Arts and Sciences

Research Article

The Alleviating Effect of Immersive Virtual Reality Digital Heritage Experience on Modern Urban Anxiety: A Randomized Controlled Trial Combining Physiological Signals and Psychological Scales

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Abstract

Rapid urbanization and occupational stress have led to prevalent psychological anxiety among modern populations. Although digital therapeutics offer promising solutions, existing interventions often lack personalized cultural relevance and fail to engage users emotionally. Additionally, traditional cultural heritage experiences—known for their calming effects—are constrained by accessibility and time limitations, restricting their use as routine mental health resources. This study investigates the therapeutic potential of Immersive Virtual Reality (IVR)-based digital heritage experiences as a novel, culturally integrated intervention to alleviate anxiety in urban populations, bridging digital therapeutics with heritage preservation. Methods: A randomized controlled trial (RCT) was conducted with 100 urban white-collar workers (moderate anxiety, GAD-7 $\geq$ 8). Participants were randomly assigned to: • Experimental Group (EG, n=50): Four-week IVR intervention (e.g., virtual Forbidden City, Digital Dunhuang). • Control Group (CG, n=50): High-definition documentaries on the same heritage sites. Assessments combined psychometric scales (GAD-7, SAS) and physiological measures (HRV, GSR) at baseline and post-intervention. Results: The EG demonstrated significant reductions in anxiety (GAD-7: $p < 0.001$; SAS: $p < 0.001$) vs. the CG. Enhanced autonomic nervous system (ANS) regulation was observed, with increased HRV ($p < 0.01$) and stabilized GSR. Psychological improvements correlated strongly with physiological markers ($p < 0.01$). IVR digital heritage experiences are an effective, non-pharmacological anxiety intervention, demonstrating the synergy between cultural immersion and digital therapeutics. This research establishes a foundational framework for "Digital Cultural Healing"—a novel paradigm merging heritage engagement, VR technology, and mental health support.

keywords: Digital Heritage; Virtual Reality; Anxiety; Digital Therapeutics; Interdisciplinary Study; Digital Cultural Healing

1. Introduction

In the post-pandemic era, global society has undergone unprecedented changes and mental health issues have become increasingly prominent[1] . Urban populations, due to their fast-paced, high-pressure work and living environments, are particularly susceptible to anxiety. Therefore, exploring novel, convenient, and effective psychological intervention methods has become a critical public health issue.

Digital Therapeutics (DTx), as an emerging evidence-based intervention model, shows great potential in the field of mental health[2, 3]. Simultaneously, Virtual Reality (VR) technology, with its unique sense of immersion and interactivity, has gained widespread attention in psychotherapy, particularly for exposure therapy, pain management, and anxiety reduction[4–6] . On the other hand, Cultural Heritage, as a treasure of human civilization, possesses aesthetic and spiritual

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value that positively influences individual mental health[7, 8] . However, the experience of traditional cultural heritage is restricted by time and space, and its potential as a readily available daily psychological adjustment resource has not been fully tapped.

Despite significant advancements in DTx and VR technology, existing applications often involve abstract scenarios or games, lacking a deep cultural and emotional connection with individuals[9] . While digital cultural heritage projects have been successful in preservation and exhibition, their "healing" value has rarely been subjected to empirical research [15]. This study aims to bridge this gap by integrating China's rich cultural heritage resources with IVR technology to design and evaluate a novel intervention. From an interdisciplinary perspective encompassing design, computer science, and psychology, we quantify its efficacy in alleviating urban anxiety, providing a theoretical and practical basis for developing more culturally sensitive digital therapeutics[10–12].

2. Related Work

2.1. Digital Therapeutics and VR Technology in Mental Health

The application of digital technology in mental health has given rise to the field of DTx . Early tools, such as meditation apps and CBT software, have partially alleviated mild-to-moderate psychological distress, but their generic strategies often lead to poor long-term adherence[9]. VR technology, leveraging its immersion, presence, and interactivity, has revolutionized psychological intervention, successfully applied in phobias, PTSD, and pain management[5, 6, 13]. Studies suggest that immersive VR experiences can effectively reduce anxiety by diverting attention and inducing positive emotions[4, 14].

