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Beyond sight: Comparing traditional virtual reality and immersive multi-sensory environments in stress reduction of university students

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Introduction: This study aims to assess the efficacy of traditional virtual reality (VR) and Immersive Multi-sensory Environments (IME) in mitigating anxiety levels among university students. The study can address the following research questions: 1) What disparities exist in anxiety levels before and after exposure to traditional VR and IME? 2) How do anxiety levels compare between participants exposed to IME and those in a VR environment?

Methods: The research adopted a twophase approach involving participants exhibiting moderate to high-stress levels. In the second phase, participants were randomly assigned to either a VR group (solely visual stimulation) or an IME group (comprising visual, auditory, and olfactory stimuli). The State-Trait Anxiety Inventory (STAI) were utilized to assess stress and anxiety levels before and after each experiment.

Results: The findings suggest that participants' experiences in both VR and IME environments effectively contributed to reducing anxiety levels and fostering a tranquil atmosphere. Both experimental groups reported a significantly heightened sense of relaxation post-experiments. Although the disparity was not statistically significant, the IME group displayed a more pronounced reduction in stress levels compared to the VR group.

Discussion: The research underscores the significance of considering the built environment and sensory design in addressing mental health challenges among college students. Further exploration and integration of such approaches into educational settings could significantly contribute to establishing more supportive and conducive environments for student success.

KEYWORDS

virtual reality, multi-sensory design, biophilic design, stress reduction, anxiety reduction

1 Introduction

The use of Virtual Reality (VR) in therapeutic settings has gained significant attention in recent years, particularly for its potential to address anxiety disorders (Premkumar et al., 2022). By creating immersive, controlled environments, VR technology offers innovative solutions that go beyond traditional treatments. Especially, by simulating natural environments and engaging multiple senses, VR can provide therapeutic experiences

that distract from real-world stressors, promote relaxation, and support emotional regulation (De Jesus Junior, et al., 2023).

1.1 Prevalence of anxiety among university students

Stress and anxiety are pervasive in modern society, often amplified by the fast-paced and demanding nature of contemporary life. In the realm of higher education, the mental health of university students has emerged as a critical concern. More than half of community university students in the United States grapple with one or more mental health issues (Mistler et al., 2011; Lipson et al., 2021). Among these challenges, anxiety disorders loom large, affecting a significant portion of university students and posing substantial obstacles to their wellbeing.

The National Institute of Mental Health (2023) defines anxiety disorders as a spectrum of conditions characterized by prolonged and excessive feelings of fear, worry, and apprehension. These disorders encompass various categories, including social anxiety disorder, panic disorder, specific phobias, and generalized anxiety disorder, each marked by distinct characteristics and diagnostic criteria. Anxiety disorders are not transient feelings; instead, they tend to worsen over time, posing challenges in achieving goals, managing academic responsibilities, and maintaining interpersonal relationships (Craske and Stein, 2016). Statistics reveal that over 70% of individuals reporting a history of suicide attempts have been diagnosed with an anxiety disorder, underscoring the severe consequences associated with such conditions (Nepon et al., 2010).

The prevalence of anxiety is especially pronounced among younger students, ages 18–22, compared to their older counterparts (Lipson et al., 2021). As stress and anxiety continue to overshadow the college experience, exacerbated by external factors such as the COVID-19 pandemic, political unrest, racism, and inequality, the need for innovative and effective interventions becomes increasingly urgent (McAlpine, 2021).

1.2 Traditional mental health interventions and built Environment's role

Traditionally, mental health interventions have relied on pharmacological treatments and psychological therapies. However, these approaches come with limitations, including side effects and accessibility challenges. Consequently, there is growing interest in exploring additional non-invasive approaches to mental healthcare. The relationship between the built environment and mental health is intricate and multifaceted, with various aspects of physical surroundings influencing individuals' psychological wellbeing. Well-designed environments can contribute to stress reduction and improved wellbeing by incorporating natural elements such as green spaces, sunlight, and views of nature (Kaplan, 1995). The built environment plays a pivotal role in shaping our emotional responses and perceptions (Campelo, 2017).

The significant impact of the built environment on individual mental health and wellbeing has been demonstrated through numerous studies focusing on the psychological implications of architectural elements and aesthetic choices (Evans, 2003; Oswald and Wahl, 2004; Riediker and Koren, 2004). An essential aspect within this domain is the integration of natural elements into built spaces, a concept central to attention restoration theory (Kaplan, 1995). Kaplan's notion of 'soft fascination,' where effortless attention to nature leads to mental rejuvenation, resonates strongly within this framework (Kaplan, 1993, p. 48). Empirical evidence supports this idea, as seen in Berman et al. (2012) findings on the cognitive benefits of indoor greenery and Ulrich's (1984) study, which revealed faster recovery rates for patients with nature views. The incorporation of natural elements such as greenery and natural light has consistently shown to reduce stress and enhance mental health (Saarloos et al., 2011; Hartig et al., 2014; Yin et al., 2018; Wang et al., 2021). Implementing biophilic design principles, therefore, offers a compelling pathway to creating environments that foster mental health by striking a delicate balance between calming and stimulating elements (Berto, 2005; Berman et al., 2008; Söderlund and Newman, 2017). This underscores the pivotal role of natural elements in positively impacting mental wellbeing.

