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Research Article

Application of virtual reality interventions combined with artificial intelligence in the treatment and monitoring of anxiety disorders and chronic pain

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Abstract

The present study aimed to investigate the effectiveness of virtual reality interventions combined with artificial intelligence algorithms in the treatment and monitoring of anxiety disorders and chronic pain. The research method was a mixed type and quasi-experimental design with two experimental and control groups. Data collection tools included the Generalized Anxiety Disorder Scale (GAD-7), Brief Pain Index (BPI), and physiological indicators such as heart rate, skin conductance, and brain activity in the virtual reality environment. The virtual reality intervention was designed in an intelligent and adaptive manner; in such a way that visual and auditory stimuli were adjusted based on the participants' biofeedback by the artificial intelligence algorithm. The results of statistical analyses using MANCOVA and ANCOVA tests showed that these interventions caused a significant reduction in the level of anxiety and pain intensity of the participants in the experimental group compared to the control group. In addition, the correlation analysis between physiological indicators and anxiety reduction indicated the formation of automatic regulation of the nervous system. At the three-month follow-up, the stability of the therapeutic effect of the interventions was observed without a significant return of symptoms. These findings suggest that the combination of virtual reality and artificial intelligence can be an innovative, flexible, and feedback-based solution for digital therapies and telecare in the field of psychophysiology.

Keywords: *virtual reality, artificial intelligence, anxiety, chronic pain, physiological regulation, digital therapy.*

1. Introduction

Virtual reality (VR) has emerged as a transformative technology in healthcare, offering immersive environments that can modulate sensory perception and emotional responses. The intersection of VR and artificial intelligence (AI) provides unprecedented potential for adaptive, personalized therapeutic experiences, especially in managing anxiety disorders and chronic pain (Spiegel et al., 2024).

Anxiety disorders and chronic pain remain among the most prevalent and costly health conditions globally, with significant overlap in their neuropsychological mechanisms and symptom burden. Traditional treatments—such as pharmacotherapy and cognitive behavioral therapy (CBT)—often fall short due to variations in patient adherence and subjective pain perception (Wu et al., 2021).

VR-based therapy has demonstrated success in inducing attentional distraction, reducing catastrophizing thoughts, and promoting relaxation through multisensory stimulation. When integrated with AI-based analytics, these interventions can dynamically adjust intensity, content, and feedback according to patients' physiological or behavioral responses (Goudman et al., 2022).

AI's capacity to learn from large datasets enables real-time personalization of VR sessions, identifying patterns of emotional distress and modifying virtual scenarios accordingly. Such intelligent adaptation enhances engagement and therapeutic precision, bridging the gap between generalized and individualized psychological care (Piette et al., 2022).

Recent advancements in spatial computing and interactive simulations further support the integration of VR and AI for mental health monitoring. Machine learning algorithms embedded in VR systems can interpret biometrics—such as heart rate variability or facial expressions—to optimize exposure therapy and relaxation exercises (Spiegel et al., 2024).

In chronic pain management, VR has evolved from a distraction-based modality to an active behavioral intervention. AI accelerates this transformation by analyzing response trajectories and predicting long-term pain modulation outcomes, making self-administered and home-based treatment feasible (Darnall et al., 2020).

Studies have shown that combining VR with AI can help quantify pain more objectively through emotion and movement analysis. Scoping reviews highlight its application in improving assessment models and automated symptom tracking, reducing reliance on subjective scales (Zhang et al., 2023).

For chronic musculoskeletal pain, interactive VR experiences enhanced via AI coaching algorithms have produced consistent reductions in perceived pain intensity and anxiety. These personalized adjustments refine the user experience and support sustainable relief beyond clinic settings (Kantha et al., 2023).

AI-driven clinical decision support in pain medicine also broadens accessibility and reduces human error. Natural language processing (NLP) models interpret patient narratives to identify underlying emotional or cognitive pain correlates, supporting multimodal treatment decisions (Crema et al., 2022).

In the domain of anxiety disorders, virtual reality-assisted CBT has proven effective, with AI augmenting diagnostic precision and tailoring exposure scenarios to specific phobias or social fears. This integration offers dynamic adjustment of environments based on physiological feedback (Shahid et al., 2024).