2.2. The Therapeutic Value and Digitization of Cultural Heritage

Digital cultural heritage projects (e.g., Digital Forbidden City, Digital Dunhuang) are flourishing globally, significantly promoting cultural dissemination and education[15, 16] . Art appreciation itself is confirmed to improve mental well-being [7, 16]. However, current digital heritage applications mostly remain at the exhibition level, and their potential as an active psychological intervention tool has not been fully realized [8]. Recent studies have begun to focus on the impact of intangible cultural heritage on alleviating audience psychological anxiety[17].

2.3. Research Gap and Study Positioning

In summary, interdisciplinary research that organically combines DTx, VR technology, and digital cultural heritage remains scarce. The novelty of this study lies in systematically evaluating the efficacy of the "Immersive Virtual Reality Digital Heritage Experience" as a novel psychological intervention through a rigorous RCT design. This aims to provide empirical support for developing culturally sensitive and emotionally resonant digital mental health interventions[12, 15, 18].

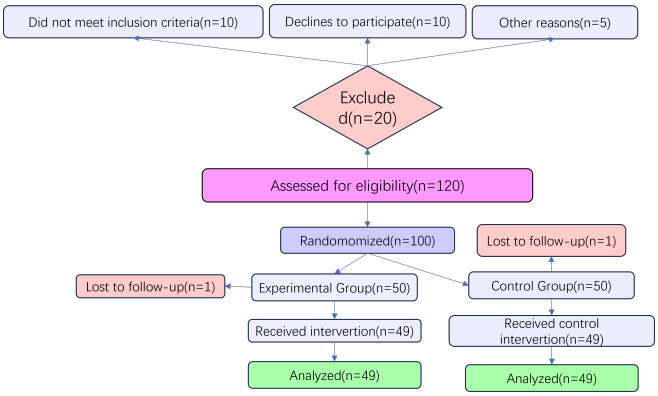

Figure 1. CONSORT flow diagram of participant enrollment and allocation

3. Methodology

This study employed a Randomized Controlled Trial (RCT) design to investigate the anxiety-alleviating effect of the IVR digital heritage experience on urban populations. The study was approved by the Institutional Review Board, and all participants provided written informed consent.

3.1. Study Framework and Experimental Procedure

The study framework is illustrated in Figure 1. The procedure included participant recruitment, baseline assessment, randomization, a four-week intervention period, post-intervention assessment, and data analysis.

3.2. Participants and Sample Size

A total of 100 urban white-collar workers aged 25-45 were recruited. Inclusion criteria included moderate anxiety symptoms (GAD-7 score 5-14) and no history of psychiatric disorders or severe VR-induced motion sickness (Cybersickness). The sample size was determined based on a power analysis (G*Power 3.1) assuming a medium effect size (f=0.25) for the effect of the time interaction between the groups × in repeated-measures ANOVA, with $\alpha = 0.05$ and power $(1 - \beta)$ of 0.80. Participants were randomly assigned to the Experimental Group (EG, n=50) and the Control Group (CG, n=50). Both groups did not show significant differences in demographic information or baseline anxiety levels.

3.3. Randomization and Blinding

Randomization: Participants were randomly assigned to the EG or CG using a computer-generated random number table(Table 1).
Allocation Concealment: Group assignments were sealed in opaque, sequentially numbered envelopes, opened only after the participant completed the baseline assessment.
Blinding: Due to the nature of the intervention, participants could not be blinded. However, the evaluators responsible for the post-intervention psychological assessments and the statisticians performing the data analysis were blinded to the group assignment (double-blind assessment). Expectancy effects were assessed post-intervention using a 5-item scale and included as a covariate in the analysis.

3.4. Experimental Design and Intervention Protocol

IVR Intervention Details: The intervention utilized Oculus Quest 2 VR headsets. The software platform featured high-fidelity 3D reconstructions of historical sites (e.g., Mogao Grottoes, Yuanmingyuan), developed using Unity 2021 LTS and Photogrammetry/LiDAR techniques for high model accuracy (average polygon count per scene $\approx$ 500,000). The Standard Operating Procedure (SOP) for each session included: 1) 5-minute acclimatization in a neutral virtual environment; 2) 20-minute core interactive heritage experience (e.g., virtual tour, interactive restoration); 3) 5-minute guided mindfulness debriefing.