1.3 Virtual reality as a tool for anxiety reduction

The effectiveness of Virtual Reality (VR) in assessing cognitive functions, including attention, memory, and executive function, has been well-documented over the past few decades (Abramowitz, 2013; Freeman et al., 2017; Fodor et al., 2018). VR surpasses traditional 2D and 3D technologies by delivering immersive and realistic experiences on a life-like scale, enhancing users' ability to perceive and cognitively process information within the virtual environment (Slater and Sanchez-Vives, 2016). This heightened level of immersion empowers users to make more precise spatial estimates, contributing to a superior and more engaging virtual experience compared to conventional methods.

VR technology has emerged as a transformative tool that can mimic natural environments, providing new possibilities for addressing stress and anxiety. Its ability to create engaging environments offers a novel approach to managing anxiety disorders, combining distraction, cognitive engagement, and exposure therapy in a controlled, immersive setting. The VR experience offers a unique mechanism to divert attention from real-world stressors, creating a sense of detachment and relaxation (Camara and Hicks, 2020). VR's ability to simulate natural elements and evoke a sense of presence makes it a relevant tool for managing anxiety disorders. Extensive research has demonstrated the potential of VR to reduce anxiety (Gorini and Riva, 2008; Opriş et al., 2012; Grenier et al., 2015; Benbow and Anderson, 2019). Especially, Camara and Hicks (2020) found that VR intervention that combined visual scenes of nature and soothing sounds significantly reduced anxiety levels and increased relaxation of participants.

1.4 Alleviating stress by interpreting the senses to the immersive environment

Immersive Multi-sensory Environments (IME) technology offers a multi-sensory experience that goes beyond visual

immersion, engaging sound, smell, and touch to create a comprehensive sensory environment. This holistic approach is instrumental in promoting emotional regulation and relaxation, thereby aiding in anxiety reduction. Environments within VR that combine peaceful natural settings, calming sounds, and pleasant scents can evoke positive emotions and induce calmness, contributing to a decrease in anxiety levels (Aiken and Berry, 2015; Seinfeld et al., 2016; Serrano et al., 2016; Putrino et al., 2020).

The sense of smell, known as olfaction, holds a profound connection to our emotional wellbeing. Specific scents, such as those found in essential oils, are recognized for their stress-relieving properties (Sowndhararajan and Kim, 2016; Masuo et al., 2021). Notably, lavender is renowned for its stress-relieving and antidepressant effects (Chioca et al., 2013; Nasiri et al., 2016; Zamanifar et al., 2020), while clary sage has been found to contribute to relaxation and pain relief (You et al., 2011; Yang et al., 2014; Mitic et al., 2020). Integrating these scents into VR environments has the potential to enhance both mental and physical wellbeing by creating a soothing atmosphere and eliciting positive emotional responses (Amores et al., 2018). This approach aligns with the growing understanding of the powerful interplay between olfaction and emotional states, showcasing the potential for scent-infused VR experiences to positively impact overall health and mood.

Similarly, sound plays a pivotal role in crafting environments that promote restoration and wellbeing. Thoughtful curation and manipulation of auditory elements, such as gentle instrumental music and nature-inspired sounds like flowing water or birds chirping, have been shown to significantly enhance relaxation, concentration, and the reduction of anxiety (Franco et al., 2017; Pickens et al., 2019). Research indicates that environmental sounds possess a stress-recovery impact, with natural soundscapes accelerating physiological recovery from stress (Alvarsson et al., 2010; Ratcliffe et al., 2013). In support of this, a study conducted by Zamanifar et al. (2020) highlights the efficacy of combining music therapy and aromatherapy as a powerful strategy for reducing anxiety. The synergistic effect of carefully chosen auditory and olfactory stimuli underscores the potential of multisensory interventions to create restorative environments that positively influence mental and emotional states.

1.5 Research purpose

As 90 percent of information transmitted to the brain is visual (Potter et al., 2014), visual stimuli play a crucial role in communication, learning, and forming perceptions of the world. Humans rely on sight for tasks ranging from interpreting our surroundings and identifying objects to understanding complex concepts through visual aids. Through VR experiences, visual stimuli create a sense of presence, enabling users to engage with environments that may be entirely distinct from their current physical setting.

The potential effectiveness of VR in alleviating anxiety hinges on its ability to simulate natural elements and evoke a sense of presence similar to real-world experiences. However, it is crucial to investigate whether these virtually presented elements can provide the same psychological benefits as their natural counterparts. The importance of other senses, such as hearing, touch, taste, and smell, should not be underestimated. These senses contribute significantly to our overall sensory experience and play unique roles. Thus, the exploration of IME, which go beyond visual stimuli to incorporate other senses like smell and auditory, is still in its infancy. While traditional VR provides a valuable escape from reality, IMEs aim to mimic real-world sensory encounters more comprehensively.