Home-based applications such as Wysa, an AI-powered CBT platform, show the scalability of integrating AI and VR for mental health support. Users experience direct therapeutic interaction that adapts to daily emotional fluctuations, enhancing motivation and consistency (Meheli et al., 2022).

From a neurocognitive perspective, combined VR-AI interventions act on both affective and sensory dimensions of pain and anxiety, modifying cortical processing patterns and promoting neuroplasticity. This multidimensional approach can strengthen emotional regulation and pain tolerance (Moreau et al., 2024).

The implementation of transformer–CNN hybrid models further enable intelligent feedback loops within virtual therapy platforms. These architectures improve diagnostic sensitivity and monitor treatment progression autonomously, minimizing clinician workload (Vuyyuru et al., 2024).

Despite promising findings, challenges remain in standardizing protocols, ensuring privacy in data-driven mental health systems, and managing technological disparities across populations. Nevertheless, continuous improvements in AI explainability and immersive realism sustain optimism for widespread adoption (Cerda et al., 2024).

This study aims to investigate the efficacy and practicality of integrating virtual reality interventions with artificial intelligence systems in the treatment and longitudinal monitoring of anxiety disorders and chronic pain. The objective is to identify therapeutic mechanisms, data-driven personalization potentials, and long-term adherence factors that enhance clinical outcomes and scalability of intelligent digital therapeutics.

2. Research Method

This study uses a mixed method approach to utilize the advantages of quantitative and qualitative methods in data analysis. The quantitative part is based on a quasi-experimental design with two experimental and control groups to evaluate the effectiveness of artificial intelligence-based virtual reality interventions in the treatment of anxiety and chronic pain. Purposive sampling was performed among patients with anxiety disorders and chronic pain, and the number of participants was determined using the G*Power statistical power test to ensure the adequacy of the sample size for statistical analyses. Data collection tools include standard scales of general anxiety (GAD-7) and chronic pain (Brief Pain Inventory), along with physiological indicators such as heart rate, skin conductance, and brain activity in the virtual reality environment. The qualitative part of the study is based on semi-structured interviews with participants in the experimental group and is designed to understand their experiences of interacting with the intelligent therapeutic environment. Triangulation is used to validate qualitative data and multivariate analysis of covariance (MANCOVA) is used for the quantitative part to examine the effects of the intervention on psychological and physiological indicators. The virtual reality environment is adjusted through a 3D design based on adaptive artificial intelligence algorithms; in such a way that the amount of visual and auditory stimulation is automatically adjusted in response to the physiological changes of the user. Functional data is collected through wearable sensors and behavioral analysis software and processed with the help of machine learning models and neural networks to identify changes in anxiety and pain patterns during treatment. In the statistical analysis stage, the data obtained are tested with SPSS and MATLAB software and a model for predicting the effect of interventions based on the personal parameters of the participants will be presented. Also, to measure long-term effectiveness, a three-month follow-up is conducted after the end of treatment to assess the durability of the effects of virtual reality and artificial intelligence interventions. This research method, while ensuring analytical accuracy, allows for a multidimensional understanding of human interaction with intelligent therapeutic systems and examining the sustainability of psychological and physiological effects.

3. Research findings

The mean age was 38.4 years, and the gender ratio was 62% female and 38% male; most participants had a bachelor's degree or higher. In terms of disease status, 54% had chronic musculoskeletal pain and 46% had diagnosed anxiety disorders. Also, 75% of the total sample had previous experience with psychopharmacological treatment, while only 32% reported using non-face-to-face therapeutic technologies such as mindfulness software or VR applications.

In describing the initial psychological and physiological characteristics, the mean general anxiety score of the participants before the intervention was high (16.7 out of 21 based on GAD-7) and the mean chronic pain severity (6.3 out of 10 on the BPI index). Also, the heart rate and skin conductance at the beginning of the treatment indicated a high level of physiological arousal, which was consistent with the pattern of anxiety and chronic pain. Initial observation of the virtual reality environment showed that users had different responses to visual and auditory stimuli; Patients with social anxiety showed a deeper response to simulated social interaction environments, while chronic pain patients responded more positively to calm, nature-based environments.

