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Immersive videos of natural and urban environments can enhance awe and psychological well-being

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Experiencing the emotion of awe has been associated with improvements in psychological wellbeing. This emotion can be systematically elicited in laboratory settings and immersive virtual reality (VR) has been shown effective for this purpose. In this work, we exposed 36 healthy participants to three immersive videos from natural and urban scenes (i.e., mountain, forest with waterfall, and city), and a 3D model of a neutral room as a baseline condition. These environments were compared in terms of self-reported levels of awe and clinically relevant aspects of psychological wellbeing, such as state depression and anxiety. In addition, we took the level of prior experience of the participants with VR into account and investigated whether the psychological effects hold for both novice and experienced VR users. The results suggest that exposure to all three immersive videos elevated the level of awe, reduced current states of depression, and increased positive affect compared to the baseline. We also discovered that, while the urban environment elicited the same amount of awe as both natural environments, only exposure to natural environments decreased current states of anxiety and negative affect. Finally, although experienced VR users had partly lower overall scores, prior experience did not reduce the relative benefits of exposure to immersive videos, as both experienced and novice users showed similar improvements compared to their respective baselines. Our findings can help guide future research and therapeutic applications that use immersive videos to harness the psychological benefits of experiencing awe.

KEYWORDS

virtual reality, immersive videos, emotion induction, awe, natural environment, wellbeing, mental health

1 Introduction

Awe is a complex emotion that can be experienced in response to vast stimuli, which can challenge one's current mental structures (Keltner and Haidt, 2003). Such stimuli (e.g., standing by a grand vista, witnessing childbirth, listening to a symphony, etc.) elicit a mixed feeling of pleasure, wonder, and sometimes fear (Chirico et al., 2017). This is considered a self-transcendent emotion, as it shifts our focus away from ourselves and makes us feel part of a larger whole (Allen, 2018; Kitson et al., 2020a). Experiencing awe can evoke physiological responses such as chills and goosebumps (Quesnel and Riecke, 2018). It has also been suggested that experiencing awe can increase life satisfaction (Rudd et al., 2012; Anderson et al., 2018), improve mood (Joye and Bolderdijk, 2015; Chirico et al., 2018) as well as longitudinal (Anderson et al., 2018) and momentary wellbeing (Gordon et al., 2017).

Unfortunately, most people cannot easily access vast, awe-inducing sceneries to benefit from their positive effects, especially people with restricted mobility (e.g., people with disabilities and the elderly) (Mostajeran et al., 2021). Furthermore, many people are not fortunate enough to live in areas where vast, awe-inspiring sceneries are readily accessible (Ritchie and Roser, 2018). Others may not have the time or means to visit such locations, especially in the midst of a busy work day or other stressful situations in which taking a break for an awe-inducing experience might be most appreciated and needed (Yang et al., 2022; OECD, 2021).

Virtual simulations of awe-inducing environments could overcome these challenges and enable a larger population to experience awe despite their current location, travel restrictions, or limited resources. To elicit awe, panoramic scenes of natural beauty have been commonly used as stimuli in previous empirical research (Shiota et al., 2007; Joye and Bolderdijk, 2015; Prade and Saroglou, 2016; Anderson et al., 2018; Van Cappellen and Saroglou, 2012; Valdesolo and Graham, 2014; Chirico et al., 2016a). For instance, a video clip from BBC's Planet Earth is a frequently employed nature stimulus (Piff et al., 2015; Bai et al., 2017; Gordon et al., 2017; Valdesolo and Graham, 2014; van Elk et al., 2016; Yang et al., 2016), which is a montage of grand, sweeping views of nature, mostly featuring mountains, canyons, waterfalls, forests and oceans, providing further evidence that panoramic nature views inspire awe.

In this context, immersive virtual reality (VR) can effectively elicit awe in laboratory settings (Quesnel and Riecke, 2018; Chirico et al., 2018; 2016b; Stepanova et al., 2019b). Researchers have used VR to immerse participants in realistic, model-based, or real-life virtual environments (VEs) to induce awe and measure their reactions in a highly controlled setting (Chirico et al., 2017).

However, several knowledge gaps remain open in the literature. The first one is regarding the strong focus on natural environments for inducing awe which has been referred to as a methodological bias (Piff et al., 2015; Bai et al., 2017; Negami, 2020). It raises the question of whether the positive effects of awe experiences can be generalized to non-natural stimuli such as urban environments or whether they are specific to awe induced by nature.

This gap is rooted in the vast body of research showing the positive effects of real or virtual nature exposure on mental health (Bowler et al., 2010; Mostajeran et al., 2023b; Mostajeran et al., 2023a; Miegel et al., 2024). For instance, forest therapy also referred to as forest bathing, is practiced widely, in particular in Asia, to derive substantial benefits from the positive health effects of walking, resting, and interacting with forests (Chun et al., 2017). This also forms a second gap, as it remains open whether awe-inspiring but non-green stimuli, such as a snow-capped mountain or an urban environment, can positively impact clinically relevant measures of psychological wellbeing such as state depression and anxiety.

The third gap concerns the novelty effect (Kormi-Nouri et al., 2005) of VR as an immersive display. Some researchers suggest that as users become more familiar with a novel tool, their initial curiosity and motivation diminish, leading to reduced performance compared to novice users (Tsay et al., 2020). The research is also scarce when it comes to the question of whether exposure to immersive content wears off for VR users or whether they could benefit from the same stimuli, such as awe-inspiring content, as much as novice VR users.

In this work, we set out to address these gaps and respective research questions by designing an experiment to study the effects of immersive videos of natural versus urban environments on perceived awe and short-term psychological wellbeing in healthy participants. For the current study, we deliberately chose immersive videos over fully interactive VR due to their high level of realism and authenticity, as well as their greater availability, making a potential therapeutic application based on such immersive videos more scalable and accessible.

We conducted a within-subject design experiment with 36 participants and four conditions: (i) a neutral VE (a model-based, low-stimulus indoor room) administered systematically as a baseline and three immersive videos depicting panoramas of (ii) a rain forest with a high waterfall, (iii) snow-capped mountains, and (iv) a city with skyscrapers. Using self-reported measures, the level of awe, general affect, momentary life satisfaction, sense of presence, simulator sickness, and the environment's beauty were assessed after each condition. In addition, current states of depression and anxiety were reported to investigate whether known positive effects of awe on wellbeing may extend to clinical aspects of mental health.

The contributions of this work are as follows: (i) including an urban environment for inducing the emotion of awe in contrast to the overuse of nature stimuli in related work, (ii) examining clinically relevant aspects of psychological wellbeing, such as state depression and anxiety, for immersive videos of not only a forest but also non-green environments of a snow-capped mountain and a city, and (iii) considering participants' prior VR experience to investigate whether the psychological effects of VR exposure hold for novice and experienced VR users.

2 Related work

2.1 Awe emotion

Awe can be characterized by two central features: (i) perceived vastness and (ii) a need for accommodation (Keltner and Haidt, 2003). Vastness can be perceived through experiencing anything much larger than the self or the self's ordinary level of experience or frame of reference. The need for accommodation addresses the process of adjusting mental structures that cannot absorb and fully understand a new experience. In other words, we feel a need to accommodate when our current understanding of the world is conflicted. Thus, our brain tries to reflect on and alter the way we view and comprehend the world in an attempt to make sense of this novel, vast stimulus (Bai et al., 2017).

Feeling awe has several positive effects on human psychology, such as a sense of diminished self (Piff et al., 2015; Bai et al., 2017), an expanded perception of time (Rudd et al., 2012), increased pro-social behavior (Piff et al., 2015; Rudd et al., 2012; Prade and Saroglou, 2016), and feeling social presence, i.e., feeling more connected to other people (Bai et al., 2017; Shiota et al., 2007). For instance, Lopes et al. discovered that increased levels of awe during a 30-min walk (in an urban park compared to a walk on a non-natural city path) were associated with a greater reduction in negative affect among participants (i.e., higher mood restoration), which eventually lead to reduced ruminative thinking (Lopes et al., 2020).

Furthermore, a theoretical paper has outlined the potential therapeutic role of awe for mental health, in particular for major depressive disorder (Chirico and Gaggioli, 2021). However, there seems to be a lack of experimental studies investigating the effect of awe on clinical aspects of mental health, such as depression and anxiety. One study found that older adults engaging in daily awe walks for 8 weeks, in contrast to participants in a control walk group, reported greater awe, joy, and prosocial positive emotions during the walks (Sturm et al., 2022). However, post-intervention depression, anxiety, and life satisfaction remained unchanged from baseline in both groups. Nevertheless, the "small self" effect, which is linked to awe experiences (Piff et al., 2015; Bai et al., 2017), may have the potential to protect against the maladaptive self-focused attention observed in people with depression. Specifically, a study by Sung (Sung, 2023), in which participants either watched an awe-inducing or amusing video, discovered that awe had a negative association with depressive symptoms at the trait level. Also, at greater levels of awe, the relationship between rumination and depressive symptoms was reduced. Based on these findings, Sung proposes that individuals who are more prone to experiencing awe might face a reduced risk of developing depression.

