Design Strategies of Immersive Audio-Visual Experience in Digital Therapeutics for Anxiety Intervention

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Abstract: Anxiety is one of the most common psychological disorders, and traditional interventions often face challenges in accessibility and adherence. With the rise of Digital Therapeutics (DTx), immersive audio-visual experience has shown unique potential in anxiety alleviation. This study proposes design strategies grounded in Self-Determination Theory and the Entrainment Principle, including task-state feedback, customized avatars, and EEG-based adaptive music. A randomized controlled trial was conducted with college students, combining questionnaires (GAD-7, STAI, PANAS), physiological measures (EEG, HRV, EDA), and subjective scales (IEQ) to evaluate intervention effects. Results demonstrate that immersive audio-visual interventions significantly reduced anxiety, enhanced positive emotions, and improved physiological indicators compared to controls, with immersion partially mediating the therapeutic pathway. These findings highlight the effectiveness of immersive audio-visual design strategies in digital therapeutics and provide interdisciplinary insights for advancing mental health interventions.

Keywords: Anxiety Intervention; Digital Therapeutics; Immersive Audio-Visual Experience; Design Strategies; Mediating Mechanism

1. Introduction

Anxiety is a major mental-health challenge, and conventional treatments such as CBT and pharmacotherapy remain limited by cost, accessibility, and adherence issues [1–3]. Digital therapeutics (DTx) offers scalable, personalized interventions by integrating mobile delivery, biofeedback, and VR [4,5]. Evidence shows clinically meaningful reductions in anxiety but highlights engagement and design challenges [6,7]. Immersive audio-visual strategies are well positioned to address these challenges through cognitive reappraisal [8], emotional regulation via presence [9], and auditory modulation through music interventions [10,11]. Behavioral design elements, such as gamified or performance-based feedback, further enhance engagement [12]. Guided by these insights, this study proposes and tests a DTx framework integrating task feedback, customized avatars, and EEG-informed adaptive music, examining immersion as a mediator of anxiety reduction

2. From Efficacy Evidence to Design Frameworks

2.1 Digital Therapeutics for Anxiety

Digital therapeutics (DTx) has shown consistent efficacy in reducing anxiety symptoms across

diverse populations. Internet-based CBT provides structured cognitive and behavioral strategies remotely, mobile health applications enable daily self-monitoring and ecological momentary interventions, and VR-assisted programs offer controlled exposure to anxiety-inducing stimuli in safe environments. Systematic reviews and meta-analyses confirm their clinical benefits, with effect sizes comparable to traditional face-to-face interventions. At the same time, challenges persist: dropout rates remain high, user adherence often declines over time, and many interventions lack tailored design features that sustain engagement and personalization. These issues underscore the need to move beyond demonstrating efficacy toward developing theory-driven and user-centered frameworks for DTx.

2.2 Immersive Audio-Visual Interventions

Immersion plays a key therapeutic role. Presence in virtual environments redirects attention and supports emotion regulation. Audio-visual strategies—such as VR nature exposure and music-based interventions—consistently lower stress and improve affect. Standardized affective sound databases further enhance reliability and precision in auditory design.

2.3 Design Theories and Research Gap

Self-determination theory (SDT) emphasizes autonomy, competence, and relatedness in sustaining engagement, while the entrainment principle explains how adaptive music aligns rhythms with internal states to regulate emotion. Gamified feedback also enhances adherence. Yet, few frameworks systematically combine task feedback, customized avatars, and adaptive music, and the mediating role of immersion remains underexplored. This study addresses these gaps by testing an immersive design model for anxiety-focused DTx.

3. RCT of Immersive Audio-Visual Strategies for Anxiety Intervention

A randomized controlled trial (RCT) was conducted with 60 students (aged 18–35) with mild-to-moderate anxiety (GAD-7 = 5–14). Participants were randomly assigned to an experimental group (n = 30) or control group (n = 30). Exclusion criteria included severe psychiatric disorders, neurological conditions, or uncorrected sensory deficits (Table 1).

The experimental group received a multimodal intervention: (1) task feedback, (2) customized avatars, and (3) EEG-informed adaptive music. The control group viewed neutral video with fixed background music. Each session lasted 20–30 minutes via head-mounted display and headphones.

Measures included GAD-7, STAI, PANAS, EEG frontal asymmetry, HRV, EDA, the Immersive. Experience Questionnaire (IEQ), and the Basic Psychological Need Satisfaction Scale (BPNS). Assessments occurred at baseline, post-test, and one-week follow-up. Repeated measures ANOVA tested group × time effects; SEM examined immersion as a mediator.

Table 1: RCT Experimental Design Comparison.

Group	Intervention Content	Duration	Sample Size
1. Experimental Group (Immersive DTx)	Task feedback + Customized avatar + EEG-driven adaptive music (immersive multimodal)	20–30 minutes/session	n = 30
2. Control Group (Conventional AV)	Standard video + Fixed background music (no personalization, no interactivity)	20–30 minutes/session	n = 30

4. Enhanced Anxiety Reduction and Emotional Regulation

Repeated measures ANOVA showed significant group × time interactions for GAD-7 and STAI-State scores ($p < 0.001$). As presented in Table 2, the experimental group's GAD-7 scores decreased from 11.2 (±2.5) to 6.3 (±2.1), while the control group only declined from 10.9 (±2.7) to 9.5 (±2.6). Similarly, STAI-State scores dropped from 48.6 (±6.1) to 36.2 (±5.5) in the experimental group, compared to 47.9 (±6.4) to 44.1 (±6.0) in the control group. Figure 1 illustrates these sharper reductions, confirming the stronger effects of the immersive intervention.