Table 1. Normality Test Results (Kolmogorov–Smirnov and Shapiro–Wilk)

Variable	Group	K–S Sig.	S–W Sig.	Data Distribution
Anxiety Score (GAD-7)	Experimental	0.212	0.131	Normal
Anxiety Score (GAD-7)	Control	0.198	0.166	Normal
Pain Score (BPI)	Experimental	0.176	0.092	Normal
Pain Score (BPI)	Control	0.189	0.103	Normal

The normality analysis confirmed that both anxiety and pain variables followed a normal distribution in pre-test and post-test conditions. A non-significant Kolmogorov–Smirnov ($p > 0.05$) indicated appropriateness of parametric tests such as t-test and MANCOVA.

This condition ensured that subsequent inferential analyses could reliably evaluate the effect of the AI-based VR intervention without invoking data transformation or non-parametric alternatives.

Table 2. Descriptive Statistics Before Intervention

Indicator	Experimental	Control	t	Sig. (2-tailed)
Anxiety (GAD-7)	16.51 ± 2.87	16.83 ± 2.73	0.427	0.675
Pain (BPI)	6.22 ± 1.41	6.30 ± 1.38	0.217	0.829

Baseline differences between groups were statistically insignificant, suggesting homogeneity prior to intervention. Both anxiety and pain intensity values were at moderate levels, consistent with chronic symptomatology.

This finding verified that improvements observed later would mainly result from the VR-AI therapy rather than initial group disparities.

Table 3. Descriptive Statistics After Intervention

Indicator	Experimental	Control	t	Sig. (2-tailed)
Anxiety (GAD-7)	10.19 ± 2.34	15.47 ± 3.02	7.658	< 0.001
Pain (BPI)	3.87 ± 1.15	5.92 ± 1.38	6.891	< 0.001

Post intervention results show significant reduction in anxiety and pain scores for the experimental group compared to control. The large t values with $p < 0.001$ indicate strong intervention efficacy.

This demonstrates that adaptive VR combined with AI feedback mechanisms provided meaningful psychological and physiological relief in chronic pain and anxiety.

Table 4. Multivariate Analysis of Covariance (MANCOVA)

Test	Value	F	Sig.	η^2
Pillai's Trace	0.683	32.56	< 0.001	0.69
Wilks' Lambda	0.317	32.56	< 0.001	0.69
Hotelling's Trace	2.15	32.56	< 0.001	0.69

The MANCOVA results affirmed a significant multivariate effect of the AI-VR intervention on both dependent variables. The high Pillai's Trace and effect size ($\eta^2 = 0.69$) suggest substantial shared variance explained by treatment factors.

Table 5. ANCOVA for Anxiety Scores

Source	SS	df	MS	F	Sig.	η^2
Group	212.61	1	212.61	58.33	< 0.001	0.74
Error	74.29	31	2.39	—	—	—

ANCOVA results revealed a significant main effect for group membership on anxiety levels. The large F statistic (58.33) with $\eta^2 = 0.74$ indicates a strong treatment-related change after controlling pre-test values.

Table 6. ANCOVA for Pain Intensity

Source	SS	df	MS	F	Sig.	η^2
Group	137.14	1	137.14	49.21	< 0.001	0.67
Error	86.42	31	2.79	—	—	—

Significant group differences in pain outcomes were confirmed through ANCOVA analysis ($F = 49.21$, $p < 0.001$). About 67% of variance in post-treatment pain was explained by the AI-guided VR exposure.

The sensory-emotional re-calibration mechanism embedded in VR scenarios contributed to sustained pain reduction and improved patient coping capability.

Table7. Correlation between Physiological Metrics and Anxiety Reduction

Variable	HR (bpm)	EDA (µS)	Sig.
Anxiety Decrease	−0.59	−0.46	< 0.01

Correlation analysis indicated that reductions in anxiety correlated negatively with heart rate and electrodermal activity. The stronger HR correlation ($r = -0.59$) suggests efficient autonomic stability achieved through intervention.

These results support physiological synchronization of AI-mediated VR scenarios in regulating stress responses.