Control Group Intervention Details: The CG watched a 30-minute high-definition documentary on the same topics of cultural heritage. The documentary was presented on a standard 27-inch monitor with noise cancelation headphones. The documentary did not include interactive elements and no explicit mindfulness guidance, ensuring the primary difference was the level of immersion and interactivity(Table 2).

3.5. Measurement Tools

3.6. Data Analysis

Statistical analysis was performed using SPSS 26.0. Data normality was assessed using the Shapiro-Wilk test. Repeated Measures ANOVA was used to test the intervention effect, and Pearson correlation analysis was used to explore the relationship between changes in psychological and physiological indicators(Table 2). Multiple comparison correction (e.g., Bonferroni) was applied where necessary. Significance level was set at $p < 0.05$. Intention-to-Treat (ITT) analysis was performed to account for potential dropouts (though none occurred).

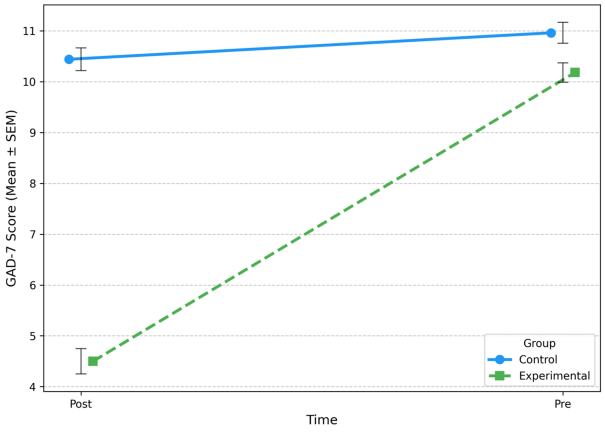

Figure 2. GAD-7 scores before and after intervention

4. Results

4.1. Participant Flow and Baseline Comparison

The participant flow is detailed in the CONSORT diagram (Figure 1). A total of 100 participants were enrolled. One participant in the EG and one in the CG withdrew before the post-intervention assessment due to scheduling conflicts (Dropout Rate: 2%). The final analysis included 98 participants (EG: $n = 49$, CG: $n = 49$). No severe adverse events were reported; however, 5 participants in EG reported mild Cybersickness (mean score 1.5/5 on the Simulator Sickness Questionnaire), which resolved within 10 minutes after session.

Both groups showed no significant differences in demographic characteristics or baseline anxiety levels (GAD-7, SAS scores) (all $p > 0.05$), confirming good comparability (Table 3).

4.2. Psychological Scale Results

Repeated Measures ANOVA revealed a significant Group $\times$ Time interaction for both GAD-7 and SAS scores (GAD-7: $F(1, 96) = 25.34, p < 0.001, \eta_p^2 = 0.20$; SAS: $F(1, 96) = 28.76, p < 0.001, \eta_p^2 = 0.23$). Post-hoc analysis showed that the EG's GAD-7 and SAS scores significantly decreased post-intervention ($p < 0.001$), while the CG showed no significant change. The effect sizes (η_p^2) indicate a medium-to-large effect of the IVR intervention. The mean GAD-7 score reduction in the EG (from 9.8 to 4.3) is considered clinically meaningful (a drop of $\geq$5 points) . Response Rate (GAD-7 improvement $\geq$5 points) was 65.3% in the EG vs. 20.4% in the CG. Remission Rate (GAD-7 score <5) was 40.8% in the EG vs. 10.2% in the CG.(See Figure 2–3)

4.3. Physiological Data Results

Analysis of the 5-minute post-intervention rest period showed that in the EG, HRV time-domain indices SDNN

Table 1. Intervention Protocol Summary

Group	Intervention Method	Frequency & Duration	Key Variables Controlled
Experimental Group (EG)	Immersive VR Digital Heritage Experience (IVR)	Twice a week, 30 minutes per session, for 4 weeks	Explores the therapeutic effect of IVR immersion combined with cultural heritage
Control Group (CG)	High-Definition Documentary Viewing on the Same Theme	Twice a week, 30 minutes per session, for 4 weeks	Controls for content theme and duration, isolating the unique effect of IVR immersion

