai, Jones, Moss, & Doane, 2014; Jeong & Fishbein, 2007; Martini, Heinz, Hinterholzer, Martini, & Sachse, 2020; Mayer & Moreno, 2003). This is consistent with recent evidence indicating that VR increases engagement with and enjoyment of content, but not learning outcomes (Makransky, Andreasen, Baceviciute, & Mayer, 2020; Makransky, Terkildsen, & Mayer, 2019; Parong & Mayer, 2021). Therefore, understanding the relationship between spatial presence, engagement, and learning in VR merits further investigation. Considering the pressing need for distance education and rising anticipation of VR's role in education and training (Kennedy, 2018; Noguchi, 2019), this is a timely investigation of VR's potentials and limitations in the context of learning.

Guided by theories from media psychology and education that apply capacity models to information processing (Lang, 2006; Mayer & Moreno, 2003) and the process model of spatial presence (Hartmann et al., 2015; Wirth et al., 2007), this paper presents a pair of studies testing the possibility that using processing resources for spatial presence may reduce processing resources available for processing other information, resulting in lower recall. We build on recent findings that suggest VR-based learning can impede learning outcomes (Makransky et al., 2020; Meyer, Omdahl, & Makransky, 2019), and shed insight on the psychosocial mechanisms that mediate, and individual differences that moderate the impact of multimedia modalities on information recall.

1.1. Rising interest in immersive technologies for education

With over 1200 studies published on VR in education in the year 2020 (Makransky & Petersen, 2021), interest is rising for immersive technologies as a learning tool. Scholars have largely focused on the positive aspects of VR in education, with recent work highlighting VR's ability to improve knowledge acquisition (Radianti, Majchrzak, Fromm, & Wohlgenannt, 2020) and knowledge development (Hamilton, McKechnie, Edgerton, & Wilson, 2021; Wu et al., 2020). Learning with VR is more enjoyable than with less immersive modalities for adults (Allcoat et al., 2021) and children (Araiza-Alba, Keane, Chen, & Kaufman, 2021).

Prior research examining VR for education has been criticized for being atheoretical and technology-centered (Radianti et al., 2020), assuming that mere exposure to VR technology is good for learning. Some scholars have argued that media only serve as vehicles of instructional delivery, with technological features have little direct impact on learning outcomes (Makransky & Petersen, 2021). A meta-analysis on VR for training demonstrated that training programs in immersive VR performed worse than those using less-immersive media (Howard & Gutworth, 2020). Another meta-analysis found that although the overall effect of 35 studies demonstrated immersive VR to be more effective than traditional learning tools, the effect size was small and over a third of the studies showed no or adverse effects of VR (Wu et al., 2020).

It is difficult to compare learning outcomes directly across studies when they do not measure or evaluate the same types of outcomes, with measures including declarative knowledge, procedural knowledge, retention, recall, or transfer (Sitzmann, 2011). Recent studies note the importance of differentiating levels of processing for a more nuanced and accurate understanding of the learning process, particularly as it pertains to immersive media (Albus, Vogt, & Seufert, 2021; Breves, 2021). Information recall is the first and most elementary level of knowledge, where individuals retrieve factual knowledge without necessarily comprehending or having the ability to transfer knowledge to different contexts (Makransky, Borre-Gude, & Mayer, 2019). Before investigating more in-depth forms of knowledge transfer, it is important to test how media features can impact recall to determine the utility of VR in education and training.

Also, despite extensive research on the effect of non-immersive VR on education (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014), these findings cannot be readily generalized to immersive VR applications in education, and research on the impact of immersive VR on learning outcomes is still limited. Wu et al. (2020) noted that immersive and non-immersive VR systems lead to a range of substantially different user perceptions and future research should focus on systematically investigating these differences on learning outcomes.

1.2. Spatial presence in immersive virtual reality

Spatial presence is defined as the perception of "being there" in a mediated environment, users feeling as if they are located in, and able to interact with objects and people depicted in the virtual or media generated environment (Biocca, 1997; Lombard & Ditton, 1997). Because the goal of VR is to create immersive experiences where users accept computer generated information to their senses as real, spatial presence is often described as the "holy grail" of VR experiences. High immersion, which is the modality's capacity to engage more sensory channels through features such as stereovision and body tracking, has been associated with increased spatial presence (Cummings and Bailenson, 2016). However, high immersion isn't required to experience spatial presence and users report it following experiences with less immersive media, including books, television, or video (Kim & Biocca, 2006; Schubert, 2003).

Researchers have posed various explications of spatial presence over the years, but they converge on some core elements. First, spatial presence increases when users feel immersed in digitally created sensory stimuli, which may be moderated by individual differences, such as interest in content (Sacau, Laarni, & Hartmann, 2008; Slater & Usoh, 1993). Also, as with any media effect, audiences must first pay attention to mediated stimuli in order for them to perceive, process, and respond (Lang, 2006). Therefore, either involuntary or voluntary attention to the mediated content is considered a prerequisite of spatial presence (Sanchez-Vives & Slater, 2005).

Early neuroscientific accounts of presence describe how the brain segments perceptual inputs into focal awareness and subsidiary awareness during VR use (Lavie & Tsal, 1994). Some measures of spatial presence are built around the notion that high spatial presence in VR is negatively associated with the ability to recognize cues from the physical world (Biocca, 1997) with cues in the virtual world placed into focal awareness (Laarni et al., 2015). Makransky et al. (2020) explained the impact of immersive VR on memory in terms of cognitive load, arguing that, "… learning in IVR leads to higher extraneous cognitive load than learning in less immersive media." (pg. 946).