2.2 Experience of awe in VR

VR can present complex and vast stimuli (Chirico et al., 2016b) that are essential to evoke awe (Keltner and Haidt, 2003; Shiota et al., 2007). The illusion of being physically present in the VE (i.e., sense of presence) is also higher in VR compared to other types of visual stimuli such as conventional photos or videos (Mostajeran et al., 2021). Typically, immersive VR systems include a head-mounted display (HMD, a.k.a. VR glasses or goggles), which displays VEs while blocking the user's field of view to the physical world, thus enhancing sensory immersion (Ermi and Mäyrä, 2005). This enables an omnidirectional view and a similar-to-reality perception of the VE (Slater and Wilbur, 1997).

In recent years, researchers have started to use VR stimuli to evoke awe in experimental studies (Quesnel and Riecke, 2018; Chirico et al., 2018; 2017; Miller et al., 2023; Gallagher et al., 2014; Quesnel and Riecke, 2017; Nelson-Coffey et al., 2019; van Limpt-Broers et al., 2020; Kahn and Cargile, 2021; Stepanova et al., 2019b). In particular, immersive videos (a.k.a. 360° videos or VR videos) have been used for this purpose (Chirico et al., 2017; Kahn and Cargile, 2021). Comparisons between immersive videos and conventional photos or videos have demonstrated that immersive videos are more effective in inducing a sense of presence (Mostajeran et al., 2021) and self-reported awe (Chirico et al., 2017). In a study by Chirico et al. (Chirico et al., 2018), computer-generated VEs were employed to induce awe. The participants of their study were immersed in one neutral VE and three model-based, awe-inducing natural environments (the sight of the Earth from deep space, a forest with a high waterfall, and high snow mountains). They found that the mountain condition was the most awe-inducing and elicited the highest positive affect compared to the other conditions. Moreover, each of the three natural conditions was more awe-evoking than the neutral environment. They also contrasted the effect sizes of their model-based, awe-inducing VEs with real-life immersive videos and found that immersive videos were more effective in inducing awe compared to the model-based VEs (Chirico et al., 2017; Chirico et al., 2018).

In contrast to natural stimuli, a small number of studies have started to investigate the awe-inducing potential of urban or built environments. For instance, Joye and Dewitte (2016) found that pictures of monumentally high-rise buildings elicit stronger feelings of awe compared to lower buildings and that architectural structures may produce similar benefits (e.g., pro-sociality and generosity) as natural awe stimuli. In another study, Collado and Manrique (2020) examined the effect of picture slideshows depicting natural or built awe-inducing scenes compared to natural or built mundane scenes. They found no significant difference in awe level between awe-inducing natural and awe-inducing built (i.e., architectural) scenes. Furthermore, the awe-inducing natural and built slideshows increased perceived psychological restoration to the same degree. While both the awe-inducing and the mundane natural slideshows improved positive affect, the built scenes had no significant effect on positive affect. Also, Dozio et al. (2021) developed ten different VEs to induce six different emotions (neutral, happy, sad, scary, angry, and disgusting). Their VEs featured a mixture of natural, urban, and fantasy environments. These VEs were either projected on a wall or displayed on a computer monitor. That is, their setup did not include fully immersive VR technology. Nonetheless, the targeted emotions could be elicited using each specific VE.

Finally, prior work (Berlyne, 1970; Tokunaga, 2013) suggests that an increased arousal could be observed in the initial stages of exposure to a new stimulus which is also known as the short-time novelty effect of that stimulus. As the novelty effect of the stimulus diminishes, the focal attention is restored toward local characteristics of the experience rather than its global ones (Hopp and Gangadharbatla, 2016; Edwards and Gangadharbatla, 2001). This may imply that novice VR users might exhibit a stronger emotional response to immersive stimuli. Therefore, it is important to determine whether the observed effects of immersive video apply not only to novice VR users but also to more experienced VR users, which is essential for understanding extended use and longer-term benefits.

3 Materials and methods

3.1 Virtual environments

Using the Unity game engine, we implemented four different experimental conditions (see Figure 1): (i) Forest with waterfall: an immersive video featuring an "Aerial view of Angel Falls, Venezuela, South America"[1], (ii) Mountain: an immersive video of "Flying over the top of Mount Elbrus, Russia"[2], (iii) City: an immersive video

1 https://stock.blend.media/library/14270

2 https://stock.blend.media/library/20025

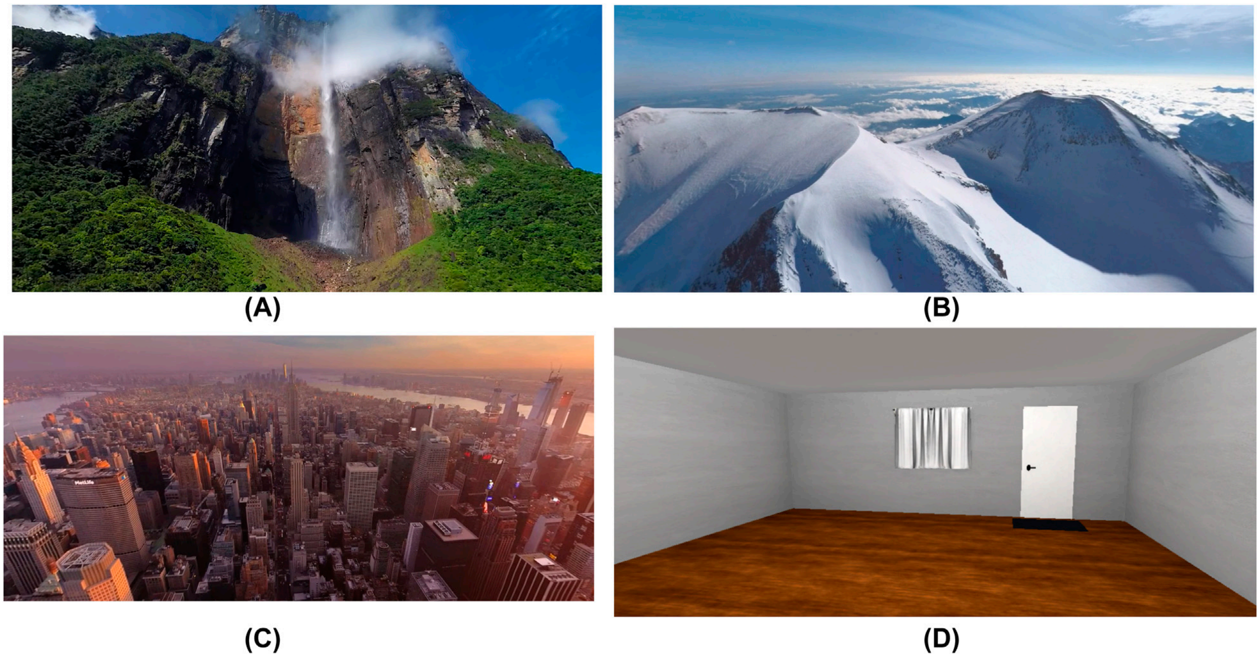

FIGURE 1
Virtual environments: **(A)** Forest with waterfall condition: Rain forest panorama with a high waterfall, **(B)** Mountain condition: Snow-capped mountain panorama, **(C)** City condition: City panorama with skyscrapers, and **(D)** Baseline condition: 3D model of a neutral low-stimulus indoor room.

depicting an "Aerial of vivid sunset over Central Park, Manhattan, New York, USA"[3], and (iv) Baseline: a model-based VE featuring a low-stimulus indoor room. Our goal when designing the baseline condition was to create a neutral environment, devoid of elements that might evoke a sense of vastness or a need for accommodation, as suggested in related studies on awe (Chirico et al., 2018). In contrast, as the immersive videos were intended to induce the target emotion of awe, their characteristics were chosen based on those two core features of awe, namely perceived vastness and a need for accommodation (Keltner and Haidt, 2003). To fulfill the vastness feature, all three immersive videos featured vast panoramic views. In addition, we chose aerial videos, as opposed to stationary videos, to evoke the impression of slowly flying or floating over the environment to increase the need for accommodation. All three videos were monoscopic 360° videos with a 4K (4,096 × 2,048) resolution and a frame rate of 30fps. They were acquired from Blend Media[4], a 360° video and image stock library. Before embedding the videos in our VR experiment, the original clips were slightly edited in Adobe Premiere Pro (version 2021). The speed of the videos was adjusted to roughly match the camera's movement speed across the three experimental conditions, using the forest video as an approximate reference. Specifically, the speed of the mountain video was reduced to 96% and the speed of the city video to 75%. Frame blending, a time interpolation method, was then applied to the mountain and city videos to regain smooth motion and help mitigate simulator sickness. In addition to the visual stimuli, a gentle breeze noise (Freesound, 2013) was played in the background on low volume via the HMD's integrated audio system during all four conditions. In between the conditions, participants found themselves in an intermediate virtual room which provided instructions on a virtual display board before and after each condition. Exposure to each condition lasted for 2.25 min.

