SIGHCI 2021 Proceedings

Special Interest Group on Human-Computer Interaction

12-12-2021

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Shady Guertin-Lahoud

Constantinos Coursaris

Jared Boasen

Theophile Demazure

Shang-Lin Chen

See next page for additional authors

Authors

Shady Guertin-Lahoud; Constantinos Coursaris; Jared Boasen; Theophile Demazure; Shang-Lin Chen; Nadine Dababneh; Sylvain Senecal, Ph.D.; and Pierre-Majorique Leger

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Shady Guertin-Lahoud
HEC Montréal
shady.guertin-lahoud@hec.ca

Constantinos K. Coursaris
HEC Montréal
constantinos.coursaris@hec.ca

Jared Boasen
HEC Montréal
jared.boasen@hec.ca

Théophile Demazure
HEC Montréal
theophile.demzure@hec.ca

Shang-Lin Chen
HEC Montréal
shang-lin.chen@hec.ca

Nadine Dababneh
Université de Montréal
nadine_dababneh@hotmail.com

Sylvain Sénécal
HEC Montréal
sylvain.senecal@hec.ca

Pierre-Majorique Léger
HEC Montréal
pierre-majorique.leger@hec.ca

ABSTRACT

Virtual Reality (VR) is known for its ability to immerse users in a parallel universe. Accordingly, VR offers great potential for mindfulness therapy, especially in a post-pandemic world. However, the extent to which our senses should be recruited to yield an optimal feeling of presence in the Virtual Environment (VE) remains unclear. This study investigates lived and perceived effects of adding auditory and motor components to VR experiences, through narration and head movements respectively. Twelve participants experienced four nature-based VR videos in a within-subjects research design. The study employed a mixed method approach of psychometric and neurophysiological measures. Results support a significant relationship between positive affect and presence. While statistical support was not obtained for the remaining relationships, this study provides a feasibility assessment of utilizing NeuroIS methods in evaluating immersive user experiences, along with qualitative insights that extend our understanding towards optimized VE designs.

Keywords

User Experience, Virtual Reality, Presence, Immersion, Multisensory Experience, NeuroIS

INTRODUCTION & RESEARCH MOTIVATION

In the context of the pandemic, chronic stress has considerably risen. In the United States, nearly 27% of adults reported symptoms of anxiety disorder in the last months, a notable increase compared to 8.9% back in 2019 (CDC, 2021). In stressful times, the practice of mindfulness, i.e., bringing our full attention to the present moment by reconnecting mind and body, has been recommended as it predicts positive emotional states (Brown & Ryan, 2003). In line with this, previous research showed that Virtual Reality (VR), a technology that mimics real-world sensory stimuli by immersing users in a simulated virtual environment (VE), has great potential for therapeutic use in today's "mental health pandemic". For instance, patients with General Anxiety Disorder showed increased alpha brain activity, i.e., a proxy for lower anxiety, increased calmness, and positive affect, while viewing natural landscapes in VR (Tarrant et al., 2018).

A distinctive feature of VR is the sense of presence it generates by means of its immersive nature. Immersion has been related to the *objective* measure of how vivid a VE qualifies, while presence has been related to the *subjective*, psychological experience of *being there* in the VE (Cummings & Bailenson, 2016). Accordingly, presence in VR is said to be determined by two dimensions: vividness and interactivity. *Vividness* refers to the number of sensory dimensions that are simultaneously presented in the VE, i.e., its multisensory breadth, and the quality of information delivered in each dimension, i.e., its sensory depth. For example, a deep auditory experience would feature different auditory components such as music, narration, etc. *Interactivity*, enabled through motor components such as head and/or body movements, refers to how a user's actions can influence the content of the VE (Steuer, 1992).