It is thus possible that users have lower learning outcomes in VR because they are detracted from the content they should be learning while paying attention to content extraneous to the learning goals, such as navigating the VR system or being overwhelmed by the sensory information (Barreda-Ángeles, Aleix-Guillaume, & Pereda-Baños, 2020). However, users do not distinguish between content that is relevant or irrelevant to the learning goals when experiencing spatial presence. When feeling high presence, users engage in what may seem like 'distractions' in VR, seeing, hearing, and feeling rich layers of sensory cues that may be irrelevant to the learning objectives, but that still engage processing resources.

Neuroscientific findings indicate that when processing load is high, it not only constrains processing capacity, but also negatively impacts the *quality* of processing when insufficient processing resources are allocated. Consequently, under high processing load, the information value of the stimulus decreases when the quality processing is low due to insufficient resources (Fitousi & Wenger, 2011). Given recent conceptualizations of information processing that posit interactions between perceptual and cognitive systems (Fisher, Huskey, Keene, & Weber, 2018), high spatial presence in VR is likely to negatively impact the both the perceptual and cognitive processing of information by placing constraints on the available resources but also by diminishing the information value of the stimulus that is insufficiently processed.

1.3. Capacity models of media message processing

The conceptualization of spatial presence as people's perceptual and cognitive systems being engaged by mediated cues is consistent with how scholars have conceptualized processing capacity, resource allocation, and processing load (Fisher, Huskey, et al., 2018; Mayer & Moreno, 2003). Spatial presence involves the allocation of mental resources to process media content as the user creates a mental representation of the mediated space based on the digital information provided (Hofer, Wirth, Kuehne, Schramm, & Sacau, 2012; Schubert, Friedmann, & Regenbrecht, 2001; Wirth et al., 2007). Rich layers of external information provided by multimedia such as VR generally enrich spatial presence perception (Wirth et al., 2007) and is likely to be more demanding of users' limited mental resources.

Both the cognitive theory of multimedia learning (Mayer & Moreno, 2003) and the Limited Capacity Model of Motivated Mediated Message Processing (LC4MP; Lang, 2006) are based on the premise that humans have limited cognitive capacity for information processing, which can be depleted and result in constraints on content processing and learning outcomes. One core assumption of the capacity models is that the brain can only process a certain amount of information at any given time and that each sensorimotor channel engaged by the media modality taxes this capacity. Therefore, it is important to consider how much resource is required, how much resource can be allocated, and what remaining resources are available when designing and evaluating multimedia learning content.

The resources required to process multimedia content depends on the modality of presentation as well as the density of information introduced in a given amount of time (Lang, Kurita, Gao, & Rubenking, 2013). Density of information refers to the quantity of information introduced by structural changes, such as camera cuts or edits. Structurally "richer" multimedia modalities such as VR or video are likely to have higher density of information introduced compared to structurally "leaner" static modalities such as print or photos. When media systems present dense information to the users' senses, it becomes difficult for users to absorb all the information and the brain becomes "the bottleneck in the communication system" (Biocca & Nowak, 2002).

Allocation of processing resources occurs as a result of two primary sources—orienting responses and motivational systems. Orienting responses are physiological changes that automatically, or subconsciously, direct processing resources toward novel stimuli (Graham & Clifton, 1966). When structural features of media content change (e.g., moving objects), the processing system allocates resources to process the novel stimuli and make sense of them (Lee & Lang, 2015). Motivational systems as described in the LC4MP framework refer to appetitive (approach reward) or aversive (avoid punishment) systems, driven by biological and evolutionary origins that increase an organism's chance for survival.

The amount of processing resources required subtracted from the amount of resources allocated is conceptualized as available resources. When the resources required to process mediated content exceeds available resources, this is referred to as cognitive overload (Lang, Bradley, Park, Shin, & Chung, 2006; Mayer & Moreno, 2003). Processing overload indicates that there are negative available resources in the processing system to adequately process information for the primary task (Fox, Park, & Lang, 2007), but also decreased information value of the information that is not receiving sufficient processing resources (Fitousi & Wenger, 2011). Paradoxically, people enjoy content with complex structural features (Bolls, Muehling, & Yoon, 2003), but when resources run out, processing overload can negatively impact task outcomes, such as recall (Martini et al., 2020).

1.4. Spatial presence and information processing while learning

Understanding the relationship between spatial presence and learning is important because, when done correctly, VR can promote active and potentially transformative learning (Johnson-Glenberg, 2019; Morélot, Garrigou, Dedieu, & N'Kaoua, 2021). Earlier research has found that VR can elicit greater spatial presence than other multimedia modalities, such as video (Ahn et al., 2016; Persky & Blascovich, 2008; Shu, Huang, Chang, & Chen, 2019), and participants' recall of content with complex structural features is higher than content presented with simpler features (Grabe, Lang, & Zhao, 2003). These findings have led to anticipations that VR may serve as an effective pedagogical tool for learning (Johnson-Glenberg, 2019; Radianti et al., 2020).

This is in line with the LC4MP framework, which predicts that primary task performance can increase up to a point as processing resources continue to be allocated to complex content. However, if users in VR deplete available processing resources while experiencing high spatial presence, information that is not directly contributing to spatial presence perception is less likely to be encoded (Fitousi & Wenger, 2011). High spatial presence is expected to overload the user's processing system, thereby reducing encoding and retrieval of other information being presented within the mediated environment. Therefore, we posed the following set of hypotheses:

H1. Media content delivered through VR will elicit higher spatial presence than watching the same content through video.