The main purpose of this study is to evaluate the effectiveness of traditional VR and IME on anxiety levels among university students. This research conducts two experiments: one focusing on a VR environment primarily reliant on visual stimuli, and the other utilizing an IME that integrates visual, olfactory, and auditory stimuli. By isolating visual stimuli in a VR setting, this research seek to better understand the unique contributions of visual elements to stress reduction, thereby providing deeper insights into the mechanisms of VR and IME in mental health interventions. The study aims to explore the following research questions: 1) What are the differences in anxiety levels before and after exposure to traditional VR and IME? 2) How do anxiety levels compare between participants exposed to IME and those in a VR environment? This study provides valuable insights for educational institutions, interior designers, mental health practitioners, and policymakers to create environments conducive to students' mental wellbeing, academic performance, and overall college experiences.

2 Methodology

This study utilized a true experimental design to evaluate the efficacy of both traditional VR and IME in mitigating stress levels. Approval for the study protocol was obtained from the Institutional Review Board (IRB) at Iowa State university. This experimental design aimed to strike a balance between the controlled conditions essential for scientific inquiry and the practical constraints inherent in a real-world setting. Participants were given informed consent before participating and were assured of their right to withdraw from the study at any point without any consequences. Confidentiality and privacy of participant data were maintained throughout the research process.

2.1 Research design and participants

Participants were recruited via convenience sampling from a university student population in the Midwest U.S. Recruitment efforts included the strategic placement of fifty flyers across the campus, each featuring a QR code linking to a Qualtrics survey. This online survey served to assess participant eligibility through various criteria, including demographic information such as age, pregnancy status, and comfort levels with aroma and VR headsets (Table 1). Additionally, participants were required to complete the Perceived Stress Scale (PSS) questionnaire to gauge stress levels. Individuals failing to meet eligibility criteria at any stage were redirected to the end of the survey and deemed ineligible.

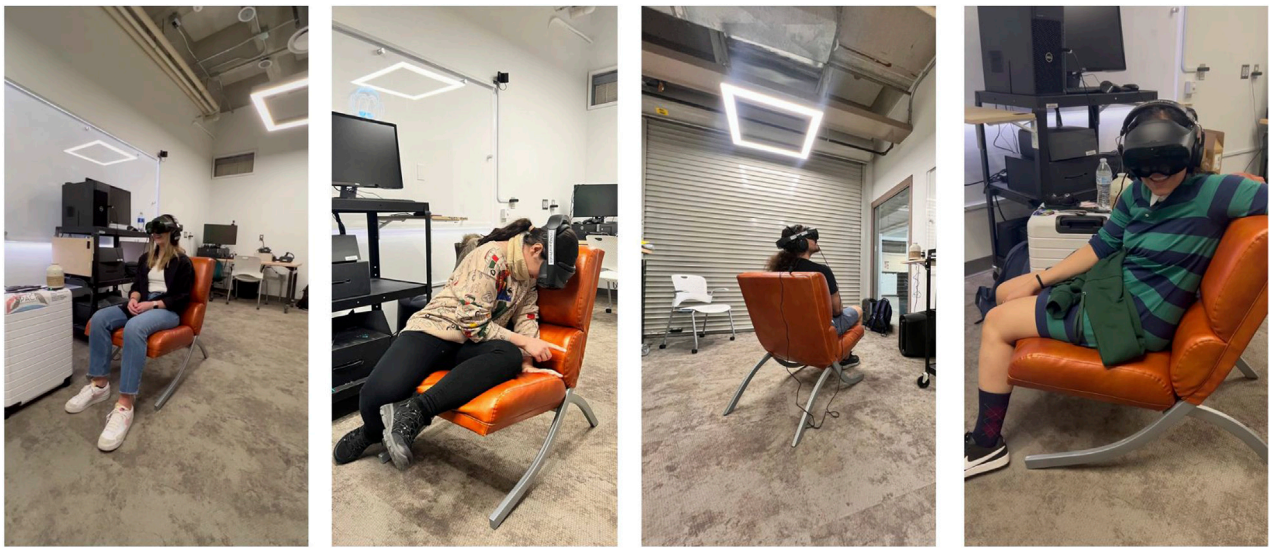

FIGURE 1
Research participants during the experiments.

Ninety participants completed the Perceived Stress Scale (PPS) questionnaire, and 36 students, including 19.45% male and 80.55% female, met the following inclusion criteria to be enrolled in this study.

The 36 participants were randomly assigned to VR group and IME group, in order to minimize selection bias and control the influence of unknown or unmeasurable variables that could impact the outcome. This methodological approach aimed to enhance the validity of the statistical analysis and findings.

The study took place in a VR lab situated on the third floor of the College of Design building at Iowa State University (see Figure 1). In the VR group, 4 men and 14 women engaged with a virtual environment featuring only visual stimuli, using the Oculus Quest Pro headset.