3 https://stock.blend.media/library/29049

4 https://stock.blend.media/360-stock

3.2 Hypotheses

We formulated the following hypotheses: **(H1)** the mountain, forest with waterfall, and city conditions induce significantly higher levels of awe compared to the baseline condition, **(H2)** there is no significant difference in the level of awe between the mountain, forest with waterfall, and city conditions, **(H3)** short-term psychological wellbeing is significantly higher after exposure to the mountain, forest with waterfall, and city conditions compared to the baseline condition. Specifically, we expected to observe **(H3.a)** lower state anxiety, **(H3.b)** lower state depression, **(H3.c)** higher positive affect (PA), **(H3.d)** lower negative affect (NA), and **(H3.e)** higher momentary life satisfaction after exposure to the awe-inducing immersive videos. Moreover, we compare those psychological wellbeing variables after exposure to any of the mountain, forest with waterfall, and city VEs. Here, we did not formulate an *a priori* hypothesis and rather explored the potential effects of the immersive urban environment on wellbeing alongside our immersive natural environments (i.e., mountain and forest with waterfall). In addition, we hypothesized that exposure to immersive videos leads to **(H4)** higher beauty ratings, **(H5)** a higher sense of presence, and **(H6)** higher simulator sickness compared to the neutral VE. Finally, we hypothesized that **(H7)** the effects of immersive videos (mountain, forest with waterfall, and city) compared to the neutral baseline condition hold for novice as well as experienced VR users.

3.3 Measures

The following self-report questionnaires and single-item measures were administered after each condition.

3.3.1 Situational awe scale (SAS)

The SAS was administered to measure the level of awe experienced during the previous VR exposure (Krenzer et al., 2020). It has 15 statements that were rated on a 7-point Likert scale from −3 (Strongly disagree) to +3 (Strongly agree) and was divided into four factors: Connection, Oppression, Chills, and Diminished Self.

3.3.2 State-trait anxiety-depression inventory-state (STADI-S)

The STADI-S measures current states of depression and anxiety and consists of 20 statements which can be scored on a 4-point Likert scale ranging from 1 (Not at all) to 4 (Very much so) (Bergner-Köther, 2014; Renner et al., 2018). To estimate the level of state anxiety, the questionnaire assesses emotionality (i.e., physiological hyperarousal) and worry (i.e., cognitive concerns), while anhedonia (i.e., lack of positive affect) and dysthymia (i.e., depressed mood) are combined to measure state depression.

3.3.3 Positive and negative affect schedule (PANAS)

The PANAS measures general affective states and was found to be sensitive to fluctuations in the mood when used with short-term time instructions (e.g., right now) (Watson et al., 1988). The scale consists of 20 adjectives that measure the two primary dimensions of mood: positive affect (PA) and negative affect (NA). The intensity of each item was scored using a 5-point Likert scale ranging from 1 (Very slightly or not at all) to 5 (Extremely).

3.3.4 Life satisfaction

Momentary life satisfaction was measured with a single item ["All things considered, how satisfied are you with your life as a whole, right now?" (Rudd et al., 2012)] which participants responded to on a 7-point Likert scale ranging from −3 (Very dissatisfied) to +3 (Very satisfied).

3.3.5 Beauty

To assess aesthetic preferences, a single question ["How beautiful did you find the environment?" (Collado and Manrique, 2020)] was administered which could be answered using a 5-point Likert scale ranging from 1 (Not beautiful at all) to 5 (Extremely beautiful).

3.3.6 Sense of presence

Participants rated their sense of being in the VE using a single item (I had a sense of "being there" in the virtual environment) on a 7-point Likert scale ranging from 1 (Not at all) to 7 (Very much). The item was taken from the frequently used, three-item SUS presence questionnaire developed by Slater et al. (Slater et al., 1994; Usoh et al., 1999). Only the first item regarding the sense of being there was chosen as it serves as a common definition of subjective presence (Schubert et al., 2001) and is considered to be the most direct elicitation of presence (Slater and Steed, 2000).

3.3.7 Simulator sickness questionnaire (SSQ)

Measures the severity of 16 symptoms (e.g., eye strain, dizziness, sweating) using a 4-point Likert scale ranging from 0 (None) to 3 (Severe) (Kennedy et al., 1993). The symptom scores were later added and weighted to calculate the three sub-scales (Nausea, Oculomotor, and Disorientation) and a total SSQ score.

3.4 Participants

The participants were recruited via mailing lists within the Department of Informatics at the University of Hamburg and the Neuroplasticity research group at the UKE. In addition, the study was promoted on messenger apps, e.g., WhatsApp. All participants were required to be at least 18 years old and to have a good comprehension of the English language. Due to the nature of the aerial videos, participating in the study was not advised for people who suffer from acrophobia (i.e., extreme fear of heights). A total of 38 participants took part in the study. In this study, we aimed to investigate the effects of immersive videos on healthy people, which can guide future research using vulnerable populations. Hence, we excluded two participants from the data analysis due to self-reported existing or previous mental health disorders (one participant with depression and one with past anxiety disorder), to allow for a more homogeneous, healthy sample and avoid confounds. The participants (22 female) were aged between 21 and 61 years ($M = 27.861, SD = 9.317$) and the majority were students (N = 24, 66.7%). The prior VR experience of the participants varied from never used VR before (N = 10, 27.778%), rare (N = 9, 25%), or occasional (N = 7, 19.444%) use of VR, to a moderate amount (N = 5, 13.9%) or a great deal (N = 5, 13.9%) of prior VR experience. Based on these ratings, we grouped the participants into novice VR users with no or rare level of prior experience with VR (N = 19, 53%) and experienced VR users (N = 17, 47%). Regarding their frequency of playing 3D video games, the majority reported playing never or almost never (N = 24, 66.7%), while the remaining participants reported playing monthly (N = 2, 5.6%), weekly (N = 8, 22.2%) or daily (N = 2, 5.6%). The participants' characteristics are summarized in Table 1.

3.5 Procedure

The study was approved by the local Psychological Ethics Committee of the Center for Psychosocial Medicine at the University Medical Center Hamburg-Eppendorf (UKE) and was performed in accordance with relevant guidelines and regulations. To increase the number of potential participants, the study was offered either in person or remotely. Most participants ($N = 23, 63.89\%$) took part in the study in person, either in a laboratory room at the University of Hamburg or in a private

TABLE 1 Sociodemographic, health and participation-related characteristics of the participants (N = 36). The right column displays the response frequencies, except for age, for which the mean (and standard deviation) are given.

Sample characteristic	Responses
Sociodemographics	
Age mean (SD)	27.861 (9.317)
Gender (male/female/other)	14/22/0
Handedness (left/right)	4/32
Student (no/yes)	12/24
Highest level of education (high school diploma/bachelor/master/doctorate)	17/11/5/3
VR experience	
Frequency of previous VR experiences (never/rarely/occasionally/a moderate amount/a great deal)	10/9/7/5/5
Frequency of playing 3D video games (never or almost never/monthly/weekly/daily)	24/2/8/2
Health	
Visual aid during experiment (none/contact lenses/glasses)	25/5/6
Eye condition (no/yes)	36/0
Currently diagnosed with a mental health disorder (no/yes)	36/0
Previously diagnosed with a mental health disorder (no/yes)	36/0
Fear of heights self-rating (none/slight/moderate/extreme)	17/13/5/1
Participation	
Type of participation (in person/remote)	23/13
Head-mounted display (Meta Quest/Quest 2)	3/33

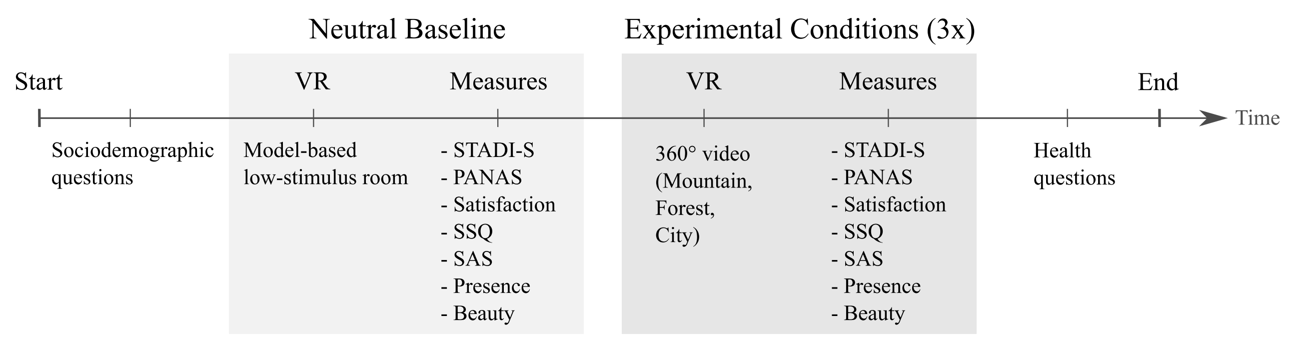

FIGURE 2
Experimental procedure. The experimental conditions were administered in a counterbalanced order. In total, the experiment lasted approximately 45–60 min and the exposures to each condition lasted for 2.25 min. VR: virtual reality, STADI-S: State-Trait Anxiety-Depression Inventory-State, PANAS: Positive and Negative Affect Schedule, SSQ: Simulator Sickness Questionnaire, SAS: Situational Awe Scale.

home. After a brief introduction, the experimenter left the study room so that the participant did not feel observed during their participation. Thirteen individuals (36.111%) participated remotely in an asynchronous manner. This meant that they participated at a time and place of their choice as long as they could ensure a quiet environment without distractions for the entire duration of the experiment. An online survey, accessible via a PC or a laptop, guided the participants through the entire study, providing instructions on when and how to start the VR sessions for both remote and in-person participation. In addition to the online survey, remote participants also received written instructions prior to the experiment regarding the application installation and the required experimental setup. We provided contact details in case they had any questions or problems during setup or participation.