H2. Recall of information in the VR content will be lower than recall of the same content provided through video.

Media content that triggers either the appetitive or aversive motivational system elicits biological and evolutionary imperatives driven by primary survival instincts and obtains processing priority, leading to better recognition and recall of the information (Keene & Lang, 2016). At moderate levels, aversive reactions toward content elicit more resource allocation than positive content (Sanders-Jackson et al., 2011; Grabe et al., 2003). Considering VR's richer array of sensory cues, we posit that aversive responses to negative VR experiences will be more intense than viewing the same experience through video (Parong & Mayer, 2021). The aversive response is likely to trigger allocation of processing resources for spatial presence and for making sense of the threat posed. Then, high spatial presence, rather than mere exposure to the VR system, is likely to expend processing resources and result in lower information recall. Given the limited evidence on the relationship between aversive responses to content, spatial presence, and information recall, we asked:

RQ1: When the content via VR or video is negatively valenced, how does the aversive response to the media content impact spatial presence and information recall?

1.5. Influence of individual differences on spatial presence

The extent to which a user feels spatial presence is often conceptualized with an element of agency, where users are motivated to actively engage with the content (Heeter, 1992; Herrera, Jordan, & Vera, 2006; Sacau et al., 2008; Schubert, 2009). We take on a more nuanced investigation of individual differences in spatial presence by assessing participants' attitudes toward media *technology* independently from their attitudes toward the media content (Wheeless, Eddleman-Spears, Magness, & Preiss, 2007). Some users may be excited about technology and enjoy the opportunity to use it, whereas others may be anxious, or dislike using technology in general (Venkatesh et al., 2003). Studies have reliably demonstrated that technology apprehensions remain stable over time, regardless of increase in prevalence and experience (Scott & Timmerman, 2005) and can even reduce the effectiveness of prior training with technology (Torkzadeh, Chang, & Demirhan, 2006).

Spatial presence involves users accepting the digitally generated information presented to their senses as "real." The fact that VR is a novel technology to most users makes it more difficult for those who are afraid or anxious about technology in general to feel present in the mediated experience. The general prediction that VR should elicit greater spatial presence than video would then be amplified or weakened by individual differences in technology apprehension—users who have lower apprehension of technology in general are anticipated to report higher spatial presence in VR than those with high technology apprehension. Therefore:

H3. Individual differences in technology apprehension will moderate the relationship between modality and spatial presence: individuals with high technology apprehension will report lower spatial presence in VR than video, and individuals with low technology apprehension will report higher spatial presence in VR than video.

In addition to individual attitudes about the modality, varying levels of pre-existing domain-specific interest on the mediated *content* is anticipated to increase spatial presence. Previous research has found that pre-existing interest in a content area is an individual difference variable that influences attention and the allocation of processing resources to the media content, which in turn increases spatial presence (Sacau et al., 2008; Wirth et al., 2007). Pre-existing interest in the content area is thought to motivate users to fill in the gaps in detail in the virtual experience, compensating for deficits in the simulation, resulting in high spatial presence (Biocca, 1997). *Connectedness to nature* (Mayer & Frantz, 2004), or an individual's experiential sense of connection to the natural world is an individual trait that predicts pro-environmental attitudes and behaviors. In the current study, the trait reflects an existing level of interest in nature and we anticipate that individuals with high connectedness to nature are likely to experience high spatial presence when exposed to nature related content in VR.

H4. Individuals with pre-existing interest in the content of the mediated experience will have higher spatial presence.

1.6. Segmentation as a strategy for learning in VR

As a potential solution to processing overload when learning with multimedia modalities, Parong and Mayer (2021) proposed segmenting, or dividing mediated content into smaller, more manageable, segments. They argued this may allow learners to digest one chunk of information before moving on to the next to maximize the learning outcomes of multimedia content. In earlier research, when non-immersive learning content was divided into small segments, with time provided between the segments for participants to process the information, participants performed better on subsequent tests than participants who received a continuous presentation without breaks (Mayer & Chandler, 2001). Breaking the information into "bite size" chunks and allowing time in between the chunks may improve learning outcomes by allowing users to replenish processing resources between the small segments before moving on.

However, segmenting content introduces pauses that may negatively impact spatial presence by reminding users that the experience is mediated. Spatial presence induces a psychological state wherein users reject the sensorimotor information of the non-mediated environment in favor of the sensorimotor information of the mediated environment (Biocca, 1997). When the mediated VR content is paused, the user's consciousness abruptly leaves the virtual environment as they switch from processing signals from one environment (VR) to another (non-mediated world). Slater and Steed (2000) referred to this event, in which the non-mediated world "becomes apparent," as *break in presence*. Wirth et al. (2007) also posited that the spatial presence is binary (on/off), implying that users feel no spatial presence when they become aware of the non-mediated world. We hypothesized that breaks in the VR content may remind users that the experience is mediated and draw their attention back to stimuli of their non-mediated environment (e.g., ambient noise), leading to lower spatial presence:

H5. Participants exposed to segmented VR content will perceive lower spatial presence than participants exposed to continuous VR content.

Finally, segmenting the content is likely to result in lower aversive response than going through the VR experience without segments or breaks. Lower aversive response is associated with lower spatial presence (Meehan, Insko, Whitton, & Brooks, 2002). Given that lower spatial presence may paradoxically be favorable for information recall, when VR content is segmented (thereby allocating less resources to experience spatial presence), more processing resources may be available for recalling information. We explored the impact of segmenting VR content on aversive response, spatial presence, and information recall:

RQ2: When VR content is segmented, how does segmentation impact aversive response to the media content, spatial presence perception, and information recall?