They immersed themselves in an 8-min VR 360° YouTube video of a serene natural setting in Waipio Valley, Hawaii Island, crafted[1] by Odyssey Visual Media (2023). This video was specifically chosen to offer participants a virtual experience promoting relaxation through nature such as beach and tropical scene in Hawaii.

Conversely, the IME group consists of 3 men and 15 women who encountered a multi-sensory environment integrating visual, auditory, and olfactory stimuli. This setup also employed the same VR headset and video but went a step further by introducing the scent of clary sage essential oil and a nature soundscape. This comprehensive approach aimed to provide participants with a more holistic and immersive sensory experience.

Both groups completed the State-Trait Anxiety Inventory (STAI) questionnaire using paper and pen before and after one of the interventions in the VR lab.

2.2 Survey tools

Standardized tools, including the PSS and STAI questionnaires, were employed to collect data on participants' stress and anxiety levels. These instruments were selected based on their reliability and validity in assessing stress and anxiety in research settings. The participants were requested to evaluate statements using predetermined scales, resulting in accurate and uniform measurement of their perceptions and experiences.

PSS is a self-report questionnaire created by Cohen et al. (1983) where individuals rate their own stress levels. The PSS includes a series of statements about thoughts and feelings experienced in the past month. Participants are asked to rate each statement on a scale of 0 (never) to 4 (very often), depending on how often they experienced stress. The scores can range from 0 to 40, with higher scores indicating higher levels of perceived stress. Scores between 0 and 13 are considered low stress, while scores between 14 and 26 are considered moderate stress, and scores between 27 and 40 are considered high perceived stress. Participants who scored 14 or more were eligible for the study's second phase. The average PSS score for the selected participants was 21.42.

The STAI is widely utilized to measure trait and state anxiety (Greene et al., 2017). It includes a series of statements that measure both temporary emotional state (state anxiety) and the general tendency to see situations as threatening (trait anxiety). This measurement tool includes 20 items that evaluate an individual's current emotional state, including fleeting feelings of nervousness, discomfort, and physical arousal. The scale includes statements such as "I feel calm" and "I worry about possible misfortunes." Participants rated their responses on a 4-point Likert scale, ranging from 1 (Not at all) to 4 (Very much), where higher scores indicate higher anxiety levels. This study measures an individual's perceived levels of state anxiety before and after the intervention.

1 The Youtube video is available here: https://www.youtube.com/watch?v=dw3ZVi7fx8M

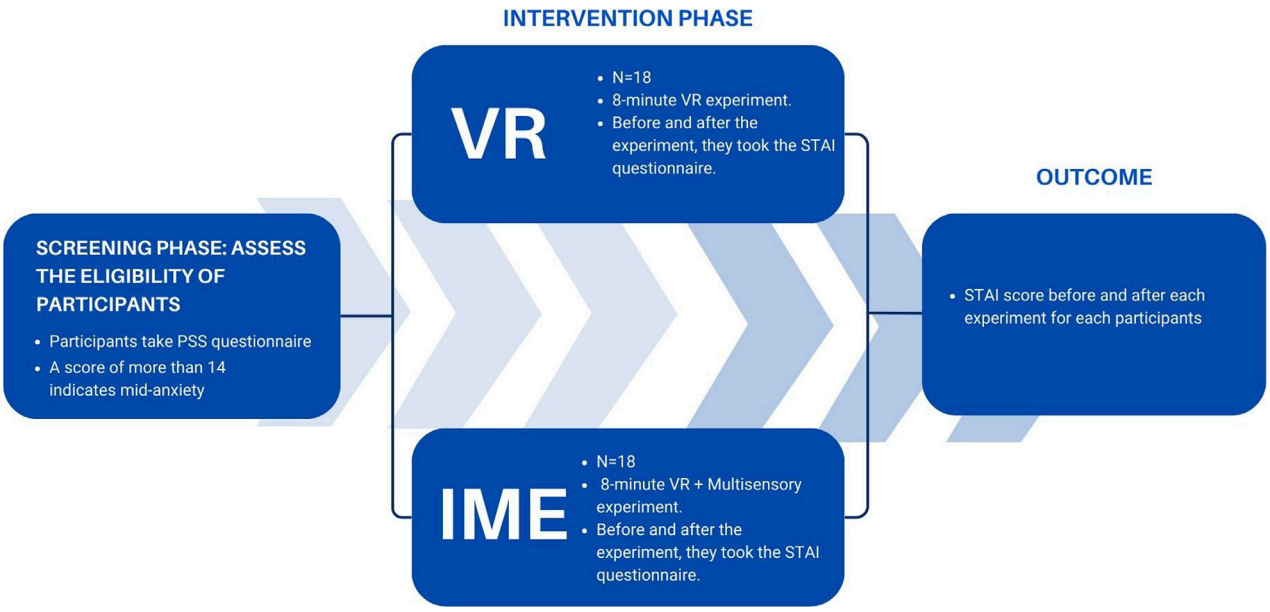

FIGURE 2
Study phases diagram.