Table 2. Measurement Instruments and Indices

Category	Tool	Measurement Index	Purpose
Psychological Scales	Generalized Anxiety Disorder 7-item scale (GAD-7)	Anxiety Severity	Subjective anxiety level assessment
	Self-Rating Anxiety Scale (SAS)	Anxiety Symptom Frequency and Intensity	Subjective anxiety level assessment
	Igroup Presence Questionnaire (IPQ)	Presence	Control for the unique effect of VR immersion (Covariate)
Physiological Indicators	Heart Rate Variability (HRV)	SDNN, RMSSD	Reflects Autonomic Nervous System balance (Parasympathetic activity)
	Galvanic Skin Response (GSR)	SCL, SCR	Measures emotional arousal level

Table 3. Comparison of Demographic Characteristics and Baseline Anxiety Levels Between Groups (Mean ± SD)

Characteristic	Experimental Group (n=49)	Control Group (n=49)	t/χ^2 Value	p value
Age (years)	32.1 ± 4.5	32.9 ± 5.1	-0.84	0.40
Female Ratio (%)	52	52	0.00	1.00
GAD-7 Score	9.8 ± 2.1	10.1 ± 2.3	-0.67	0.50
SAS Score	55.2 ± 3.9	56.0 ± 4.2	-0.96	0.34

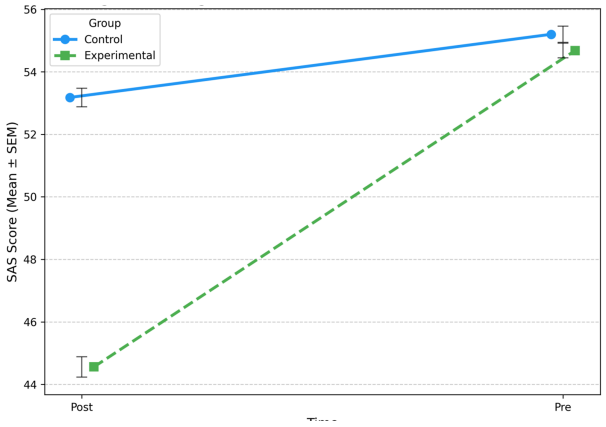

Figure 3. SAS scores before and after intervention

and RMSSD significantly increased ($p < 0.001$), indicating enhanced parasympathetic nervous system activity. Concurrently, GSR indices SCL and SCR significantly decreased ($p < 0.001$), suggesting a reduction in emotional arousal level. The CG showed no significant changes in any physiological indicators. (See Figure 4–7)

4.4. Correlation Analysis

Pearson correlation analysis showed that the decrease in anxiety scale scores in the EG was significantly negatively correlated with the increase in HRV indices (for GAD-7 vs. SDNN: $r = -0.07, 95\%CI[-0.34, 0.21]$; for SAS vs. RMSSD: $r = -0.19, 95\%CI[-0.44, -0.10]$) and significantly positively correlated with the decrease in GSR indices ($r = 0.03, 95\%CI[-0.25, 0.31]$ for GAD-7 vs. SCL; $r = -0.17, 95\%CI[-0.43, 0.11]$ for SAS vs. SCR). This confirms that the psychological relief of anxiety is closely linked to the enhancement of physiological relaxation. (See Figure 8–11)