2. Study 1

The media content presented as experimental stimulus was approximately 12 min and discussed the issue of ocean acidification, the disruption of marine systems as a result of decreased pH levels in the ocean (Caldeira & Wickett, 2003). Participants started the VR or video experience by learning about the process of ocean acidification and how the waters' pH levels begin decreasing because of human produced carbon emissions. They were then taken underwater to become a piece of coral in the virtual ocean, learning about how climate change and ocean acidification impact marine life and eventually their own coral body in negative ways. The factual information was delivered through an audio narration, which earlier studies of LC4MP have found to be more sensitive toward assessments of information encoding and retrieval than visual stimuli (Lang, Schwartz, Chung, & Lee, 2004).

2.1. Participants and design

Participants ($N = 100$) were recruited from a large university in the United States where they were given extra credit for participating. Participants were female ($n = 34$) and male ($n = 66$), with the majority being Caucasian (70%), followed by African American (9%), Asian (10%), Hispanic (4%) and other (7%). The mean age was 19.67 ($SD = 2.07$) with a range between 18 and 37. Participants first completed a short online survey assessing demographic information and technology apprehension (Time 1). Several weeks later, participants arrived at the laboratory (Time 2) and were assigned to conditions based on the days they came to the lab, between the VR condition ($n = 71$) and the video condition ($n = 29$).

In the VR condition, participants put on a head-mounted display (Oculus DK2, 1029 × 1080 resolution; 75 Hz refresh rate, 100° field of view) and entered a virtual ocean to see a three-dimensional digital representation of a piece of coral, which they were told was their body. Participants could look around the ocean with natural head movements to see their coral avatar's branches. By embodying the piece of coral, participants' mobility in the VR condition was limited for tighter experimental control across conditions. An audio narrative described the rocky reef and the marine life living there, as well as the consequences of ocean acidification while visually showing the process of ocean acidification as the water discolored, marine life died, the coral body corroded and its limbs broke off to the sound of cracking to promote a vivid sensory experience. Spatial audio was provided in the VR condition. In the video condition, participants watched the same events on a computer monitor without natural head movements or spatial audio. After the treatment, all participants completed an online survey asking about aversive responses (i.e., concern about climate change), spatial presence, and recall of the facts presented.

2.2. Measures

2.2.1. Technology apprehension

At Time 1, eight items (*1 = Strongly disagree; 7 = Strongly agree*) from the Computer Anxiety Rating Scale (Heinssen, Glass, & Knight, 1987) (Cronbach's $\alpha = 0.87$) were assessed ($M = 4.72$, $SD = 1.13$). Examples of items included, "I feel apprehensive about using computers" and "I hesitate to use a computer for fear of making mistakes that I cannot correct."

2.2.2. Climate change concern

Aversive response to the content was operationalized as climate change concern, which assesses negative emotional responses (i.e., concern) for climate change issues (Fischer et al., 2012; Lebowitz & Dovidio, 2015), such as ocean acidification featured in the current study. This measure assessed participants' negative valence toward the climate change content, to parse this out from their negative valence toward the modality assessed through technology apprehension. At Time 2, participants' aversive responses to the mediated content were measured by assessing their concerns toward climate change. Five items (*1 = Not at all concerned; 7 = Extremely concerned*) from the Maibach et al. (2011) Six America Screening tool (Cronbach's $\alpha = 0.89$) were adapted ($M = 3.42$, $SD = 0.93$). Examples of items included, "How worried are you about climate change?" and "How much do you think climate change will harm you personally?"

2.2.3. Spatial presence[2]

At Time 2, the five-item spatial presence scale (Cronbach's $\alpha = 0.91$) from assessed the degree to which participants felt they visited the coral reef (*1 = Not at all; 7 = Very much*) ($M = 4.46$, $SD = 1.60$). Sample items included, "To what extent did you feel like you were inside the rocky reef?" and "To what extent did you feel like you really visited the rocky reef?"

2.2.4. Information recall

At Time 2, information recall was tested to index retrieval of facts presented in the audio narration. The assessment consisted of eight multiple-choice and one true/false questions of the information presented in the audio narration, wherein participants were asked to engage in cued recall with cues provided in the multiple-choice options (Lang, 2006). Sample questions included, "Which of the following has had the greatest impact on the acidity levels of our oceans?" and "Which of the following directly contributes to acidification of the ocean?" A sum of correct answers was used to assign each participant one total recall score ($M = 5.66$, $SD = 1.70$, $Min = 1$, $Max = 9$).

2.3. Results

All independent samples *t*-tests demonstrated equal variances between the experimental groups, following the Levene's test for equality of variances, all $ps > .05$. In support of H1, an independent samples *t*-test, adjusting for unequal sample sizes, found that participants in the VR condition perceived significantly higher spatial presence ($M = 4.86$, $SD = 1.52$) than participants in the video condition ($M = 3.48$, $SD = 1.37$) with a large effect size, $t(98) = 4.40$, $p < .001$, $d = 0.95$, 95% CI [0.73, 2.03]. A second independent samples *t*-test found that, although means trended toward the hypothesized direction, media modality alone did not directly impact recall; participants in the VR condition did not significantly differ in recall of the information presented on ocean acidification ($M = 5.46$, $SD = 1.70$) from participants in the video condition ($M = 6.14$, $SD = 1.72$), $t(98) = 1.80$, $p = .07$, $d = 0.41$, 95% CI [-0.07, 1.43]. H2 was not supported.