A visual overview of the experimental procedure can be found in Figure 2. At the beginning of the experiment, our online survey provided participants with information about the study procedure, objective, and participation criteria as well as the benefits and risks related to their participation. They were informed about data protection and their right to withdraw from the study at any time. All participants agreed to the experiment's informed consent form. After providing consent, participants answered some sociodemographic questions using our online survey. Thereafter, they wore an HMD to begin the VR exposure. The majority used a Meta Quest 2 headset which was provided to them for the purpose of the experiment. Three participants used the previous model of Meta Quest. The VR application was compatible with both HMDs. Participants were instructed to stand in an upright position inside the tracking area, configured as a room-scale boundary guardian of approximately 2 × 2 meters. They were also asked to hold a controller in their dominant hand and independently start each VR session. Before each condition, participants were encouraged to have a look at their whole surroundings in VR by moving their heads, without any specific task to complete. Additionally, they were advised not to walk around during the VR exposure.

By pressing the Start button on the virtual display board in the intermediate scene, they entered the first VE. The neutral baseline condition was always shown first to capture the participants' initial levels of awe and wellbeing. After exactly 2.25 min, the scene automatically transitioned back to the intermediate scene. Participants were prompted to take off the HMD and to return to the online survey where they filled out all self-report measures. The same procedure was then repeated for all three experimental conditions (mountain, forest with waterfall, city). The order of the immersive videos was counterbalanced following the Latin square method (Bradley, 1958). After the fourth round of questionnaires, the experiment concluded with a few questions regarding the participants' general health. The entire experiment lasted approximately 45–60 min in total. Participants did not receive compensation, apart from 13 individuals who were awarded university course credits.

4 Results

The normality of the data was assessed visually by inspecting histograms and Q-Q plots, and statistically by running Shapiro-Wilk tests. The results showed that some of the data was normally distributed (e.g., awe total and state depression) while other variables were not (e.g., simulator sickness). As simulation studies have shown that the F-test is robust against violations of normality (Harwell et al., 1992; Schmider et al., 2010; Blanca Mena et al., 2017), we decided to report the analysis results based on parametric tests for all variables to avoid switching between statistical tests. To perform the repeated-measures ANOVAs (RM ANOVAs), we tested the sphericity assumption using Mauchly's test of sphericity. If the assumption was violated, we corrected the degrees of freedom using Greenhouse-Geisser estimates of sphericity. As an effect size, we report the partial eta squared (η_p^2), whereby a value of 0.01 is considered a small effect, 0.06 a medium effect, and 0.14 a large effect (Cohen, 1992). For all tests, the significance level was set at $\alpha = .05$.

4.1 Effects of exposure to immersive virtual environments

We performed a one-way repeated-measures ANOVA (RM ANOVA) on the type of environment. If the RM ANOVA was significant, we conducted post-hoc tests and corrected the p-values using the Bonferroni method (Armstrong, 2014). The main results are plotted in Figure 3 in which error bars illustrate 95% confidence intervals, while asterisks represent Bonferroni adjusted p-values ($^*p < .05$, $^{**}p < .01$, $^{***}p < .001$) of post-hoc tests. Additionally, the means and standard deviations of all study measures can be found in Table 2.

4.1.1 Awe (SAS)

There was a significant effect of environment on the level of awe ($F(1.991, 69.682) = 22.153, p < .001, \eta_p^2 = .388$). Bonferroni post-hoc tests revealed that the mountain ($M = -.859, SD = .669, p < .001$), forest with waterfall ($M = -.787, SD = .594, p < .001$), and city environments ($M = -.778, SD = .656, p < .001$) each elicited significantly higher levels of awe than the neutral baseline condition ($M = -1.559, SD = .763$). Thus, H1 was supported by the results. Furthermore, there was no statistically significant difference between the mountain, forest with waterfall, and city environments, which supports H2.

Regarding the sub-scales of the SAS questionnaire, a significant difference between means was found for the Connection ($F(3, 105) = 21.247, p < .001, \eta_p^2 = .383$), Oppression ($F(1.870, 65.449) = 26.567, p < .001, \eta_p^2 = .432$), Chills ($F(3, 105) = 25.554, p < .001, \eta_p^2 = .422$) and Diminished Self sub-scale ($F(1.995, 69.818) = 28.820, p < .001, \eta_p^2 = .452$). Bonferroni post-hoc tests revealed that the RM ANOVA results were attributable to the neutral baseline environment having induced significantly lower awe values regarding Connection ($p < .001$), Chills ($p < .001$) and Diminished Self ($p < .001$) and a significantly higher Oppression level ($p < .001$) compared to each experimental condition. As already observed in the total awe score, the mountain, forest with waterfall, and city environments did not differ significantly on any SAS sub-scale.

4.1.2 State anxiety and depression (STADI-S)

State anxiety differed significantly between environments ($F(2.239, 78.381) = 6.420, p = .002, \eta_p^2 = .155$). Bonferroni post-hoc tests revealed that state anxiety was significantly lower after the mountain ($M = 13.75, SD = 2.02, p = .01$) and forest with waterfall environments ($M = 13.5, SD = 2.324, p = .018$) compared to the baseline ($M = 15.944, SD = 4.249$). When comparing state anxiety after exposure to the baseline and the city environment ($M = 15.389, SD = 4.101$), the mean difference did not reach statistical significance. Therefore, H3.a can be confirmed only for natural immersive videos. In other words, only virtual nature environments were able to significantly reduce state anxiety compared to the baseline. However, comparing the immersive videos with one another did not result in any significant difference when applying Bonferroni corrections.

Furthermore, the type of environment had a significant effect on state depression ($F(2.292, 80.237) = 14.534, p < .001, \eta_p^2 = .293$). Bonferroni post-hoc tests revealed that state depression was significantly lower after the mountain ($M = 15.444, SD = 3.211, p < .001$), forest with waterfall ($M = 15.361, SD = 2.958, p < .001$) and city environments ($M = 17.028, SD = 4.219, p = .025$) compared to the baseline ($M = 19.028, SD = 3.783$). Therefore, H3.b can be confirmed for all immersive videos (natural and city). No other