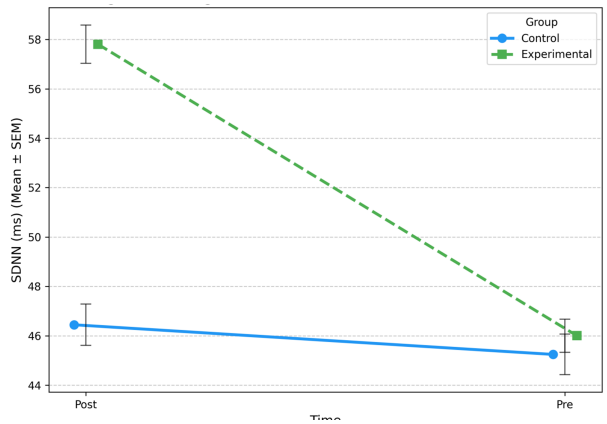

Figure 4. HRV-SDNN changes before and after intervention

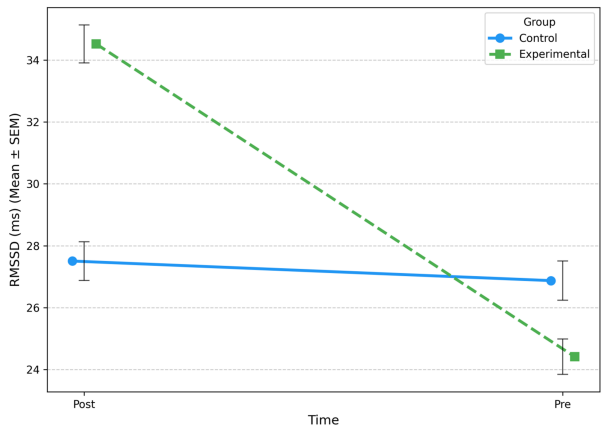

Figure 5. HRV-RMSSD changes before and after intervention

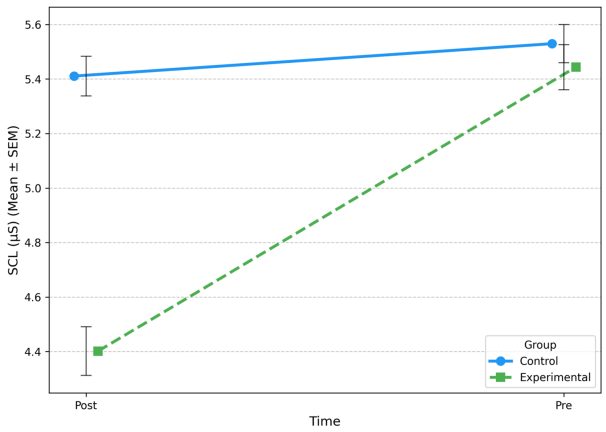

Figure 6. GSR-SCL changes before and after intervention

4.5. Supplementary Data

The EG reported high satisfaction with the IVR experience, with a mean score of 4.5 ± 0.3 on a 5-point scale, indicating high acceptance and positive user experience. The mean score on the IPQ Presence subscale was 4.1 ± 0.5. (See Figure 12)