While immersion is a core attribute of VR, there remains an important lack of evidence regarding *which* sensory dimensions of the VE are responsible for optimizing its immersive nature. To date, multisensory VR has been mainly investigated in learning or educational contexts, rather than from a mindfulness or therapeutic lens (Baceviciute et al., 2021). Another reason fueling this gap in literature is that the addition of motor components to VR experiences is difficult to evaluate through measures of lived experience, such as electroencephalography (EEG), due to the noise that movements introduce in the analysis of brain activity (Baka et al., 2018). As a result, restricting movements comes at the cost of evaluating ecologically valid immersive user experiences. Building upon the existing literature, our study aims at resolving the aforementioned limitations by, first, varying the sensory vividness of the VE by manipulating its auditory and motor components and, second, compensating for movement by adopting a mixed methods approach. The main objective of this study is to explore the effects of multisensory VEs on the user's lived and perceived experience in VR; hence:

RQ1. Does the addition of an *auditory* component to the VR experience, through narration, increase a user's sense of presence and immersion?

RQ2. Does the addition of a *motor* component to the VR experience, through head movements, increase a user's sense of presence and immersion?

THEORETICAL BACKGROUND & HYPOTHESES

To date, numerous studies came to the agreement that 3D immersive experiences elicit a greater subjective sense of presence than their 2D counterparts (Xu & Sui, 2021). These findings suggest that 3D representations, which offer closer-to-reality graphics, provide an additional layer of visual information. Applying this logic to our context, we expect the addition of sensory layers to the VE (i.e., other than visual) to act similarly by eliciting greater presence.

> **H1a:** VEs that engage auditory senses to a higher degree will generate a greater sense of presence.
>
> **H1b:** VEs that engage motor senses to a higher degree will generate a greater sense of presence.

Pleasurable emotions (i.e., feeling content, good and happy) are characterized as positive affect (Pressman et al., 2019). A recent study, performed in augmented reality (AR), investigated the impact of adding sensory layers of visual, auditory, and olfactory stimuli on presence and enjoyment (Marto et al., 2020). Results showed that multisensory conditions were rated higher on enjoyment than the baseline condition. With AR sharing a similar digital nature to VR, and enjoyment being a main component of positive affect, we expect positive affect to fluctuate similarly in multisensory VR experiences.

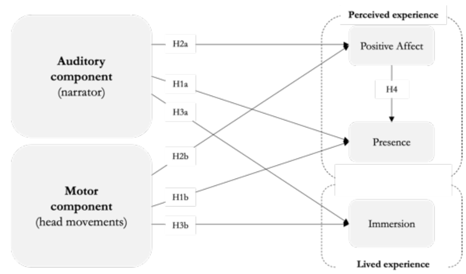
> **H2a:** The addition of an auditory component to the VR experience will generate more positive affect.
>
> **H2b:** The addition of a motor component to the VR experience will generate more positive affect.

Previous research also showed that flow, a state of absolute absorption and complete immersion, is predicted by positive affect (Tobert & Moneta, 2013). Accordingly, we expect positive affect to increase a user's sense of presence.

> **H4:** Greater positive affect will generate a greater sense of presence.

Post-immersive measures of presence are vulnerable to memory, recency and recall biases, thus failing to capture the intricate processes that occur *during* immersion (Marto et al. 2020). As a solution, a study by Kober & Neuper (2012) showed that Event-Related Potentials (ERPs), i.e., very small voltages generated by the brain in response to specific events or stimuli, can be used as a proxy for a user's sense of presence in a VE. A study by Marucci et al. (2021) on multisensory VR driving simulations showed performance to be higher in bimodal (i.e., visual-audio) and trimodal (i.e., visual-vibrotactile) than unimodal visual simulations. In line with the positive relationship between performance and immersion supported by Slater et al. (1996), we expect greater immersion in multisensory VEs that feature added auditory or motor components.

> **H3a:** VR conditions that recruit auditory senses to a higher degree will increase user immersion.
>
> **H3b**: VR conditions that recruit motor senses to a higher degree will increase user immersion.



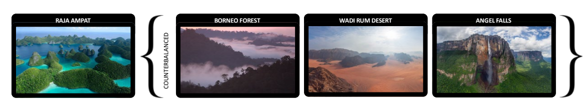
METHODS

Sample

This study was completed by 12 healthy participants (F=8, M=4) aged between 19 and 31 years old (M = 22.92 years, SD = 3.90). All reported a normal or corrected-to-normal vision and no history of a psychiatric or neurological disorder. The study was approved by the Ethics Research Committee of the authors' institution, with participants' prior written consent and their verbal consent reiterated at the time of the study (Certificate number 2022-4458). Although all participants were inexperienced with VR, none reported cybersickness during the experiment. Participants were compensated with CA$40 for their time.