2.3 Data collection and analysis

Quantitative data were collected through the pre-and post-experiment questionnaires. The primary outcome measure was the change in STAI scores, indicating variations in anxiety levels. This research employed the software R version 4.3.1 for statistical analysis. Multiple statistical techniques were used to analyze the experiments' data and draw conclusions, which included descriptive statistics, paired t-tests, and two-sample t-tests. Descriptive statistics were used to summarize and understand the features of the data from the two groups. Since paired t-test is an approach to test whether the mean difference between measurement pairs of individuals is zero (Gravetter et al., 2021), we implemented paired t-tests to assess the effectiveness of VR and IME in reducing anxiety in each experiment. This test was applied to the mean STAI scores of individuals before and after the two experiments. A two-sample t-test was conducted to compare the mean difference in STAI scores between groups who participated in the experiments with VR and IME. The purpose of this test was to determine if there was a significant difference in anxiety levels between the two independent groups. The results from the Shapiro-Wilk test for normality (Shapiro and Wilk, 1965) indicated no discernible departure from normal distribution within the IME experiment dataset, encompassing scores before and after the IME experiment and their differences. However, it is noteworthy that the normality assumptions were only rejected in the dataset collected post-VR. Upon thorough examination, it became apparent that a potential outlier existed within the post-VR experiment data (as seen in Figure 3), leading to the failure of the normality assumption. A comprehensive sensitivity analysis was undertaken to evaluate the influence of the potential outlier on the study outcomes. Subsequent analysis revealed that this potential outlier exerted no impact on the results. Consequently, the decision was made to disregard the slight departure of the normality assumption in the VR data, as its presence did not substantively affect the study findings. Therefore, we assumed the distribution of the STAI scores was approximately normal, the two groups were independent, and implementing the paired t-test and two-sample t-test was valid in this analysis (Gravetter et al., 2021). These rigorous approaches increase the validity of the findings, the study's credibility, and transparency, allowing other researchers to replicate and expand upon the findings easily.

3 Results

3.1 Descriptive analysis

The STAI scores were recorded before and after the interventions, and the difference between STAI scores was calculated for each subject (Table 2). The 'Before' column represents the scores recorded for each participant prior to the VR or IME experience, while the 'After' column shows the scores for each participant following the VR or IME experience. The last column is the difference between the score after minus the score before the experiment for each participant. According to the STAI survey, a higher score indicates a higher level of anxiety. For example, participant 8 in Experiment 1 had an STAI score of 58 when taking the survey before the VR experience and 29 after the experience. The difference between the scores is −29, which shows a 29-unit decrease in the stress level.

As shown in Table 3, in the VR experiment, the pre-intervention STAI scores ranged from 22 to 76 ($M = 39.94$, $SD = 14.94$). The post-intervention scores varied from 20 to 62, yielding a mean of 29.44 ($SD = 9.83$). The difference in STAI scores post-VR intervention

TABLE 1 Inclusion criteria for research participation.

• University students older than 18 years
• Not being pregnant (for female participants only)
• Comfortable using a VR headset and the scent of clary sage essential oil in the space
• Not having a prior history of motion sickness, nausea, vomiting, or epilepsy while using VR headsets
• Not experiencing symptoms such as motion sickness, nausea, dizziness, photosensitivity, eye strain, or headaches, or having a history of seizures or epilepsy
• Not having a history of respiratory diseases, such as asthma, and allergies to aroma essential oils
• Scored 14 or more of PSS test

showed a mean decrease of 10.50 (SD = 9.01), indicating reduced anxiety levels. The minimum and maximum changes in STAI scores were −29 and 5, respectively, with a median change of −9.5.

In the IME experiment, the initial STAI scores were within the range of 27–63 (M = 45, SD = 10.83). Following the IME intervention, the scores ranged from 23 to 43, with a mean of 30.61 (SD = 4.90). The mean decrease in STAI scores post-IME was 14.39 (SD = 9.06), suggesting a more pronounced reduction in anxiety compared to the VR intervention. The changes in STAI scores ranged from a decrease of 28 to an increase of 4, with a median change of −15. These findings suggest that both VR and IME interventions can lead to a decrease in anxiety levels, as measured by the STAI. However, the IME intervention appeared to be more effective in reducing anxiety, as evidenced by a greater mean decrease in STAI scores.

<Please add Table 3. STAI scores before and after the Experiments and their differences. The summary statistics of each column are provided at the bottom of table (N = 36).>

3.2 Inferential analysis

This research employed a paired t-test and a two-sample t-test to investigate whether the mean STAI score significantly decreased after the experiments. Figure 2 shows that the scores are approximately bell-shared for all six plots (Gravetter et al., 2021). Since the participants were randomly assigned to the two groups and they were independent, the assumptions were met, and we could conduct the t-tests.

<Please add Figure 3. Histogram of the STAI scores of participants before and after the experiment and the difference between the scores>

As shown in Table 4, the paired t-test results indicate a significant reduction in stress levels in both experiments. In the first experiment with VR, participants exhibited a significant reduction in stress levels from before (M = 39.94, SD = 14.94) to after (M = 29.44, SD = 9.83); $t(17) = -4.81$, $p = 0.0017$. Similarly, in the second experiment where participants experienced IME, there

TABLE 2 STAI scores before and after the Experiments and their differences.