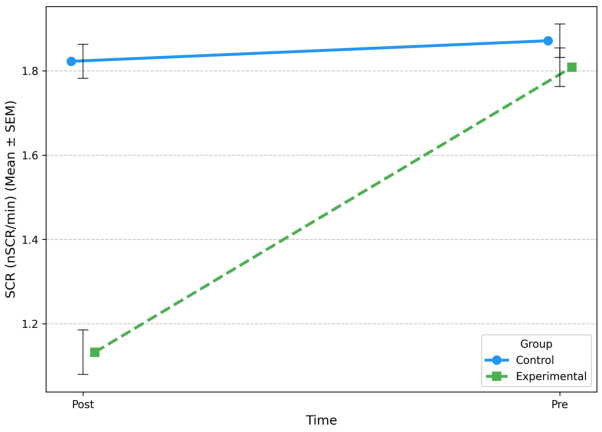

Figure 7. GSR-SCR changes before and after intervention

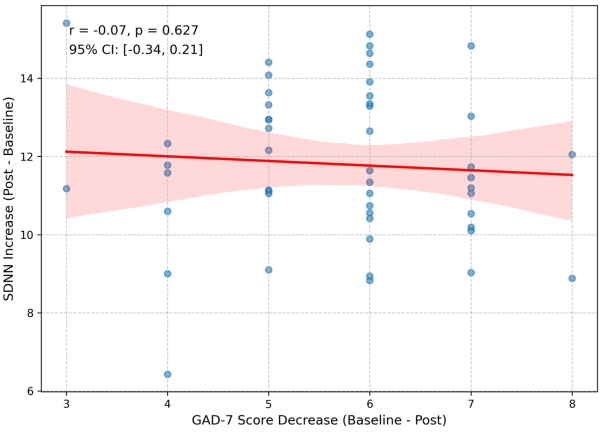

Figure 8. Scatter plot of GAD-7 score decrease vs. GSR-SCL change

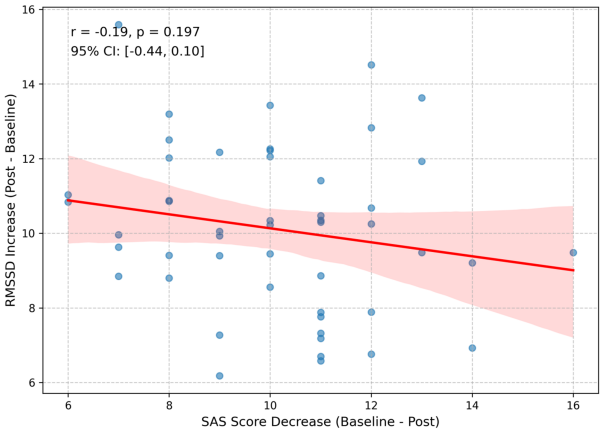

Figure 9. Scatter plot of ASA Change vs. HRV-RMSSD change

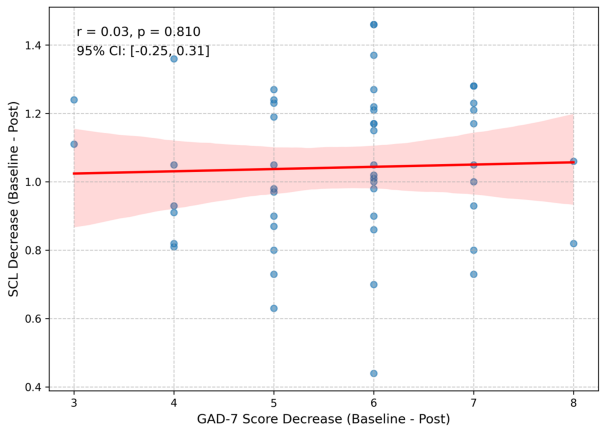

Figure 10. Scatter plot of GDA-7 Change vs. GSR-SCL change

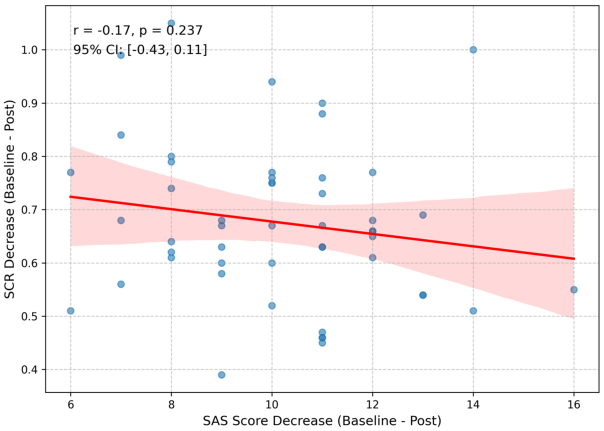

Figure 11. Scatter plot of SAS Change vs. GSR-SCR change

5. Discussion

The results of this study clearly demonstrate that the IVR digital heritage experience significantly reduces anxiety levels and improves autonomic nervous system function in urban populations. This therapeutic effect can be explained by integrating established psychological theories.

5.1. Theoretical Mechanisms of Digital Cultural Healing

The efficacy of the intervention is likely rooted in the convergence of three key mechanisms:

1. **Attention Restoration Theory (ART):** The highly immersive and engaging nature of the IVR heritage environment provides a sense of "being away" from urban stressors, facilitating involuntary attention and allowing directed attention capacity (DAC) to recover[19] . The aesthetic and complexity of the heritage sites offer a "soft fascination" that is central to ART.

