

Research and Analysis on the Application of VR Technology in the Treatment of Post-Traumatic Stress Disorder

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Abstract. Post-traumatic stress disorder (PTSD) is a common clinical psychiatric disorder. Traditional treatments are limited by difficulties in scenario reconstruction, low patient compliance, and insufficient controllability during intervention. Virtual reality (VR) technology has been widely used in clinical PTSD intervention owing to its advantages of immersive scene construction, multi-sensory interaction, and precise controllability. This paper reviews the application of VR technology in PTSD treatment, expounds the technical principles, clinical application, and efficacy evidence of virtual reality exposure therapy (VRET), sorts out the challenges in technology implementation such as hardware cost, clinical standardization, and ethical safety, and prospects the directions of technology integration, standardized treatment, and inclusive application. Studies show that VRET can significantly improve the core symptoms of PTSD, with better safety and compliance than traditional exposure therapy, and possesses favorable clinical promotion value. This paper systematically summarizes the research findings of VR-assisted PTSD treatment, providing theoretical references and practical bases for clinical psychotherapy and the development of immersive healthcare.

Keywords: Virtual reality, Post-traumatic stress disorder, Virtual reality exposure therapy, Psychotherapy, Immersive healthcare

1. Introduction

Post-traumatic stress disorder (PTSD) is mostly induced by major traumatic events, characterized by core symptoms such as intrusive traumatic recollections, persistent avoidance, and hyperarousal, which severely impair patients' daily life, social function, and mental health [1]. Traditional PTSD treatments are dominated by pharmacotherapy, cognitive behavioral therapy, and conventional exposure therapy. Although effective to a certain extent, they have prominent limitations: conventional exposure therapy struggles to authentically reconstruct traumatic scenes and easily triggers patient resistance; medications have side effects and cannot fundamentally correct traumatic cognitions; traditional psychological intervention features long cycles and insufficient individualization, failing to meet diverse therapeutic needs [1].

With the rapid development of immersive technology and digital healthcare, VR technology has been gradually applied in the field of psychiatric rehabilitation due to its high immersion, strong interactivity, and customizable scenes. Virtual reality exposure therapy (VRET) helps patients

gradually confront traumatic memories in a safe and controllable environment by constructing highly simulated trauma-related scenes, realizing psychological intervention and symptom alleviation, and becoming an important innovative direction in PTSD treatment [2]. In recent years, numerous domestic and international clinical studies have confirmed the favorable efficacy and safety of VR technology in PTSD treatment, making it a research hotspot in the interdisciplinary field of psychiatry and engineering technology [3, 4].

A meta-analysis by Chang et al., including 7 randomized controlled trials, verified that virtual reality exposure therapy (VRET) has a moderate and significant therapeutic effect on PTSD symptoms (Hedges' $g = -0.51$, $P < 0.001$), significantly reducing core symptoms such as avoidance and hyperarousal, with good safety and a severe adverse event rate of less than 5% [4]. A RCT study by Rothbaum et al. on veterans showed that the PTSD Checklist-5 (PCL-5) score in the VRET group decreased by 42%, significantly better than traditional exposure therapy ($p=0.003$), with a higher treatment compliance rate (82% vs 65%) and no severe psychophysiological adverse reactions [5]. A study by Difede et al. on 9/11 trauma survivors reported a 65% clinical response rate of VRET, significantly improving comorbid anxiety and depression; transient anxiety responses during treatment were rapidly relieved, verifying its safety [6].

A Chinese multi-center study by Li et al. demonstrated that localized VR scenes are effective for PTSD caused by earthquakes, accidents, and other traumas, with a symptom remission rate of 71% and a dropout rate of only 18% (35% for traditional therapy), no persistent negative emotions, and good adaptability to the local population [3, 7].

Theoretically, this paper systematically sorts out the technical logic, application models, and research findings of VR technology in PTSD treatment, improves the theoretical system of immersive technology in psychiatric treatment, and compensates for the deficiencies of single-technology or single-case studies [2]. Practically, it summarizes application advantages and existing problems, providing references for clinicians to carry out VR-assisted treatment, supporting the optimization direction of technology research and development, and promoting the transformation of VR psychotherapy from pilot projects to standardized popularization [8]. Socially, it enhances the accessibility and effectiveness of PTSD treatment, facilitates the psychological recovery of trauma populations, and reduces the social medical burden, with important practical value [8].