2.3.1. Underlying mechanisms of information recall – serial mediation analysis

To address RQ1, the PROCESS path-analysis macro for SPSS (Hayes, 2012; Model 6) was employed with experimental condition as the independent variable, concern for climate change as the first mediator, spatial presence as the second mediator, and recall as the dependent variable. Bootstrapping methods were used (5000 samples; Preacher & Hayes, 2008). The VR condition led to higher spatial presence than the video condition ($b = 1.39$ $p = .0001$, $R^2 = 0.18$), but did not lead to greater climate change concern ($b = -0.02$, $p = .92$). Climate change concern had a marginal but non-significant impact on spatial presence ($b = 0.29$, $p = .07$). Higher spatial presence led to lower recall ($b = -0.22$, $p = .05$), whereas higher concern for climate change led to higher recall ($b = 0.47$, $p = .01$, $R^2 = 0.12$). Experimental condition did not directly impact recall ($b = -0.37$, $p = .36$).

Significant direct effects are unnecessary for establishing indirect effects (Hayes, 2012) and exploring indirect effects in the absence of direct effects provides nuanced insights about psychosocial mechanisms that may not be immediately evident. In the serial mediation analyses, the hypothesized indirect effect from experimental condition to concern for climate change, spatial presence, and recall was not significant (95% CI [-0.04, 0.05]). The indirect effect from experimental condition to concern for climate change and then to recall was also not significant (95% CI [-0.77, 0.05]). However, the indirect effect from experimental condition to spatial presence to recall was significant (95% CI [-0.70, −0.01]). Therefore, only spatial presence mediated the relationship between media modality and information recall.

2.3.2. Impact of individual differences on spatial presence

To test H3, the PROCESS path-analysis macro for SPSS (Hayes, 2012; Model 1) was employed with experimental condition as the independent variable, technology apprehension as the moderator, spatial presence as the dependent variable. Bootstrapping methods were used (5000 samples). Findings indicated that high technology apprehension positively influenced spatial presence ($b = 0.63$, $p = .02$). Experimental condition did not directly influence spatial presence ($b = -1.18$, $p = .37$), but the interaction between experimental condition and technology apprehension did positively impact spatial presence ($b = 0.59$, $p = .04$). Following the guidelines by Aiken & West (1991), the effect of technology apprehension's moderation on experimental condition is depicted in Fig. 1. The difference in spatial presence from VR and video was larger for participants with low technology apprehension. For these participants, VR was more effective than video in eliciting higher spatial presence. The difference in spatial presence fostered by VR or video was smaller for

[2] Participants in study 1 are a subset of the participants from Ahn et al., 2016, which showed that the VR condition increased spatial presence, but did not include the hypotheses and research questions in this study, including data on individual trait differences, attitudes, and recall

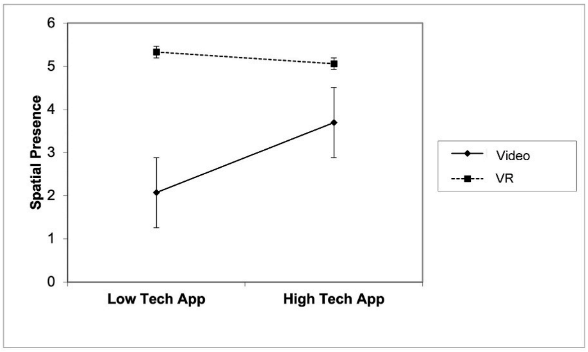

Fig. 1. Simple slopes graph of moderation by technology apprehension.

participants with high apprehension. H3 was partially supported in that technology apprehension did moderate how participants perceived spatial presence through different media modalities. However, the direction of moderation was not in the hypothesized manner; participants with high technology apprehension did not necessarily perceive lower spatial presence in VR. The interaction was largely driven by participants with low apprehension who perceived low spatial presence when exposed to content through video.

2.4. Discussion

Current findings provide insights to the role that spatial presence plays in the context of information processing and recall. When users engage with high volumes of sensory-rich information in VR and experience high spatial presence, this triggers allocation of resources at the possible expense of encoding other content. Echoing earlier research (Ahn et al., 2016; Persky & Blascovich, 2008; Shu et al., 2019), VR induced greater spatial presence than video in the current study. The difference in modality, however, did not directly lead to lower recall. Rather, mediation analyses demonstrated that users who reported higher spatial presence had lower information recall. This suggests that VR technology, in and of itself, does not directly impact recall. These results are consistent with predictions that when users are immersed in a mediated world, they use processing resources to experience spatial presence, leaving fewer resources available to simultaneously encode information that is unrelated to spatial presence. This suggests a paradoxical situation for learning in VR, wherein an individual may be highly engaged because of high spatial presence but recalls less information.

Compared to video, immersive VR did not increase participants' negative valence to the mediated content as measured via climate change concern. Climate change concern had a marginally positive relationship with spatial presence but did not reach statistical significance. Regardless of modality, climate change concern was positively and significantly associated with recall. Recent findings indicate that resources may be reallocated when there are pressing or motivating tasks (Huskey, Craighead, Miller, & Weber, 2018; Park & Bailey, 2018). Echoing earlier findings, the current findings suggest that mediated content that elicits aversive responses (e.g., concern) receives priority in processing resource allocation, resulting in higher recall.

Individuals with high technology apprehension experienced greater spatial presence regardless of media modality than those with low technology apprehension who received the same information through video. One explanation is that individuals with high technology apprehension (i.e., aversive response to modality) allocated more processing resources for spatial presence and for evaluating the threat posed. Conversely, individuals with low technology apprehension may have allocated fewer processing resources and experienced less spatial presence when using video, leaving more resources available to process information.