Experiment 1:VR				Experiment 2:IME			
Subject	$STAI_{before}$	$STAI_{after}$	D_{VR}	Subject	$STAI_{before}$	$STAI_{after}$	D_{IME}
1	25	30	5	1	61	33	−28
2	23	20	−3	2	36	33	−3
3	37	32	−5	3	63	35	−28
4	38	25	−13	4	47	28	−19
5	76	62	−14	5	41	31	−10
6	38	22	−16	6	59	43	−16
7	29	26	−3	7	27	24	−3
8	58	29	−29	8	42	28	−14
9	22	20	−2	9	37	26	−11
10	37	29	−8	10	51	25	−26
11	56	27	−29	11	38	29	−9
12	61	42	−19	12	54	36	−18
13	27	22	−5	13	28	32	4
14	48	37	−11	14	54	35	−19
15	27	20	−7	15	51	33	−18
16	43	28	−15	16	48	23	−25
17	49	34	−15	17	44	31	−13
18	25	25	0	18	29	26	−3

TABLE 3 STAI scores before and after the Experiments and their differences. The summary statistics of each column are provided at the bottom of table (N = 36).

	Experiment 1:VR (n = 18)			Experiment 2: IME (n = 18)		
	$STAI_{before}$	$STAI_{after}$	D_{VR}	$STAI_{before}$	$STAI_{after}$	D_{IME}
Min	22	20	−29	27	23	−28
Max	76	62	5	63	43	4
Mean	39.94	29.44	−10.50	45	30.61	−14.39
SD	14.94	9.83	9.01	10.83	4.90	9.06
Median	37.5	27.5	−9.5	45.5	31	−15

$D_{VR} = STAI_{after} - STAI_{before}$ for VR scores; $D_{IME} = STAI_{after} - STAI_{before}$ for IME scores.

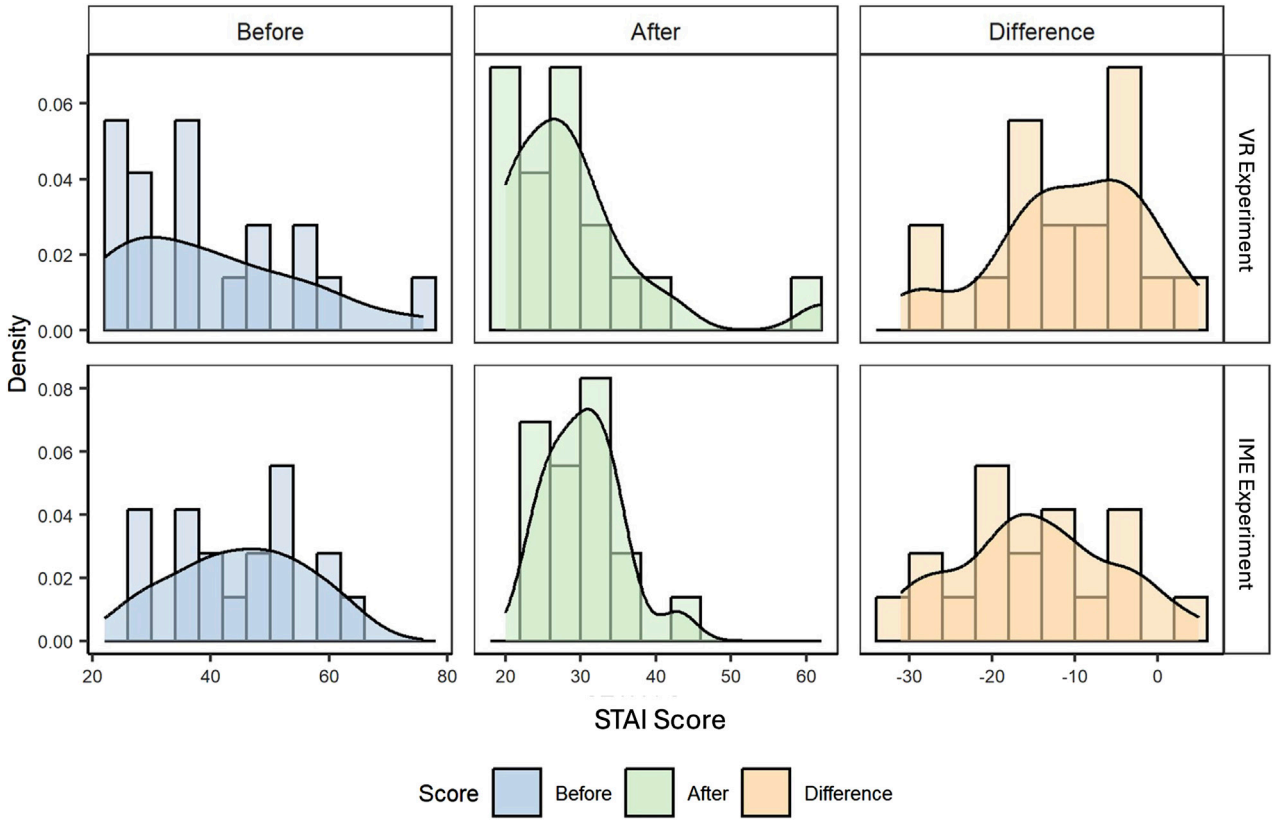

FIGURE 3
Histogram of the STAI scores of participants before and after the experiment and the difference between the scores.

was a significant reduction in stress levels from before (M = 45.00, SD = 10.83) to after (M = 30.61, SD = 4.90); $t(17) = -6.39$, $p < 0.0001$.