Experimental Design

The experiment presented four unique VR experiences of natural landscapes in randomized order (2 x 2 design: with/without music; with/without head movement), with no music/movement used as baseline and always presented first (Figure 2). In movement conditions, participants explored the VE through slow and lateral head movements. Videos were chosen based off similarity criteria, and video preference was assessed during the experiment.



Materials & Measures

Surveys & Psychometric Measures

Surveys were administered in English on Qualtrics via the VR browser. Pre-test survey items measured participant demographics and VR experience. After viewing each video, sense of presence (Usoh et al., 2000) was assessed with 7-point Likert items from (1) not feeling there at all to (7) feeling as present as in the real world; positive affect (IJsselsteijn et al., 2013) was assessed with 7-point Likert items from (1) not at all to (7) extremely. At the end of the experiment, video preference was assessed with a ranking from (1) preferred video to (4) least preferred video.

VR Head-Mounted Display (HMD)

For the immersive experience, the Oculus Quest 2 HMD was used and interactions with the VE were enabled through two controllers (Figure 3). Researchers monitored the VE in real-time on a laptop.

VR Stimuli

All four VR stimuli were bird's-eye view videos of natural landscapes with soft music. Passive stimuli were selected to minimize participants' movements and optimize overall EEG quality. Two were music-only videos [7]; two featured narrated historical and geographical facts [20, 21]. Both videos were narrated by the same male voice.

Neurophysiological Measurement Stimuli

Building upon Kober & Neuper's (2012) methodology, our study used auditory tones as ERP stimuli, and investigated the resulting amplitude values of P200 peaks as a proxy for user immersion. The auditory tones were emitted in the test room at a mean inter-stimulus interval of 7s and standard deviation of +/-3s through two identical Logitech speakers placed on a table in front of the participant at an interior angle of 25°, 70 cm apart, and 120 cm away from the seated participant. The auditory ERP stimuli were launched simultaneously to the start of each VR stimulus and were ended automatically as the VR stimulus came to its end.

Neurophysiological Measurement Tools

The EEG data was collected with gelled electrodes using the Unicorn Hybrid Black wireless 8-channel system at a sampling rate of 250 Hz per channel. Electrodes were positioned at F3, F4, FC5, FC6, C3, C4, P3, P4 according to the extended 10-20 international placement system, and referenced to linked mastoids. The EEG data and markers of the ERP stimuli were collected and synchronized through the Lab Streaming Layer (LSL) protocol.

Procedure

The experiment was conducted in a soundproofed room with stable lighting and window blinds shut. Participants were seated on a fixed chair at 45 cm above floor level with both feet on the ground. They were briefed on the tools and the general format of the experiment, after which their consent was obtained. With regards to moving conditions, participants were instructed to keep their torso still and move their heads slowly on the horizontal axis only (i.e., to avoid fast, vertical, circular motion), and to maintain their head position for a few seconds following each movement. Participants were then fitted with the EEG cap, followed by the VR HMD. EEG impedance was checked, and the VR HMD was turned on while the virtual experience was streamed to the researchers' laptop. Participants were left alone in the test room and further instructions were delivered via a mic/speakers setup. Researchers monitored the participants continuously throughout the experiment. Concluding the 2-hour test session, a short interview was conducted to better grasp participants' overall experience. The institution's COVID-19 sanitary protocol was applied.