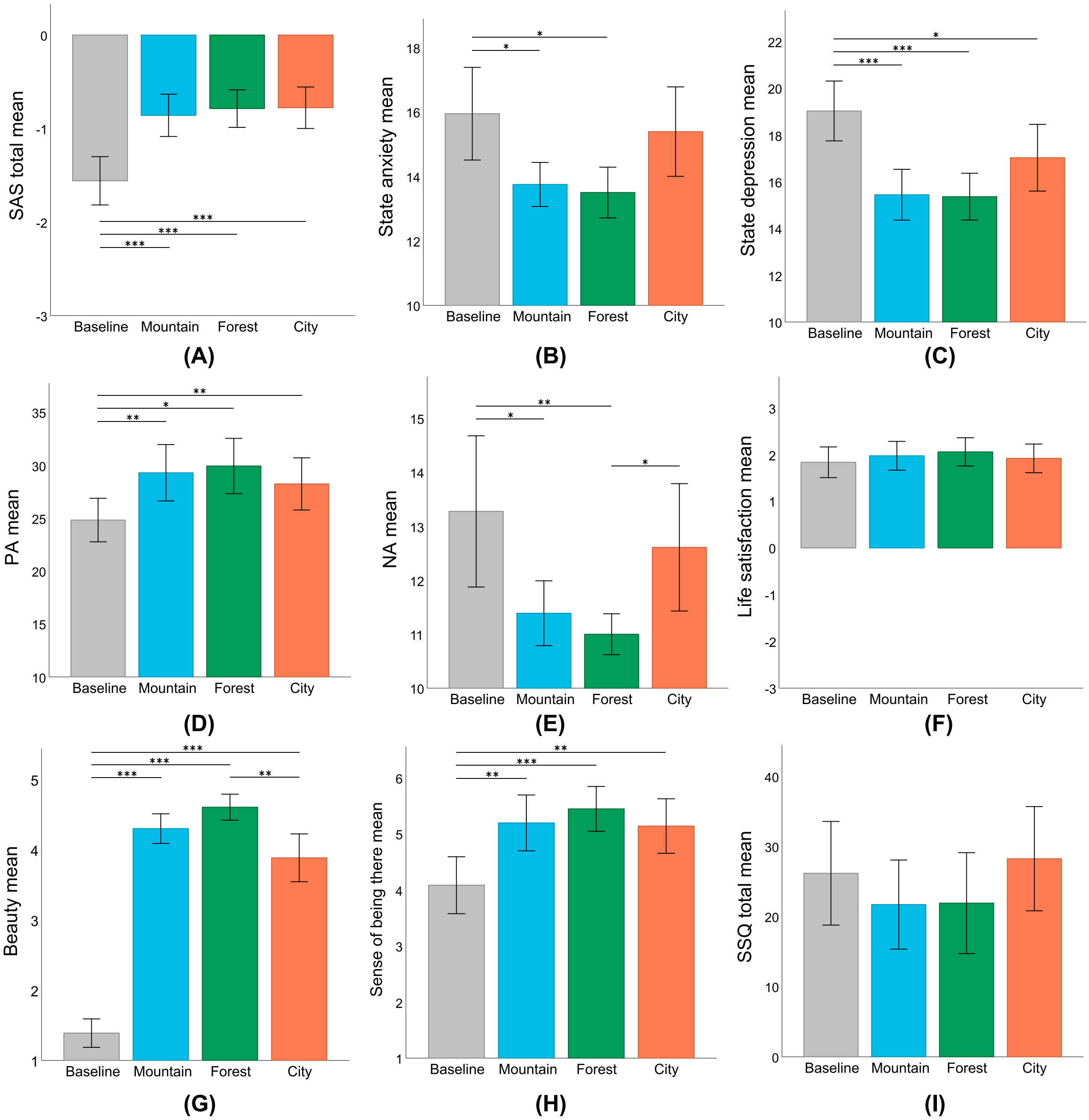

FIGURE 3
Study Results: **(A)** SAS: Awe total mean [-3, 3], **(B)** STADI-S: State anxiety mean [10, 40], **(C)** STADI-S: State depression mean [10, 40], **(D)** PANAS: Positive affect (PA) mean [10, 50], **(E)** PANAS: Negative affect (NA) mean [10, 50], **(F)** Life satisfaction mean [-3, 3], **(G)** Beauty mean [1, 5], **(H)** Sense of presence mean [1, 7], and **(I)** SSQ: Simulator sickness total mean [0, 235.62].

statistically significant differences were found between the environments using Bonferroni corrections.

4.1.3 Affect (PANAS)

An RM ANOVA showed that the type of environment had a statistically significant effect on positive affect (PA) $(F(2.087, 73.038) = 6.991, p = .001, \eta_p^2 = .166)$. Bonferroni post-hoc tests revealed that the mountain $(M = 29.306, SD = 7.877, p = .008)$, forest with waterfall $(M = 29.944, SD = 7.716, p = .011)$ and city environments $(M = 28.25, SD = 7.280, p = .003)$ induced higher levels of PA than the neutral baseline $(M = 24.833, SD = 6.087)$. Thus, H3.c can be accepted regarding all immersive videos (natural and city), with no significant differences between them.

Moreover, NA significantly differed between environments $(F(2.144, 75.042) = 7.601, p = .001, \eta_p^2 = .178)$. Bonferroni post-hoc tests showed that the mountain $(M = 11.389, SD = 1.777, p = .012)$ and forest with waterfall $(M = 11.000, SD = 1.121, p = .006)$ environments induced significantly lower levels of NA compared to

TABLE 2 Means (and standard deviations) of all dependent variables for each condition with $n = 36$.

Variable	Baseline	Mountain	Forest with waterfall	City
SAS				
Awe Total	−1.559 (0.763)	−0.859 (0.669)	−0.787 (0.594)	−0.778 (0.656)
Connection	−1.688 (1.149)	−0.056 (1.441)	0.146 (1.293)	−0.063 (1.338)
Oppression	−0.743 (1.453)	−2.514 (0.734)	−2.493 (0.820)	−2.201 (0.943)
Chills	−2.444 (0.671)	−1.076 (1.148)	−1.125 (1.254)	−0.965 (1.229)
Diminished Self	−1.296 (1.425)	0.565 (1.359)	0.694 (1.209)	0.417 (1.404)
STADI-S				
State Anxiety	15.944 (4.249)	13.750 (2.020)	13.500 (2.324)	15.389 (4.101)
Emotionality	7.083 (2.430)	6.556 (1.557)	6.417 (1.697)	7.361 (2.587)
Worry	8.861 (2.416)	7.194 (1.527)	7.083 (1.461)	8.028 (2.118)
State Depression	19.028 (3.783)	15.444 (3.211)	15.361 (2.959)	17.028 (4.219)
Anhedonia	13.500 (3.334)	10.306 (3.214)	10.222 (3.015)	11.694 (3.846)
Dysthemia	5.528 (1.028)	5.139 (0.351)	5.139 (0.424)	5.333 (0.894)
PANAS				
Positive Affect	24.833 (6.087)	29.306 (7.877)	29.944 (7.716)	28.250 (7.280)
Negative Affect	13.278 (4.145)	11.389 (1.777)	11.000 (1.121)	12.611 (3.491)
Single-item				
Life Satisfaction	1.833 (0.971)	1.972 (0.910)	2.056 (0.893)	1.917 (0.906)
Beauty	1.389 (0.599)	4.306 (0.624)	4.611 (0.549)	3.889 (1.008)
Presence	4.083 (1.500)	5.194 (1.470)	5.444 (1.182)	5.139 (1.437)
SSQ				
SSQ Total	26.180 (21.844)	21.713 (18.771)	21.921 (21.273)	28.258 (21.962)
Nausea	19.080 (16.758)	16.960 (15.982)	18.020 (18.913)	22.260 (21.755)
Oculomotor	24.635 (18.950)	18.739 (16.655)	18.108 (18.325)	22.740 (16.308)
Disorientation	24.360 (28.697)	21.653 (29.845)	22.040 (36.659)	30.933 (32.622)

the neutral baseline ($M = 13.278, SD = 4.145$), whereas the city ($M = 12.611, SD = 3.491$, $p = 1.000$) did not significantly differ from baseline. Therefore, only natural environments were able to reduce NA, which only partially supports H3.d. Furthermore, NA was significantly lower after the forest with waterfall than after the city VE ($p = .041$). Using Bonferroni corrections, no further significant differences were found.

4.1.4 Life satisfaction

While momentary life satisfaction was rated slightly higher for all immersive videos compared to the neutral baseline, an RM ANOVA showed that this effect did not reach statistical significance ($F(2.357, 82.484) = 2.742, p = .061, \eta_p^2 = .073$). Therefore, H3.e cannot be confirmed.

4.1.5 Beauty

An RM ANOVA revealed that beauty ratings significantly differed between VEs ($F(3, 105) = 162.065, p < .001, \eta_p^2 = .822$). Bonferroni post-hoc tests indicated that the mountain ($M = 4.306, SD = .624, p < .001$), forest with waterfall ($M = 4.611, SD = .549, p < .001$) and city environments ($M = 3.889, SD = 1.008, p < .001$) received significantly higher beauty ratings than the neutral baseline room ($M = 1.389, SD = .599$), which supports H4 regarding all immersive videos. Moreover, the forest with waterfall environment was rated as significantly more beautiful than the city environment ($p = .001$), while beauty ratings did not differ significantly between mountain and forest with waterfall ($p = .235$) and mountain and city ($p = .180$) using Bonferroni adjustments.

4.1.6 Sense of presence

A statistically significant effect of the type of environment on presence was observed ($F(2.005, 70.160) = 10.730, p < .001$, $\eta_p^2 = .235$). Bonferroni post-hoc tests determined that the result was attributable to lower ratings regarding the neutral baseline room ($M = 4.083$, $SD = 1.500$) compared to the mountain ($M = 5.194$, $SD = 1.470$, $p = .009$), forest with waterfall ($M = 5.444, SD = 1.182, p < .001$) and city ($M = 5.139, SD = 1.4373, p = .019$) immersive videos. Therefore, H5 was supported by these results. No statistically significant differences were found between the experimental conditions.