A two-sample t-test was employed to assess if there was a significant difference between the two experiments (Table 5). Results showed that there was no statistically significant difference between the two experiments (M_{VR} = −10.50, SD_{VR} = 9.01, M_{IME} = −14.39, SD_{IME} = 9.06); $t(34) = 1.30$, $p = 0.202$). Therefore, it can be stated that, based on this data and sample size, there is no significant difference in the level of relaxation experienced by participants in the IME compared to the VR.

<Please add Table 5. Two sample t-test results for the difference in mean STAI scores in two experiments (N = 36).>

4 Discussion

The analysis revealed significant reductions in anxiety levels in both conditions, indicating the potential effectiveness of these interventions in promoting relaxation and wellbeing. The results indicate that IME shows more reduction of anxiety levels between groups, but it did not show a significant difference between the two experiments. This study serves as a pilot and can guide future studies with larger participant populations for a more comprehensive analysis.

First, the VR experiment with only visual stimuli showed that the simple VR experience with nature significantly reduces

TABLE 4 Paired t-test result for STAI scores before and after experiments (N = 36).

	Mean difference	*SD*	Std. Error mean	*t*	*df*	*p*
D_{VR}	−10.50	9.01	2.18	−4.81	17	0.0017
D_{IME}	−14.39	9.06	2.28	−6.39	17	0.0000

TABLE 5 Two sample t-test results for the difference in mean STAI scores in two experiments (N = 36).

	Mean difference	Std. Error mean	*t*	*df*	*p*
D_{IME} - D_{VR}	−3.89	3.16	1.30	33.93	0.202

anxiety levels. This indicates that the VR experience was effective in promoting relaxation and reducing anxiety. The findings support previous research highlighting the positive impact of VR experiences on mental wellbeing (Premkumar et al., 2022). That is, utilizing VR technology to create visual stimulation allowed participants to focus their attention on the virtual environment, diverting their thoughts from anxious thoughts and worries, which induced a sense of calm and relaxation. This redirection of attention is a common therapeutic strategy used in anxiety management, as it helps individuals break free from negative thought patterns and shift their focus to more positive and calming stimuli. The IME experiment with audio-smell stimuli also enhanced the reduction of anxiety levels of participants with anxiety disorders. This indicates that integrating various sensory modalities enhanced the relaxation effect and contributed to a reduction in anxiety levels. These findings align with existing literature on the therapeutic benefits of multi-sensory interventions for anxiety management (Putrino et al., 2020). The multi-sensory design aimed to create a more holistic and immersive experience, capitalizing on the connection between sensory perception and emotional states. By engaging multiple senses, the intervention likely facilitated a deep sense of relaxation and increased emotional regulation, leading to the observed reductions in anxiety levels.

Second, exploring virtual reality (VR) applications for therapeutic purposes in stress reduction has gained considerable attention (De Jesus Junior, et al., 2023). However, limited research has delved into the distinct effects of various VR experiences. The IME design was more likely to reduce stress levels compared to only VR, but the statistical analysis did not reveal a significant difference between the two experiments. Both experiments indicated a noteworthy reduction in anxiety levels, indicating the effective implementation of principles derived from the Attention Restoration Theory and biophilic design. The Attention Restoration Theory suggests that exposure to natural surroundings or environments that mimic natural elements can aid in restoring attention, diminishing mental exhaustion, and alleviating stress (Kaplan, 1995). This approach helped participants shift their focus from stressors to calming stimuli. The simulated natural environments in VR can be considered an application of biophilic design, creating spaces where participants could feel an enhanced sense of connection with nature, contributing to their overall relaxation and reduction in anxiety levels. Our research findings offer practical evidence to support the attention restoration theory and the efficacy of biophilic design in managing anxiety by using VR experience. Especially, this finding underscores the feasibility of employing a multisensory, relaxing natural virtual reality application as a therapeutic modality for university students.

Notably, the college student demographic often grapples with elevated stress and anxiety levels throughout the academic year. The findings from our research suggest that a relaxing VR experience could offer a practical and accessible means for them to reduce stress levels easily. This insight highlights the potential significance of tailoring VR interventions to address the specific stressors faced by university students, thereby contributing to their overall wellbeing. Future research could further explore and refine the design of VR experiences to optimize stress reduction outcomes in this particular demographic.