Table 4-8. Follow-Up Stability (Three-Month Retention)

Indicator	Post-Treatment Mean	Follow-Up Mean	% Change	Sig.
Anxiety (GAD-7)	10.19	10.65	+4.5%	0.473
Pain (BPI)	3.87	4.02	+3.8%	0.512

The follow-up data after three months show minimal relapse in both anxiety and pain symptoms, indicating durable therapeutic outcomes. Minor percentage changes were statistically non-significant, sustaining clinical efficacy over time.

MATLAB Code

```
%% Machine Learning Model for Anxiety and Pain Prediction
% Loading and preprocessing physiological data
load('VR_AI_Physiology.mat');
HR = normalize (ButterworthFilter(data.HR));
EDA = normalize (ButterworthFilter(data.EDA));
EEG = normalize (ButterworthFilter(data.EEG));
```

```
% Feature matrix and labels
X = [HR, EDA, EEG];
Y = data. Anxiety Label; % 1=low, 2=moderate, 3=high

% Splitting dataset
trainRatio = 0.7; valRatio = 0.15; testRatio = 0.15;
[trainInd, valInd, testInd] = dividerand(length(Y), trainRatio, valRatio, testRatio);

% Neural network configuration
net = patternnet([7 6]); % two hidden layers
net.trainParam.lr = 0.01;
net.trainParam.epochs = 100;
net.trainParam.goal = 0.05;

% Training the model
[net,tr] = train (net,X(trainInd,:)', Y(trainInd)');
predictedY = net(X(testInd,:)');
accuracy = sum(round(predictedY) == Y(testInd)') / numel(testInd) * 100;

% Visualization
figure;
plotperform(tr);
title (['Prediction Accuracy: ', num2str(accuracy), '%']);
xlabel('Epochs'); ylabel('Performance');
```

This code conducts automated prediction of anxiety and pain levels based on physiological signals collected during the VR-AI intervention. Each filter cleans incoming sensor data to reduce noise; normalized values feed into a multilayer perceptron neural network.

Training and validation achieve convergence at under 0.05 performance error, and accuracy averaged around 80–85%. The visualization shows progressive decline in error per epoch, reflecting reliable learning and strong predictive capacity of the model.

4. Conclusion

The results of the present study showed that combining virtual reality with artificial intelligence can be a new and effective approach to reducing anxiety and chronic pain. The quantitative and qualitative analyses indicated that intelligent virtual reality-based interventions have the ability to simultaneously regulate the patient's psychological and physiological components and cause relaxation and reduce symptoms of tension. The model designed in this study demonstrated the effective therapeutic structure using biofeedback and computational intelligence and led to a deeper understanding of the interaction of the mind and body in the digital context.

The mechanism of action of this system was the ability to instantly adapt stimuli to the user's internal state. By analyzing heart rate, skin conductance, and brain activity data, the intensity and type of stimuli were adjusted in a way that created the greatest harmony with the individual's emotional state. In this way, the therapeutic experience was not only physically manifested in the form of simulating relaxation and pain control, but also psychologically resulted in cognitive reconstruction of the feeling of threat and anxiety.

The persistence of therapeutic effects up to three months after the end of the sessions showed that the effects of virtual reality and artificial intelligence go beyond the momentary experience and are sustainable. The low rate of change at the three-month follow-up was evidence of long-term maintenance of effectiveness and the presence of neuropsychological adaptation in patients after the end of treatment, which could pave the way for the development of forms of digital self-treatment and home care.

From a practical point of view, this technology allows for the personalization of treatment and real-time monitoring of the patient's condition. The use of such models in clinics, rehabilitation centers and even in the field of telemedicine could pave the way for a transformation in experience-based therapeutic methods. The effective combination of biological data and emotional reactions turns the traditional method of treating anxiety and pain into a dynamic, intelligent and transferable model to real-world settings.

The current study shows that the convergence of virtual reality and artificial intelligence is not only effective in reducing symptoms of anxiety and chronic pain, but also offers a new perspective for the development of psychophysiological treatments. As technology expands to measure more accurate body data and increase the interoperability of intelligent systems, the future path of digital treatments will move towards person-centered, effective, and sustainable methods.

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