4.1.7 Simulator sickness (SSQ)

An RM ANOVA revealed that there was no statistically significant effect of the type of environment on the SSQ total score ($F(2.401, 84.052) = 2.333, p = .093, \eta_p^2 = .063$). This finding suggests that the aerial immersive videos did not induce any more

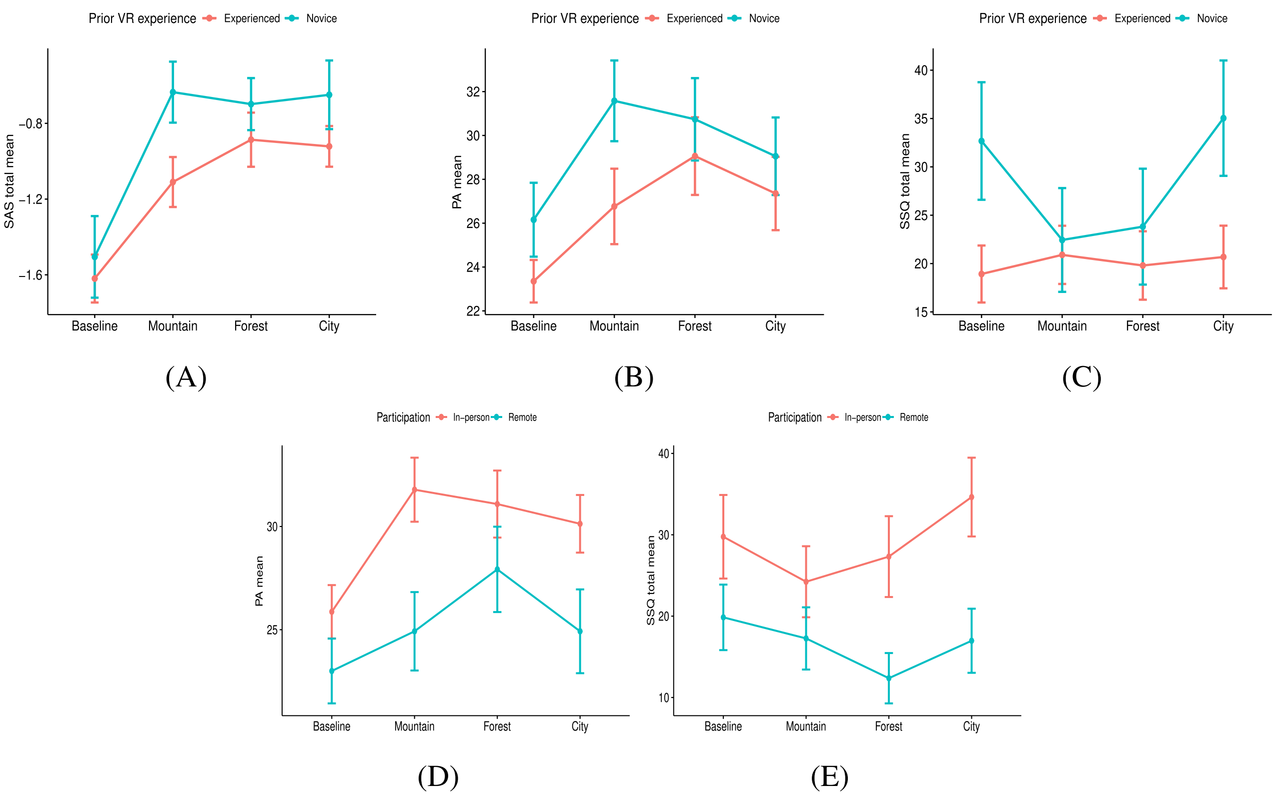

FIGURE 4
Experienced vs. novice users: **(A)** Awe total, **(B)** Positive Affect, and **(C)** Total simulator sickness. In-person vs. remote participation: **(D)** Positive Affect, and **(E)** Total simulator sickness.

self-reported simulator sickness compared to the baseline condition, which rejects H6.

4.2 Effects of prior VR experience

To examine the potential effects of prior VR experience on the study measures, we first ran unpaired t-tests to compare the values of each study measurement between novice and experienced VR users. No significant differences could be observed for state anxiety $(p = .411)$, state depression $(p = .673)$, negative affect $(p = .103)$, life satisfaction $(p = .294)$, beauty $(p = .29)$, and sense of presence $(p = .125)$.

For the rest of the variables, after observing a significant difference between the groups using a t-test, we ran separate RM ANOVAs on the type of environment for each group (VR novices and VR-experienced users) and employed planned contrasts comparing the neutral baseline condition against the immersive video conditions (mountain, forest with waterfall, and city combined). This was done to investigate whether the effects of immersive videos (mountain, forest with waterfall, and city) compared to the neutral baseline condition hold for novice as well as experienced VR users (H7).

Experienced VR users showed overall lower awe scores $(M = -1.134, SD = .594)$ compared to novice VR users $(M = -0.872, SD = .838, t(135.15) = -2.184, p = .031)$. The RM ANOVA showed a significant main effect of the environment on the total awe scores for both novice and experienced VR users (Novices: $F(1.84, 33.2) = 14.52, p < .001, \eta_p^2 = .447$, Experienced: $F(1.68, 26.90) = 8.48, p = .002, \eta_p^2 = .346$). The planned contrasts indicated that both groups experienced significantly higher total awe scores after exposure to immersive videos compared to the baseline (Novices: $p < .0001, 56.099\%$ increase, Experienced: $p = .005, 39.952\%$ increase). Figure 4A shows the total awe scores after exposure to each VE for novice and experienced VR users.

Experienced VR users reported overall lower PA $(M = 26.632, SD = 6.653)$ compared to novice VR users $(M = 29.382, SD = 7.941, t(141.41) = -2.259, p = .025)$. The RM ANOVA showed a significant main effect of environment on PA for experienced VR users $(F(2.17, 34.66) = 5.91, p = .005, \eta_p^2 = .27)$ but not for VR novices $(F(1.77, 31.86) = 3.01, p = .069, \eta_p^2 = .143)$ and. Nonetheless, the planned contrasts indicated that the PA after exposure to immersive videos was significantly increased compared to the baseline condition for both novice and experienced VR users (Novices: $p = .012, 16.432\%$ increase, Experienced: $p = .009, 18.724\%$ increase). Figure 4B depicts PA scores after each environment for each group of users.

Experienced VR users showed significantly lower simulator sickness $(M = 20.075, SD = 12.89)$ compared to VR novices $(M = 28.493, SD = 25.614, t(113.3) = -2.529, p = .013)$. However, no significant effect of environment could be observed for any of the groups (Novices: $F(2.14, 38.53) = 3.09, p = .054, \eta_p^2 = .146$, Experienced: $F(2.25, 36.04) = .26, p = .8, \eta_p^2 = .016$). The planned contrasts also did not show any significant difference between the baseline and the immersive videos for either novice or experienced VR users (Novices: $p = .218$, Experienced: $p = .446$). Figure 4C shows simulator sickness scores after each environment for each group of users. Thus, H7 was supported.

4.3 Effects of the type of participation

While the type of participation was mandated by health requirements during the COVID-19 pandemic, we used this as an opportunity to investigate potential effects of remote vs. in-person participation. To do so, we repeated the analysis reported for the prior VR experience in the previous section, this time for the type of participation (remote or in-person). Therefore, we ran unpaired t-tests to compare the values of each study measurement between remote and in-person participation. Among all study measures, we only found a significant difference for PA (see Figure 4D) and simulator sickness (Figure 4E). More specifically, in-person participation led to higher values in PA ($M = 29.72, SD = 7.31$) compared to remote participation ($M = 25.19$, $SD = 6.89$, $t(111.4) = 3.703, p = .0003$). The RM ANOVA showed a significant main effect of environment on PA for in-person participation ($F(1.86, 40.92) = 5.73, p = .007, \eta_p^2 = .207$) but not for remote participation ($F(1.79, 21.47) = 2.28$, $p = .131$, $\eta_p^2 = .159$). Also, planned contrasts indicated that the PA after exposure to immersive videos was significantly increased compared to the baseline condition for in-person participation ($p = .0002, 19.83\%$ increase) but not for remote participants ($p = .069, 12.71\%$ increase). Although simulator sickness was on average higher for in-person participation ($M = 28.99, SD = 23.13$) compared to remote participation ($M = 16.61, SD = 13.36$), neither the RM ANOVAs (in-person: $F(2.33, 51.20) = 2.01$, $p = .138$, $\eta_p^2 = .084$, remote: $F(1.82, 21.86) = 2.58$, $p = .102$, $\eta_p^2 = .177$) nor planned contrasts (in-person: $p = .77$, remote: $p = .06$) showed significant differences between environments. That is, for both types of participation, simulator sickness was equally experienced during exposure to baseline or immersive videos.