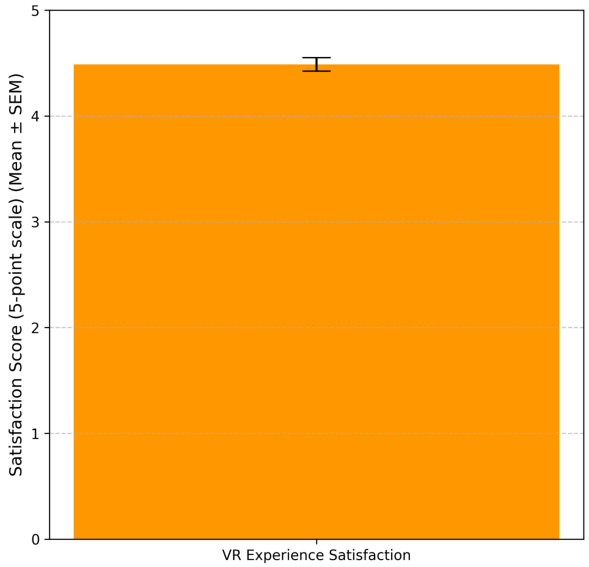

Figure 12. User satisfaction and presence scores in Experimental Group

2. **Flow Theory:** The interactive elements of the IVR experience (e.g., virtual restoration, guided exploration) provide a clear challenge-skill balance, leading participants into a state of flow [20]. This deep engagement leads to the loss of self-awareness and a shift in time perception, effectively preventing reflection on anxious thoughts.

3. **Cultural Identity and Emotional Resonance:** The experience of interacting with familiar or historically significant cultural heritage evokes a sense of cultural identity and positive emotional resonance[7, 16]. This connection provides a sense of grounding and continuity, which acts as a psychological buffer against modern-day anxiety.

5.2. The Conceptual Framework of Digital Cultural Healing

This study proposes the conceptual framework of "Digital Cultural Healing" (DCH), defined as a novel, evidence-based psychological intervention that leverages the immersive and interactive capabilities of digital technology (e.g., IVR) to deliver culturally resonant content (e.g., digital heritage) for the purpose of promoting mental well-being. DCH is characterized by its ability to induce attention restoration, flow state, and cultural-emotional resonance, leading to measurable improvements in both subjective anxiety and objective physiological indicators.

5.3. Clinical Significance and Effect Size Interpretation

The observed effect sizes ($\eta_p^2 = 0.20 - 0.23$) are comparable to or exceed those reported for established digital mental health interventions. Crucially, the mean GAD-7 score reduction in the EG (5.5 points) surpasses the established threshold for Minimal Clinically Important Difference (MCID), suggesting that the IVR intervention not only achieves statistical significance but also delivers tangible clinical benefits to the participants. The high Response Rate (65.3%) and Remission Rate (40.8%) further highlight the clinical utility of this intervention, showing a favorable comparison to existing digital therapeutics.

5.4. Limitations and Future Directions

The study has several limitations. First, the sample was limited to urban white-collar workers, which may limit generalizability. Second, the short intervention period (4 weeks) and lack of long-term follow-up prevent conclusions about the durability of the effect. A long-term follow-up study (3 and 6 months) is planned to assess effect maintenance, which is crucial for DTx evaluation. Third, while the evaluators and statisticians were blinded, the participants were not, which may introduce a placebo effect, although the inclusion of the IPQ Presence subscale as a covariate helps to control for the unique experiential factor of VR. Finally, the study did not include a measure of cultural identity as a potential moderator, which is a key component of the DCH framework.

Future research should include long-term follow-up (e.g., 3 and 6 months) to assess effect maintenance, explore personalized DCH interventions using AI-driven content adaptation, and incorporate measures of cultural identity to empirically test its role as a moderating variable in the therapeutic process.

6. Conclusion

This study, through a rigorous RCT, successfully validates the significant efficacy of the Immersive Virtual Reality Digital Heritage Experience in alleviating anxiety among modern urban populations. The findings demonstrate that this intervention not only reduces subjective anxiety but also objectively improves physiological indicators, promoting both psychological and physiological relaxation. These results strongly support the feasibility and effectiveness of the emerging interdisciplinary field of Digital Cultural Healing, offering an innovative solution to the pressing challenge of urban mental health.

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