3. Study 2

Study 1's findings that VR elicits high spatial presence, which paradoxically leads to lower information recall, may limit VR's potentials for delivering dense information in learning and training. Study 2 tested the efficacy of segmenting the immersive learning content into small, digestible chunks as a potential solution, by assessing the impact of segmentation on spatial presence, aversive responses, and information recall. We also investigated the relationship between participants' pre-existing interest on the mediated content and spatial presence.

3.1. Participants and design

Participants ($N = 260$) were recruited from a large university in the United States. Participants were female ($n = 150$) and male ($n = 110$), with the majority being Caucasian (64%), followed by Asian (19%), Hispanic (9%), African American (5%), and other (3%).

The mean age was 18.83 ($SD = 1.15$, age range 18–30). Seventy-six percent had no prior experience with VR. A two condition between-subjects design comparing segmented and continuous VR experiences of a coral reef used in Study 1 was employed. Participants arrived at the laboratory and were randomly assigned to one of two conditions, segmented VR ($n = 129$) and continuous VR ($n = 131$). In the continuous VR condition, the ocean acidification content from Study 1 was used. In the segmented condition, the same VR content was presented in 1-min segments. After each segment, the simulation provided a 20 s break[3] During the break, participants did not remove the head-mounted device and saw a large black box with instructions that informed them of a 20 s break. After the break, the next segment ensued.

3.2. Measures

3.2.1. Pre-existing interest in content

Before exposure to the treatment, fourteen 5-point Likert items from the connectedness to nature scale (Mayer & Frantz, 2004) assessed the degree to which participants felt as if they were a part of nature and their interest in the natural world (Cronbach's $\alpha =$ 0.82). Sample items included, "I often feel a sense of oneness with the natural world around me," and "I feel as though I belong to the Earth as equally as it belongs to me." This measure was employed to assess domain specific pre-existing interest among participants while reducing the influence of social desirability effects or demand characteristics.

3.2.2. Climate change concern

Following the experimental treatment, the same five items from Study 1 assessed participants' aversive response to the virtual experience ($M = 4.76$, $SD = 1.06$).

3.2.3. Spatial presence

Following the experimental treatment, the same five items from Study 1 assessed perceptions of spatial presence (Cronbach's $\alpha =$ 0.92).

3.2.4. Recall

Following respective treatments, the eight multiple-choice and one true/false questions from Study 1 were used to assess information recall ($M = 6.12$, $SD = 1.61$, $Min = 2$, $Max = 9$).

3.3. Results

To test H4, a multiple linear regression test with pre-existing interest and experimental condition as independent variables and spatial presence as the dependent variable was conducted. The results of the regression indicated that the model explained 6.6% of the variance and that pre-existing interest was a significant predictor of spatial presence ($R^2 = 0.07$, $F(2, 257) = 9.06$, $p < .001$). Pre-existing interest significantly contributed to the model ($B = 0.41$, $p < .001$) but experimental condition did not ($B = -0.26$, $p =$ .10). H4 was supported.

The Levene's test demonstrated equal variances between the experimental groups, all $ps > .1$. Participants in the segmented VR condition ($M = 4.81$, $SD = 1.39$) perceived lower spatial presence than participants in the continuous VR condition ($M = 5.13$, $SD =$ 1.21), $t(258) = 1.98$, $p = .049$, $d = 0.25$, 95% CI [0.002, 0.64]. H5 was supported, but with a small effect size.

To explore RQ2, the PROCESS path-analysis macro for SPSS (Hayes, 2012; Model 6) was employed with experimental condition as the independent variable, climate change concern as the first mediator, spatial presence as the second mediator, and recall as the dependent variable, using bootstrapping methods (5000 samples). Segmentation of VR content had no direct impact on climate change concerns ($b = -0.10$, $p = .46$, $R^2 = 0.002$) or recall ($b = 0.06$, $p = .77$, $R^2 = 0.04$). However, climate change concerns had a positive linear relationship with spatial presence perception ($b = 0.27$, $p = .0006$, $R^2 = 0.06$). Climate change concerns also had a positive linear relationship with recall ($b = 0.28$, $p = .005$, $R^2 = 0.04$), wherein greater concern led to greater recall scores. However, spatial presence, net of experimental condition and climate change concern, did not have a significant impact on recall ($b = -0.13$, $p = .09$). None of the indirect effects pathways were significant.

3.4. Discussion

Segmenting VR content only had marginal direct impact on spatial presence. This is inconsistent with previous research examining breaks in presence (Slater & Steed, 2000), which found that breaks in the content reduced spatial presence. Segmentation also had little impact on aversive responses (i.e., concern) toward the content as well as recall. The indirect effect of spatial presence on recall (Study 1) was not replicated, which is not surprising given the marginal influence that segmentation had on spatial presence and the low variance between participants on this variable. Participants' pre-existing interest in the mediated content about nature predicted spatial presence. As with Study 1, climate change concern was again positively associated with spatial presence and information recall,

[3] The length of the 20-s break was determined following several pilot tests, in which participants confirmed that breaks shorter than 20 s were too brief for some participants to recognize that the breaks were intentional (i.e., not a technical error). Longer breaks rendered the segmented VR stimulus excessively longer than the continuous VR stimulus.

indicating that mediated content that triggers biological imperatives receives priority in the allocation of processing resources. This seems to boost spatial presence as well as information recall. However, none of the indirect pathways with climate change concern or spatial presence as mediators directly influenced recall. These results suggest that segmenting VR content may not be an effective strategy for reversing the negative impact of spatial presence on information recall.