5 Discussion

In this research paper, we compared the effects of exposure to three aerial immersive videos from natural environments (i.e., mountain and forest with waterfall) and a city environment, to a 3D model of a neutral room at the baseline. In line with our hypothesis (H1), exposure to all three immersive videos was associated with higher levels of awe compared to the baseline. However, it has to be noted that the level of awe was relatively low across all VEs. On a scale from −3 to +3, the total awe scores after exposure to the immersive videos stayed below zero. Nevertheless, the Diminished-Self sub-scale showed positive values for all immersive videos (Piff et al., 2015; Bai et al., 2017). In addition, the forest with waterfall environment yielded a positive mean score on the Connection sub-scale of awe, indicating a feeling of connectedness with others and the surroundings. All in all, our results are in line with previous findings in which VEs (Quesnel and Riecke, 2017; Chirico et al., 2018; Quesnel and Riecke, 2018; Nelson-Coffey et al., 2019; van Limpt-Broers et al., 2020), and immersive videos, in particular, (Chirico et al., 2016a; 2017; Kahn and Cargile, 2021), were effective in inducing awe, although some (Gallagher et al., 2015) have reported higher awe values (e.g., averaging above 70 on a 0–100 scale (Quesnel and Riecke, 2018)) compared to our study. One possible reason could be experimental differences such as the use of different awe scales, the duration of the experience, and the presence or absence of interactivity in VR. Nonetheless, our results extend previous research by demonstrating that exposure to aerial immersive videos enhances awe compared to the baseline.

Furthermore, we found that the amount of awe did not significantly differ between the mountain, forest with waterfall, and city conditions. This supports our second hypothesis (H2) suggesting that natural and urban immersive videos can induce the same intensity of awe. These results are in line with findings from Collado et al.'s study (Collado and Manrique, 2020), which showed that a photo slideshow of awe-inducing built (i.e., architectural) scenes evoked the same degree of awe as an awe-inducing nature slideshow. Taking into account the methodological bias (Bai et al., 2017; Piff et al., 2015; Negami, 2020) that nature stimuli are commonly used to elicit awe in psychological studies, our findings demonstrate that awe-inspiring stimuli can be diversified to include non-natural stimuli, such as urban environments, at least when they contain some natural elements such as the sunset sky and rivers.

In addition, our results suggest that the participants felt the same degree of awe in the snow-capped mountain and green forest with waterfall environment, which contradicts findings from a previous VR study by Chirico et al. (2018). They found that a panorama view of snow-capped mountains elicited more awe than walking through a forest with tall trees and a waterfall. One difference is that those environments were model-based simulations, whereas the current study used real-world immersive videos. Furthermore, all of the experimental conditions in our study presented vast panoramic views, which can be categorized as "vastness in width" (Chirico et al., 2018), whereas Chirico et al. designed a mountain VE with panoramic views and a forest VE composed of only "vastness in height". Consequently, one possible explanation might be that their mountain condition was more awe-inducing than their forest condition because of the different types of vastness, not due to the type of nature scene. Further research is needed to test the awe-inducing potential of different types of natural VEs, preferably using the same type of vastness for better comparability. Furthermore, research is needed to clarify how and to what degree other factors contribute to awe experiences, such as camera height, path, movement direction and smoothness, scene depth and complexity, lighting, time of day, and other stimulus parameters, but also how participants are transition into and out of VR (Kitson et al., 2020b), or participant factors such as their prior experiences with similar stimuli, which can have substantial effects (Stepanova et al., 2019b).

Concerning short-term psychological wellbeing, we hypothesized that the self-reported levels of state depression, state anxiety, and negative affect (NA) are lower and levels of positive affect (PA) and momentary life satisfaction are higher after exposure to the three experimental conditions compared to the baseline (H3). Our results only partially support this hypothesis and indicate that positive effects on wellbeing depend on the type of environment and the particular aspect of wellbeing and mental health.

The two natural environments (mountain and forest with waterfall) did not differ significantly in any of the outcome variables. Both had positive effects on self-reported PA, NA, state depression, and state anxiety compared to the baseline. These findings are consistent with previous research on awe, demonstrating that awe-inducing nature stimuli can increase general wellbeing (Gordon et al., 2017; Anderson et al., 2018) and mood (Joye and Bolderdijk, 2015; Chirico et al., 2018). To the best of our knowledge, this was the first experimental study that compared the effect of different awe-inducing environments on depression and anxiety. Relative to the neutral baseline, exposure to all three awe-inducing videos (mountain, forest, city) reduced participants' current state of depression. Moreover, exposure to both natural environments decreased their current state of anxiety. These findings support a recent theoretical work by Chirico and Gaggioli (2021), which outlined a potential therapeutic role of awe for mental health and, in particular, proposed a link between awe and major depressive disorder. Note, however, that our analyses are based on the responses from healthy participants who had no diagnosed mental disorder, and future research is needed to investigate how the observed effects might generalize to different populations and repeated exposure.

The city condition showed positive effects for some of our measures of wellbeing, but not for all. Specifically, PA was significantly higher and state depression lower after exposure to the city VE compared to the baseline. Additionally, the city, mountain, and forest with waterfall VEs did not differ regarding these two measures, indicating that the city condition was able to increase PA and reduce state depression to the same degree as the mountain and forest with waterfall conditions. This contradicts numerous studies in environmental psychology according to which exposure to nature has more positive effects on psychological wellbeing and health than urban scenes (Ulrich, 1979; Velarde et al., 2007; Mostajeran et al., 2021). One possible explanation is that the induced feeling of awe led to the observed positive effects on PA and state depression, independent of the type of environment. An alternative explanation could be that the existing natural elements depicted in the city VE, such as the view of the sky, or even the act of flying were sufficient to evoke these positive effects. Future studies comparing awe-inducing natural and urban VEs should aim to completely avoid or carefully experimentally control natural components in their urban scenes. Our results also contradict findings by Collado and Manrique (2020), who showed that watching photo slideshows depicting awe-evoking or mundane nature both increased pleasant deactivation, a measure of positive affect, whereas no significant changes were found for awe-evoking or mundane architectural scenes. As far as we know, our study is the first to demonstrate that natural and urban environments, that elicit the same level of awe, positively affect state depression and PA to the same degree. This contributes to research on awe by indicating that some beneficial effects of awe on wellbeing described in the literature may not be limited to awe-inducing natural VEs, but can also be caused by exposure to urban VEs.

However, the city condition did not show significant effects for all examined aspects of wellbeing. Self-reported state anxiety and NA after exposure to the city environment were not significantly different from the baseline. Furthermore, NA was significantly lower after the forest with waterfall than after the city condition. This finding is in line with research showing that virtual forest with waterfall environments reduce negative mood whereas virtual urban environments disturb mood (Mostajeran et al., 2021). It also suggests that the awe-inducing nature VEs, especially the forest with waterfall environment, improved short-term wellbeing and mental health to a broader extent than the awe-inducing urban VE, where positive effects were limited to state depression and PA. These results suggest that an increased feeling of awe, irrespective of the type of environment, is not sufficient to decrease NA and state anxiety. This finding is in line with the stress recovery theory (SRT) (Ulrich et al., 1991), which states that exposure to natural environments is more restorative than exposure to urban environments, for instance leading to physiological relaxation (Jo et al., 2019), increased PA and decreased stress (Valtchanov et al., 2010). Consequently, it seems reasonable that positive awe, experienced in a natural environment, yields a favorable combination and hence may provide more wellbeing benefits than awe induced by urban environments. In addition, several differences between the urban and natural environments could have contributed to the observed results. Thus, future research is needed to unearth underlying factors while controlling for confounds.

Contrary to our hypothesis (H3.e) and previous studies (Rudd et al., 2012; Anderson et al., 2018), none of the awe-inducing conditions showed a statistically significant effect on life satisfaction. Throughout our study, the participants were asked to rate their momentary life satisfaction four times over a period of approximately 45–60 min using a single-item measure. One reason that may explain why we did not find a significant difference is that life satisfaction is known to be rather stable over periods of time (Pavot and Diener, 1993) since the construct is closely related to personality traits (Costa and McCrae, 1980; Schimmack et al., 2009). In the future, the long-term effects of awe experiences on general life satisfaction could be investigated using a multi-item scale, such as the Satisfaction with Life Scale (Diener et al., 1985).

In addition to the main outcomes discussed above, three further variables were assessed: (i) beauty, (ii) sense of presence, and (iii) simulator sickness. Firstly, the participants gave higher beauty ratings to the mountain, forest with waterfall, and city VEs than to the neutral baseline VE. This was expected (H4) because the three experimental conditions were intended to induce awe and depict spectacular panoramic views. However, the forest with waterfall environment received higher beauty ratings than the city, which can be explained by people's general aesthetic preference for natural over urban environments (Ulrich, 1983). Additionally, preferred environments have been found to be associated with higher affective restoration (Van den Berg et al., 2003). Therefore, participants' aesthetic preference for the forest with waterfall over the city environment could be related to their level of self-reported wellbeing, which would be in line with the NA results, as NA was lower after the forest with waterfall than after the city VE.