EEG Data Processing

The EEG data was preprocessed and analyzed using Brainstorm (http://neuroimage.usc.edu/brainstorm). Noise artifacts were removed using Independent Component Analysis. EEG data was then bandpass filtered from 1–40 Hz, and then epoched from -1000ms to 2000ms relative to ERP stimulus onset and visually inspected. On average, 11% of 46 total epochs were rejected. Time-series ERP waveforms were averaged across epochs for each VE within each participant. These ERP waveforms were then averaged across all participants to produce a grand-average ERP for each condition. The time point of peak amplitude for P200 peaks were identified, and the mean time point across all conditions was calculated. Amplitudes of the P200 peaks were averaged over time within each participant from -25ms to +25ms relative to these peak amplitude time-points. The resulting values were used in subsequent statistical analyses.

Statistical Analysis

Statistical analyses were performed using SAS version 9.4. The effect of the two independent variables of interest (i.e., narrator and head movement) on the sense of presence and positive affect were examined using a linear regression with random intercept model. Additionally, the effect of positive affect on the sense of presence was examined using a multiple linear regression with random intercept model. Differences in ERP P200 amplitudes between conditions were analyzed using repeated measures ANOVA, with movement and narrator as factors.

RESULTS

Psychometric Results

Narrator and Head Movements Effects on Presence

Descriptive statistics show that presence was rated lower in conditions with a narrator ($M = 3.99$, $SD = 1.72$) than without ($M = 4.18$, $SD = 1.37$), but higher in conditions with head movements ($M = 4.18$, $SD = 1.62$) than without ($M = 3.99$, $SD = 1.48$). These trends, however, were not significantly supported by the linear regression. In fact, neither the addition of a narrator ($t = - 0.67$, $p = 0.5094$) nor the addition of head movements ($t = 0.67$, $p = 0.5094$) had a significant effect on a user's subjective sense of presence, therefore H1a and H1b respectively are not supported.

Narrator and Head Movements Effects on Positive Affect

Descriptive statistics show that positive affect scores between conditions with ($M = 5.65$, $SD = 1.30$) and without a narrator ($M = 5.68$, $SD = 1.01$) did not vary significantly ($t = -0.13$, $p = 0.8987$). Thus, H2a is not statistically supported. Similarly, the positive affect scores between conditions with ($M = 5.81$, $SD = 1.11$) and without ($M = 5.53$, $SD = 1.20$) added head movements did not significantly vary ($t = 1.11$, $p = 0.2754$). As a result, H2b is not supported either. Nevertheless, a significant and positive relationship emerged between positive affect and presence. That is, the higher the positive affect elicited by an experience, the greater the subjective sense of presence in the VE ($t = 5.64$, $p < 0.0001$). Hence, H4 is supported.

Video Preference Effect on Presence

An interesting trend emerged between video preference and presence. The two videos in which the highest presence was reported (M = 4.31) were also the ones that had been most preferred by participants (M = 2.08, SD = 1.24 and M = 2.17, SD= 0.94; note that video preference was reverse coded; i.e., lower scores correspond to greater preference). This relationship was investigated using a multiple linear regression, and the effect of video preference on presence was found to be significant ($t = -4.83$, $p < 0.0001$).

Neurophysiological Results

Results from the repeated measures ANOVA show no significant difference in the P200 mean amplitudes according to the main effects of narrator ($F = 0.472$, $p = 0.506$) and head movement ($F = 3.299$, $p = 0.097$), nor was there a significant interaction effect ($F = 0.024$, $p = 0.881$). Hence, although descriptive statistics show that the lowest mean amplitude of the P200 peak (M = 0.366, SD = 1.793) was observable in the condition with an added narrator but without head movements; and that the largest mean amplitude of the P200 peak (M = 1.194, SD = 0.955) was observable in the condition without a narrator but with added head movements, these differences were not supported by statistical tests. Therefore, H4a and H4b, by which the addition of narration and head movements would increase immersion respectively, are not supported.

Qualitative Results

Downside Effect of Added Narration

During the interview phase, more than half participants (i.e., 7/12) expressed feeling most present in the baseline condition, and half participants (i.e., 6/12) reported a preference for music-only conditions. Reasons included that the clarity of nature sounds (e.g., birds chirping, wind blowing, etc.) were put forward in the absence of a narrator, thus enhancing the immersive nature of the environment. A few participants reported that added narration modified the inherent nature of their experience as it made them feel like "watching a documentary, a movie, rather than discovering a virtual experience [by themselves]" (P01).