4.1 Conclusion

This study demonstrated the efficacy of both Virtual Reality (VR) and Immersive Multi-sensory Environments (IME) in significantly reducing anxiety levels among individuals contending with anxiety disorders. These findings echo and fortify prior research, indicating that immersive experiences positively influence mental wellbeing. By offering a temporary respite from real-world stressors, redirecting attention, and promoting relaxation, these interventions prove to be valuable in the realm of anxiety management. The augmentation of these interventions with multi-sensory stimuli further amplifies their relaxation effect, resulting in notable reductions in anxiety levels.

While our study did not uncover a statistically significant difference between the VR and IME designs, both interventions exhibited promise as non-pharmacological approaches to anxiety management. This research makes a distinctive contribution to the growing body of studies emphasizing the pivotal role of sensory experiences within spatial contexts. The VR and IME employed in our experiments align with restorative environments described in attention restoration theory and biophilic design principles, effectively mitigating anxiety levels among individuals with anxiety disorders. These findings unveil a promising convergence between cutting-edge technological interventions, established psychological theories, and design principles centered around human-nature interaction, paving the way for future

interdisciplinary research. As innovative technologies continue to evolve, further exploration of these intersections holds the potential to refine and expand our understanding of anxiety management, enhancing the overall wellbeing of individuals facing mental health challenges.

4.2 Implications and applications

The outcomes of this study hold profound implications for advancing mental health support and anxiety management among university students. The demonstrated effectiveness of both Virtual Reality (VR) applications in reducing anxiety levels underscores their potential as valuable non-pharmacological interventions for individuals grappling with anxiety disorders. These interventions not only stand to complement conventional therapeutic approaches but also offer an accessible and cost-effective avenue for promoting relaxation and overall wellbeing.

The realm of higher education, encompassing spaces such as libraries, student centers, and community hubs, emerges as fertile ground for the application of immersive technologies. The versatility of immersive experiences allows for tailoring interventions to individual needs and preferences, paving the way for personalized anxiety management strategies. The incorporation of multi-sensory stimuli further enriches therapeutic possibilities, fostering a more nuanced and individualized approach to anxiety reduction.

Moreover, this study significantly contributes to the expanding body of literature concerning the therapeutic benefits of immersive technologies. The findings underscore the pivotal role of designing immersive experiences that engage multiple senses, fostering a profound sense of presence and absorption. As technology advances, future research endeavors can delve into innovative methods to enhance the immersive experience, thereby maximizing its therapeutic potential. This ongoing exploration promises to unlock novel avenues for leveraging technology in mental health interventions and enhancing the overall wellbeing of university students.

4.3 Limitations and future directions

Despite the valuable contributions made by this research, it is essential to acknowledge and address certain limitations. A significant constraint lies in the relatively small sample size employed in each experiment, consisting of 18 participants. While the results demonstrated noteworthy reductions in anxiety levels, the limited sample size raises concerns about the generalizability of the findings. Subsequent research endeavors should prioritize replicating this study with a larger and more diverse participant pool to bolster the external validity of the results.

Another noteworthy limitation pertains to the duration of the immersive sessions. In both experiments, the sessions lasted approximately 8 minutes. While this design facilitated a controlled experimental setting, it may not fully encapsulate the potential long-term effects of immersive interventions on anxiety levels. Future investigations could extend the duration of immersive experiences to explore sustained impacts and assess the persistence of anxiety reduction over an extended timeframe. Also, this research has a limitation due to the absence of a control group. Participants might naturally feel more anxious at the beginning of the experiment compared to right after it. Including a control group would help determine if the observed reduction in anxiety is solely due to the VR or IME intervention, or if it could be attributed to participants' decreasing nervousness over time as they become more familiar with the experimental procedure.

One significant limitation of this research is the demographic imbalance among participants, with a predominant representation of female subjects. This gender imbalance may skew the results, making it difficult to determine if the observed effects of VR and Immersive Multi-sensory Environments (IMEs) on anxiety reduction are equally applicable to males or individuals of other genders. Future studies should aim for a more balanced sample to ensure findings are representative of the general population. Additionally, this research lacks detailed age distribution information, as only college students aged 18 and above were included. This lack of age granularity means the study does not account for potential variations in anxiety experiences and responses to VR therapy across different age groups. Future research should include more detailed age distribution analysis to enhance the validity and applicability of the results.

Furthermore, the reliance on self-reported measures of anxiety levels introduces a potential source of bias, as interpretations may vary among individuals. To enhance the robustness of findings, future research should consider incorporating objective measures, such as physiological indicators of stress (e.g., heart rate variability, skin conductance). This multi-method approach would provide a more comprehensive and objective assessment of anxiety reduction, mitigating potential biases associated with self-reported data.

In conclusion, while this study offers valuable insights into the potential benefits of IME in reducing anxiety among university students, addressing these limitations in future research endeavors is crucial. A larger and more diverse participant sample, extended intervention durations, and a multi-method approach to data collection would contribute to a more nuanced understanding of the long-term and objective effects of immersive interventions on mental health.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Iowa State University Office of Research Ethics. 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. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for

the publication of any potentially identifiable images or data included in this article.

Author contributions

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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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