These results contradict findings from Parong and Mayer's (2021), which found positive effects of segmentation on learning outcomes. However, in addition to receiving segmented VR content, participants watching the segmented VR content in the Parong and Mayer's study (2018) were given unlimited time to summarize the content after each segment, whereas participants who viewed continuous VR content did not summarize the material. Summarizing learned content requires additional cognitive effort to encode the new information and generate connections between the new material and the learner's existing knowledge (Wittrock, 1990). Therefore, earlier findings that demonstrate better learning outcomes for participants who learned through segmented than continuous VR content may be an artifact of the summarization activity which introduced redundancy in information processing. To accurately assess the efficacy of segmentation, the current study independently observed the impact of segmentation on spatial presence and recall when delivering information through VR.

4. General discussion

Extant literature in education and training has typically considered high spatial presence to be universally favorable, particularly when using VR (Howard & Gutworth, 2020; Johnson-Glenberg, 2019). Contrary to the anticipation that VR will serve as an effective pedagogical tool for education and training, present findings suggest that VR may not be an optimal modality to deliver dense information where recall of specific facts is important. Education scholars have suggested segmenting the content as one potential solution to incorporate multimedia in education (Parong & Mayer, 2018), but current results did not find measurable effects of segmentation on recall. Current findings also suggested that education theories may need to re-examine the impact of different media modalities on users' immersive experiences and resulting recall of information presented during the experience.

4.1. Summary of findings

Findings suggested that high spatial presence in VR may trigger allocation of resources at the possible expense of encoding learning content. VR induced greater spatial presence than video, and high spatial presence led to lower recall of the mediated information. Regardless of modality, increase in climate change concern was positively and significantly associated with recall. Participants with high technology apprehension experienced greater spatial presence for both VR and video than those with low technology apprehension who received the same information through video. Participants' pre-existing interest in the mediated content led to high spatial presence. Segmenting VR content had marginal direct impact on spatial presence, and had no impact on aversive responses (i.e., concern) toward the content or recall.

4.2. Spatial presence—A double-edged sword for information processing

VR research has noted a linear relationship between spatial presence and enjoyment of content (Shafer et al., 2011; Skalski et al., 2010), with the assumption that increased attention driven by high spatial presence will lead to favorable learning outcomes. However, the current findings echo earlier work in computer-mediated communication, which argues that although individuals may enjoy and prefer communication through richer, multi-sensory modalities, leaner forms of information delivery are just as, or in some cases, more effective (Walther, 2011).

Determining the role of spatial presence as a mediator of information processing in VR is a critical question as this directly tests the proposition that immersive technology can engage users, leading them to enjoy the experience, but the increase in engagement and resulting demand on processing resources may leave insufficient resources for information processing that does not directly contribute to experiencing spatial presence. Current findings revealed that heightened spatial presence led to significantly lower recall of information provided during the VR experience than watching the same content through video (Study 1). Modifying the VR content to provide segmented information, in hopes of reducing processing load, had little direct impact on either spatial presence or recall (Study 2).

These results did not replicate earlier work recommending segmentation of content when using multimedia modalities for learning (Mayer & Chandler, 2001; Parong & Mayer, 2018) and provides an in-depth, theoretically-driven explanation for recent findings that indicate no meaningful differences between VR and video for learning outcomes (Makransky et al., 2020; Parong & Mayer, 2021). In a structurally complicated media environment, such as VR, spatial presence may be treated as a pressing task which receives priority in the allocation of processing resources. Consequently, there may have been insufficient resources for processing information outside of experiencing spatial presence.

Providing systematic relief to the processing systems through segmenting the content did not resolve the issue. Finding little difference in spatial presence despite segmentation was unexpected, considering the breaks in presence. One explanation may be that people are accustomed to having mediated content disrupted by irrelevant messages (e.g., advertising) and have learned to process media content with interruptions. Another explanation might be that because the participants did not remove their HMDs during the pauses, or because the segments were not very long, this did not impact spatial presence or the reduction was minimal or undetected by the self-reported measures taken after the experience. Some earlier conceptualizations of presence (e.g., Wirth et al., 2007) have argued that it is a binary experience—one's senses are either connected to the mediated or the non-mediated stimuli. Current findings suggest that there may be a threshold of disruptions before individuals' perception of presence is "broken," warranting a re-examination of earlier assumptions.

Theoretically, the findings shed light on the question of whether it is the modality itself (VR) or individuals' subjective perception of the multimedia experience (spatial presence) that impacts information recall. That is, spatial presence, and not just exposure to VR technology, seems to be driving the lower recall observed in the current study. Practically, the findings yield implications for designing learning VR materials to enhance or inhibit spatial presence perception and optimize information recall in multimedia content.

4.3. Processing information in immersive media content

Information encoding and recall generally increase when the mediated content activates aversive systems at a low to moderate rate because our systems are hardwired to quickly and accurately respond to potential threat (Lang, Sanders-Jackson, Wang, & Rubenking, 2013). In studies 1 and 2, the content generated a moderate level of aversive response as assessed by self-reported concerns for climate change. The direct effects of climate change on information recall supported earlier findings, by demonstrating that aversive reactions led to better recall. Participants who felt greater aversive responses from the mediated content experienced higher spatial perception in Study 2 (marginally significant in Study 1). However, only spatial presence (and not aversive responses) served as a mediator, with those reporting more spatial presence scoring lower on recall (Study 1). One potential explanation for these findings may be that spatial presence was more salient in an environment where the aversive response was moderate. LC4MP research has demonstrated that assessment of aversive responses can differ between self-report and physiological measures (Lavie & Tsal, 1994) and further research should determine how different VR experiences impact aversive responses.