Furthermore, the sense of presence was significantly higher for all immersive videos compared to the baseline condition, which supports H5. In future studies, longer exposure durations and multi-sensory VR stimuli, which provide the possibility to interact with the VE (Quesnel and Riecke, 2018), could be used to further increase the sense of presence. As the sense of presence and emotions are known to be positively related (Baños et al., 2004), it could potentially intensify the emotion of awe.The role of immersion could also be studied in future work. Some studies suggest that although the sense of presence is higher in VR, it does not necessarily contribute to a stronger effect of the stimuli on the users. For example, Mostajeran et al. (Mostajeran et al., 2021) discovered that exposure to a virtual forest environment has a positive effect on cognition regardless of the mode of presentation (immersive videos versus photo slideshows, all presented in a VR HMD). Similarly, since most people tend to watch awe-inducing videos of natural environments in non-immersive media such as TV (e.g., nature documentaries), the question arises whether our results might change when the same videos are presented on a non-immersive medium.

There were also no statistically significant differences between the level of experienced simulator sickness in all four conditions, which remained at an overall very low level. This implies that the aerial immersive videos did not induce more simulator sickness than the stationary VE at baseline, which rejects H6. One possible explanation could be that the camera movements in the aerial videos were quite smooth and devoid of any sharp turns or accelerations, and objects were far away, thus reducing the overall amount of optic flow and sensory conflict known to contribute to motion sickness (Reason and Brand, 1975; Rebenitsch and Owen, 2016; Keshavarz et al., 2015; Freiwald et al., 2020).

Moreover, the analysis of our participants' prior VR experience showed that the effects of exposure to immersive videos (mountain, forest with waterfall, and city) compared to our neutral baseline condition hold for novice as well as experienced VR users, which supports H7. These results are in line with previous research proposing that the novelty effect may not be a concern while designing VR usage over multiple sessions, as they showed that participants' psychological responses do not steeply decline with an increase in their experience with VR (Huang et al., 2021; Huang, 2020).

5.1 Limitations and future work

One limitation of this study is that not all participants took part in a controlled laboratory setting experiment. By allowing for remote participation, we enabled the participation of more volunteers who agreed to do the study in a quiet room. However, this led to a lack of physical environmental control. Due to health-related constraints during the COVID-19 pandemic, our study included both in-person ($N = 23$) and remote participants ($N = 13$). While not originally intended for comparison, this mixed participation mode allowed us to explore contextual influences on affective responses to VR. An exploratory analysis revealed that only in-person participants showed significant increases in positive affect relative to baseline, whereas this effect was not observed in the remote group. This suggests that remote participation may reduce emotional engagement, potentially due to reduced environmental control, headset setup variability, differences in set and setting, or lack of researcher presence. Future studies should systematically examine how participation context influences psychological outcomes in immersive VR settings.

Another limitation is that emotions other than awe were not assessed in this study, hence, it is uncertain whether awe was the dominant emotion felt by participants. Future studies should test whether the awe-inducing video stimuli primarily induce the target emotion of awe, compared to other distinct emotions (e.g., happiness, amusement, fear). For that, previous studies on awe have used a conventional manipulation check with single items to measure different emotional states (Rudd et al., 2012; Bai et al., 2017; Anderson et al., 2018; Chirico et al., 2018). However, as awe is a complex emotion (Shiota et al., 2007), future studies should consider accompanying such manipulation checks with a validated, multi-item awe questionnaire. Inclusion of qualitative instruments, as employed in prior research (Gallagher et al., 2015; Stepanova et al., 2019b; Kitson et al., 2020b; Stepanova et al., 2019a; Miller et al., 2023; Quesnel and Riecke, 2018; Liu et al., 2022), may also facilitate the unraveling of different emotions and intricacies of the user experience that standard questionnaires may not explicitly measure.

A further limitation is the subtle environmental differences between the immersive videos. For instance, they slightly differed regarding the amount of clouds and light they featured, which may have influenced participants' mood reports (Kööts et al., 2011; Denissen et al., 2008) and beauty ratings, as people generally prefer sunny and bright scenes (Beute and de Kort, 2013). Besides, natural features could not be entirely avoided in our city environment, and in addition, our mountain environment showed a few hikers at a distance.

These limitations could be avoided in future studies by using computer-generated VEs. The advantage of using immersive videos in this study was that they offered real-world simulations of natural and urban environments, which granted a high sense of presence in those environments. They had the additional advantage of immersing the users in real-world environments that are difficult to access otherwise (e.g., for people with restricted mobility or because of restricted time or travel access). However, their disadvantage was that not all elements of the video stimuli were systematically controlled. Computer-generated VEs, on the other hand, can be more interactive and provide researchers with more experimental control over the stimuli (Chirico et al., 2016b). For instance, seasonal changes, weather conditions, vegetation, and even subtle movements of leaves and grass could be modeled and controlled. However, allowing participants to interact and control their own locomotion will introduce additional confounds and can result in rather different VR experiences. To further understand the (dis)advantages of computer-generated versus video-based immersive experiences regarding the complex emotion of awe, future studies could directly compare their effectiveness of high-resolution stereoscopic immersive videos and model-based VR simulations of the same environment in evoking awe.

Another limitation of our study design is that the neutral condition was always administered first. This was done to assess baseline scores for all measures before the subjects were exposed to any awe-inducing material so that any effects of the experimental conditions could be compared to the participants' initial levels of wellbeing and awe. However, it was not possible to administer all questionnaires at baseline without first exposing the participants to a specific environment that they could refer to when answering the questionnaires. For example, the items of the SAS are phrased in the past tense (e.g., “My heart was racing”, “The world seemed vast.“), so it was necessary to immerse the participants in a neutral environment for a fixed amount of time. For that matter, a model-based indoor room was designed, which served as a non-awe-inducing, neutral environment. A disadvantage that follows from this procedure is that the baseline condition was a stationary computer-generated model of a room, whereas the experimental conditions were aerial immersive flying videos depicting real-world environments. This is a limitation of our study, as this discrepancy between the baseline and experimental conditions might have affected the users’ perception of these environments. We chose immersive videos in contrast to computer-generated virtual environments to ensure high realism of the presented environments. However, the use of computer-generated VEs as experimental conditions could help overcome this limitation by making the baseline more comparable to the experimental conditions. Alternatively, future studies based on immersive videos could use a neutral 360° video of a real-world environment as a counterbalanced control condition that does not induce feelings of awe. Further investigations should be carried out on the potential transfer or cumulative effects of exposure to multiple awe-inducing VEs. In addition, the neutral condition could be administered systematically as the last condition to investigate whether and to what degree different measures go back to baseline scores.

While our findings highlight the short-term psychological benefits of awe-inducing immersive videos, the potential for long-term impact remains to be explored. Both novice and experienced VR users showed significant improvements in awe and positive affect compared to baseline, supporting the use of immersive videos as a broadly effective medium. Although experienced users reported slightly lower levels of awe and positive affect overall, they still experienced meaningful benefits, suggesting that prior VR exposure does not diminish the emotional impact of immersive environments. However, participants’ familiarity with the specific content was not assessed, leaving open the possibility that novelty contributed to the observed effects. Repeated exposure to identical immersive content may reduce its emotional salience, even if the medium itself retains its efficacy. Future longitudinal studies should investigate whether these psychological benefits persist over time and how strategies such as content variation, personalization, or dynamically/procedurally generated environments might help maintain awe and wellbeing benefits over time. Understanding how repeated VR exposure interacts with emotional and cognitive adaptation will be key to harnessing VR’s full therapeutic and wellbeing potential.

Finally, future studies may combine self-report questionnaires with physiological measures such as skin conductance responses (Chirico et al., 2017) and goosebumps (Quesnel and Riecke, 2018). Unfortunately, we had to refrain from using biosensors to allow for remote participation. In addition, future research should examine the long-term wellbeing effects of regular exposure to awe-inducing VEs with larger, more diverse samples. Randomized controlled clinical trials should be conducted to investigate whether experiencing awe has therapeutic benefits for people with mental disorders, particularly depression and anxiety.

6 Conclusion

This work provides novel insights into the psychological effects of awe-inducing immersive videos of natural and urban environments, demonstrating improvements in multiple measures of psychological wellbeing. Notably, we demonstrated for the first time that exposure to awe-inducing immersive videos of both natural and urban environments reduced current states of depression. However, only nature-based environments additionally decreased anxiety. By extending the focus to urban environments, our study broadens the understanding of awe’s emotional and psychological impact beyond the dominant emphasis on green nature in related research. The benefits were also observed in participants with prior VR experience, suggesting that immersive video interventions could be effective for both novice and experienced VR users. These preliminary yet promising results can guide the design of future clinical and non-clinical studies and potentially aid in developing awe-based therapeutic interventions aimed at improving mental health.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by The Center for Psychosocial Medicine at the University Medical Center Hamburg-Eppendorf (UKE). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

LB: Conceptualization, Methodology, Investigation, Software, Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review and editing. FM: Conceptualization, Methodology, Data curation, Formal analysis, Visualization, Project administration, Supervision, Writing – original draft, Writing – review and editing. FS: Resources, Writing – review and editing. BR: Writing – review and editing. SK: Conceptualization, Methodology, Supervision, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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