Table 2: Results of Key Psychological Indicators Before and After Intervention.

Measure	Experimental Group (n = 30) Pre-test	Experimental Group (n = 30) Post-test	Control Group (n = 30) Pre-test	Control Group (n = 30) Post-test
GAD-7	11.2 ± 2.5	6.3 ± 2.1	10.9 ± 2.7	9.5 ± 2.6
STAI-State	48.6 ± 6.1	36.2 ± 5.5	47.9 ± 6.4	44.1 ± 6.0
STAI-Trait	46.8 ± 5.9	34.9 ± 6.0	45.7 ± 6.2	42.7 ± 6.1
PANAS-Positive	20.4 ± 5.2	28.7 ± 4.8	21.1 ± 5.5	22.5 ± 5.0
PANAS-Negative	27.5 ± 6.0	19.1 ± 5.2	26.8 ± 6.3	25.2 ± 6.1

In terms of affect, the experimental group reported higher positive affect and lower negative affect ($p < 0.01$), whereas the control group showed no significant changes. Physiological measures reinforced these findings: the experimental group demonstrated greater positive shifts in frontal EEG asymmetry, increased HRV ($p < 0.01$), and reduced EDA ($p < 0.01$), indicating enhanced affective regulation and reduced physiological arousal.

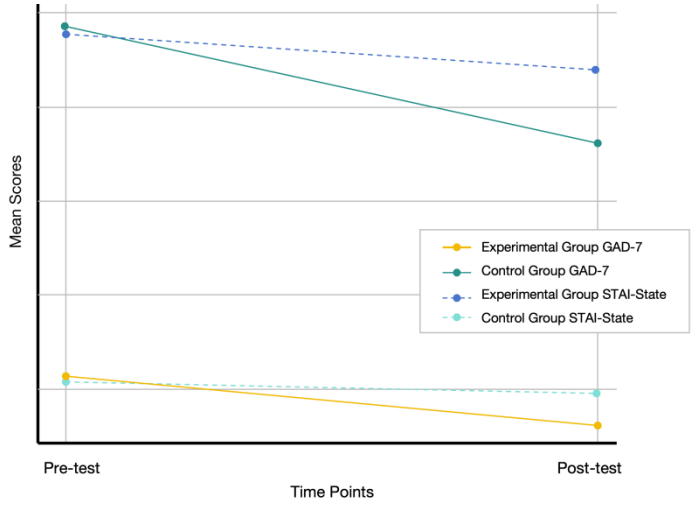

Figure 1: Trends in GAD-7 and STAI-State Scores for Experimental and Control Groups.

Subjective experience results highlighted the mediating role of immersion. The experimental group reported significantly higher IEQ scores than the control group ($p < 0.001$), indicating stronger immersion and presence. Additionally, autonomy, competence, and relatedness scores from the BPNS were significantly higher in the experimental group, suggesting that the intervention successfully addressed basic psychological needs. SEM analysis further revealed that immersion partially

mediated the relationship between design strategies and anxiety reduction, with significant indirect effects ($p < 0.01$). The model showed good fit indices ($x^2/df = 1.95$, RMSEA = 0.045, CFI = 0.96, TLI = 0.95), supporting the hypothesized mechanism of design→immersion→anxiety alleviation.

5. Immersion as the Mechanism of Therapeutic Impact

This study confirmed the efficacy of immersive audio-visual design in digital therapeutics for anxiety intervention. Participants exposed to task-state feedback, customized avatars, and EEG-informed adaptive music showed significant improvements in anxiety, affect, and physiological regulation, whereas the control group exhibited only minor changes. These findings demonstrate the added value of multimodal design strategies in enhancing therapeutic efficacy and overcoming challenges of adherence and engagement.

Theoretically, the study extends understanding of how digital therapeutic design promotes anxiety reduction. Consistent with self-determination theory, task feedback and personalized imagery enhanced autonomy, competence, and relatedness, strengthening motivation and sustained participation. Adaptive music, guided by the entrainment principle, synchronized external rhythm with internal states to improve emotional regulation, reinforcing prior evidence on music-based interventions. Importantly, SEM analysis highlighted immersion as a mediating mechanism, bridging design strategies and therapeutic outcomes, and providing empirical support for the pathway design→immersion→anxiety alleviation.

Practically, these results provide actionable guidance for digital therapeutic design. Real-time feedback and personalized avatars enhance engagement and self-relevance, while adaptive music enables dynamic regulation of physiological and affective states. Together, these strategies inform the development of scalable, user-centered tools for clinical, educational, and public health applications.

Nonetheless, limitations must be noted: the restricted student sample limits generalizability, the short intervention duration constrains long-term evaluation, and EEG-based personalization, while promising, remains technically demanding. Future work should broaden participant diversity, extend intervention periods, and explore multisensory immersion (e.g., haptic and olfactory cues) to strengthen ecological validity.

6. Conclusion

This study demonstrated through a randomized controlled trial that immersive audio-visual strategies—combining task feedback, personalized avatars, and EEG-informed adaptive music—significantly improved anxiety reduction, emotional regulation, and physiological balance compared to a conventional control condition. Structural equation modeling further confirmed immersion as a mediating mechanism, providing empirical support for the pathway design → immersion → anxiety alleviation. The findings contribute to theory by extending self-determination theory and the entrainment principle into digital therapeutics, and to practice by offering design guidelines for scalable and user-centered interventions. Although limited by sample scope, short intervention duration, and the technical accessibility of EEG-based personalization, this research highlights immersive audio-visual design as a promising paradigm for next-generation digital therapeutics. Future studies should broaden participant diversity, adopt longitudinal approaches, and integrate multisensory modalities to enhance ecological validity.

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