Upside Effect of Added Head Movements

The majority of participants (i.e., 10/12) benefited form the addition of head movements as the broader field of view allowed them to visually explore more of the landscape, thus empowering their sense of presence and enhancing the immersive nature of the experience.

Meditative Potential of VR

When queried about their states of mind, the majority of participants (i.e., 10/12) reported feeling much more relaxed. For some participants, viewing the natural landscapes in VR allowed them to "feel as if [they were] flying" (P04). For others, the multisensory experience even went beyond the recruited senses as they "could smell the warmth of the desert" (P04) and "feel the water [on their skin]" (P03).

DISCUSSION & CONCLUSION

The theoretical grounding underpinning this research was that multisensory virtual environments, through their vividness and ability to recruit a user's senses to a greater extent, would enhance user experience by optimizing presence, positive affect and immersion. With regards to *RQ1*, descriptive results indicate an opposite directionality than the one we had hypothesized. Indeed, it seems that the addition of an auditory component (i.e., narrator) to the VR experience might have had a *negative* effect on a user's presence and positive affect. This might be partially explained by the narrator overshadowing the clarity of other core audio components (i.e., nature sounds), the latter being identified by many participants as highly supportive of their meditative experience. With regards to *RQ2*, the addition of a motor component (i.e., head movements) to the VR experience seems to have had a *positive* effect on a user's presence and positive affect. Many participants reported that head movements enhanced their experience, while the physical limitation arising from keeping their head still acted as a reminder of their surrounding reality, thus hindering their presence in the VE. As such, qualitative results indicate that a wider variety of head movements would have further improved the experience, which should be considered in the design of future studies.

On a practical standpoint, the significant relationship that was supported between positive affect and the sense of presence could serve as a motivation for VR developers to focus on experiences that elicit joy and happiness, rather than promoting violent and/or negatively loaded content. From a therapeutic lens, this supports that VEs should promote positively loaded content to enhance a user's presence and thus optimize the meditative benefits of VR.

Beyond the theoretical and practical implications, a number of valuable methodological insights emerged from this study. First, the lack of statistical difference obtained in the amplitudes of the P200 component between conditions can help orient future VR studies that choose to use auditory ERP as a proxy for user immersion. In fact, the small amount of stimulation epochs per condition (i.e., an average of 46), might have proven to be too low given the noise induced by surrounding equipment, namely the VR headset, as well as motion artefacts introduced in a subset of the conditions. On that note, however, head movements did not seem to be the main cause of induced noise, as the proportions of rejected epochs were on average lower in movement (9.87%) than in still (11.5%) conditions. Nevertheless, results suggest that at least twice as many stimulations would be desirable or, alternatively, VR stimuli of longer duration should be selected. Second, this study successfully combined two wireless devices, i.e., a wearable EEG headset with a wireless all-in-one VR HMD. This reveals opportunities for future studies to use this approach to test even more ecologically valid contexts of virtual reality applications. Moreover, in line with the call for research from vom Brocke et al. (2020), this study aimed to perform a feasibility assessment of combining more commonplace UX evaluation methods with NeuroIS methods. Our feasibility assessment paves the way for enriched future studies to move beyond the use of predominantly self-reported measurement methodologies (Coursaris & Kim, 2011) in VR studies, which in turn would allow for a more holistic assessment of the user's immersive experience.

In closing, we hope our study can motivate greater adoption of a mixed methods approach for measuring immersive user experience. Although our results did not offer statistical support for a number of hypothesized relationships, descriptive statistics, along with qualitative data, seem to indicate an overall preference and immersive benefits to the addition of a motor component to VR experiences. Thus, we hope to inspire future empirical studies to move past movement restrictions and aim for novel ways of accounting for movements on, namely, the EEG signal quality. Finally, we believe that, as the majority of participants reported a more relaxed post-experience state of mind, this pilot study paves the way towards a motivation for VR to be used, and further tested, in meditative and therapeutic contexts.

ACKNOWLEDGMENTS

This study was financially supported by NSERC (Grant number DDG-2020-00041).

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