Findings further emphasized the importance of individual differences in attitudes toward the technology and content. Participants with high technology apprehension seemed to feel high spatial presence regardless of the media modality, possibly because negative valence increases arousal and engagement. On the other hand, those with lower technology apprehension perceived lower spatial presence when they used video compared to VR. It may be that these participants were more attuned to spatial cues in a mediated environment and were aware of the leanness of spatial cues in video. Participants with lower technology apprehension may have better encoded information via video than VR, suggesting that, for these individuals, using less immersive modalities to deliver information may unexpectedly be advantageous for information recall.

These results are consistent with LC4MP's predictions that individual motivation and existing interest are important facilitators of information processing (Lang, 2006). Study 2 results indicate that existing interest regarding the topic can heighten spatial presence perception when exposed to mediated content on the topic. The findings provide empirical support to Wirth et al.'s (2007) theorizing of spatial presence, wherein an individual's existing interest in a specific domain is an important user factor leading to spatial presence perception. LC4MP also assumes that existing interest in the content may motivate cognitive effort and trigger active allocation of resources for information processing (Lang, 2006). By considering an individual's motivation driven by existing interest in the content, the conceptualization of spatial presence may be further approached as a human-driven perception through motivated information processing, rather than a technology-driven experience.

4.4. Limitations and future directions

Several limitations qualify the interpretation of the current findings. First, although we demonstrated interstudy replication of variables across two studies, participants in Study 1 were not randomly assigned to their experimental conditions, leading to the possibility that external factors aside from the treatment may have influenced observations. Additionally, given that attitudes toward climate change can be politically polarized, particularly in the US (Bolsen & Shapiro, 2017), controlling for baseline levels of climate change concern may provide a more accurate assessment of how user responses to VR content impact spatial presence and recall. The relative novelty of VR as a media modality may intensify apprehension in ways not fully captured by traditional measures of technology apprehension that focus on computers and may have impacted learning outcomes. Some recent evidence noted that the effect of novelty is negligible using immersive VR experiences for learning (Huang, Roscoe, Johnson-Glenberg, & Craig, 2021) and physical rehabilitation training (Elor, Powell, Mahmoodi, Teodorescu, & Kurniawan, 2021), but further research is warranted.

Also, the current study focused on information processing as measured by recall, but the accurate subprocesses of encoding, storage, and retrieval were not directly assessed. To better understand how spatial presence can influence information processing, future studies need direct assessments of encoding, storage, retrieval, and secondary task response times. Earlier conceptualizations of spatial presence involve a combination of perception (e.g., visual, auditory signals) and cognition (e.g., information). The exact nature of how resources are allocated or shared in the processing system is still being debated, but the LC4MP literature indicates that perceptual and cognitive processing can be meaningfully, but not completely, separated (Fisher, Huskey, et al., 2018). Future research can shed insight into how resources are allocated amidst competing processing needs to process perceptual and cognitive signals that lead to spatial presence.

Furthermore, there are different ways to assess learning outcomes outside of information processing, such as behavior change (Gosen & Washbush, 2004) or knowledge transfer (Bhargava, Bertrand, Gramopadhye, Madathil, & Babu, 2018). Earlier research indicates that VR can enhance procedural knowledge while negatively impacting factual knowledge (Makransky et al., 2020); although users fail to accurately recall information, their learning might be manifested later through behavior change. High pre-existing interest in the learning content may motivate users to override the priority that spatial presence seems to have in processing resource allocation. Future studies should parse out different learning goals and outcomes for accurate interpretations of findings.

Recent studies also point to a possible negative relationship between "cybersickness," a type of visually induced feeling of discomfort and malaise as a result of VR exposure (Stanney, Kennedy, & Drexler, 2016), and spatial presence (Kim, Luu, & Palmisano, 2020; Weech, Kenny, & Barnett-Cowan, 2019). However, existing studies investigating cybersickness present a number of problems, such as small sample sizes, poor study design, or lack of details in the reported findings (Macarthur, Grinberg, Harley, & Hancock, 2021) and do not provide a comprehensive picture of the complex relationship between cybersickness and spatial presence. The virtual experience in the current study did not involve virtual camera movements outside of the user movements (i.e., visual scene updated when the body moved), and no participants reported cybersickness after the experience when asked during their debriefing. Future studies should consider cybersickness as a potential negative influence on spatial presence, and how that relationship can impact recall.

5. Conclusion

As immersive VR becomes increasingly more affordable, best practices for educating users in immersive VR is receiving resurgent interest. Although VR experiences can be more powerful than traditional media messages in transforming attitudes and behaviors, current findings suggest that high immersion and spatial presence may not always enhance learning goals, particularly for information recall. Furthermore, we reconfirm that spatial presence is a subjective experience, with individual factors impacting user experiences. Future work should continue to examine different approaches to designing multimedia learning content, such as segmentation paired with reflection (Parong & Mayer, 2018) or signaling (Albus et al., 2021), that may enhance learning outcomes. By parsing out the strengths and weaknesses of spatial presence in different contexts, we hope that the current findings encourage further discussions of efficiency and effectiveness of learning through multimedia and immersive modalities.

Credit author statement

Sun Joo (Grace) Ahn: Conceptualization, Formal analysis, Writing-original draft preparation. **Kristine L. Nowak**: Conceptualization, Investigation, Writing-reviewing and editing. **Jeremy N. Bailenson**: Conceptualization, Software, Writing-reviewing and editing.

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