2. Review scope and research methods

2.1. Review scope

This paper focuses on the clinical application research of VR technology in PTSD treatment, with a time frame limited to core domestic and international literature, clinical research reports, and authoritative medical cases in the past decade; the research subjects cover different PTSD populations such as adults and adolescents [9]; the content includes technical principles, clinical application models, efficacy data, existing challenges, and future trends, excluding studies related to non-clinical applications and pure technology development without therapeutic verification.

2.2. Research methods

This paper adopts a research paradigm combining literature research, case analysis, and inductive summary. High-quality literature and authoritative cases are screened by retrieving academic journal databases and clinical medical databases; representative domestic and international VR PTSD treatment clinical projects are selected to extract treatment procedures, core viewpoints, and efficacy

data; data are integrated and summarized to systematically analyze the advantages, problems, and trends of technology application, forming objective and comprehensive review conclusions [3, 4].

3. Review of core content of VR technology for PTSD treatment

3.1. Technical principles of VR therapy for PTSD

VR therapy for PTSD is centered on virtual reality exposure therapy (VRET), based on exposure therapy and cognitive behavioral therapy theories, combined with computer graphics, sensing technology, and multimodal interaction technology to construct highly simulated and precisely adjustable virtual scenes as alternatives to real traumatic environments [2].

During treatment, patients wear VR devices to enter customized scenes and receive multi-sensory stimuli such as vision and hearing, gradually contacting trauma-related memories and situations in a safe therapeutic environment. Physicians can adjust scene intensity, content, and interaction modes in real time to control the intervention rhythm, and cooperate with psychological guidance to help patients reconstruct cognition and alleviate anxiety and fear, ultimately achieving traumatic memory restructuring and symptom improvement [2]. Meanwhile, the VR system can synchronously collect patients' physiological data, providing objective evidence for efficacy evaluation and protocol optimization [10].

3.2. Typical clinical cases and application effects

US research on VR for PTSD started early and has formed a mature clinical application model. The US military has carried out VR treatment for veterans with PTSD by constructing simulated scenes such as battlefields and explosions, combined with standardized procedures, resulting in significant remission of core symptoms in more than half of the patients, and treatment compliance is much higher than traditional exposure therapy [9]. Multiple psychiatric medical centers in Europe have applied VR to PTSD caused by accidents and violent injuries; data show effective improvement in patients' avoidance behaviors, sleep disorders, and anxiety, with a low long-term follow-up recurrence rate [11].

Domestic application is mainly clinical pilot, mostly used for psychological intervention after natural disasters, accidental traumas, and stressful events [7]. Studies in psychiatry departments of many tertiary hospitals have confirmed that VR scenes can reduce patients' psychological defense and resistance, especially suitable for patients who are difficult to verbalize traumas, with better treatment efficiency and acceptance than traditional methods [3, 7]. Overall clinical evidence indicates that VR plays a positive role in both acute intervention and recovery consolidation of PTSD, and the combined effect with traditional treatment is better [2].

3.3. Application advantages of VR technology for PTSD treatment

Compared with traditional treatment, VR technology has significant advantages: first, high scene restoration, accurately matching trauma types and compensating for the defect that real scenes cannot be simulated; second, safe and controllable process, physicians can pause and adjust intensity at any time to avoid secondary trauma; third, higher compliance, immersive experience reduces psychological resistance and improves participation; fourth, standardizable and reusable, the same set of scenes adapts to multiple patients, facilitating large-scale clinical promotion [3, 4].

4. Analysis and discussion

4.1. Existing challenges of VR technology for PTSD treatment

Technically, high-precision VR hardware is costly, and scene modeling has a long cycle and high cost, making it difficult to popularize in primary-level institutions [12]; some devices have problems such as discomfort during wearing, picture delay, and insufficient realism, affecting immersion experience and treatment effect.

Clinically, there is a lack of unified operational specifications and efficacy evaluation standards for VR PTSD treatment; most protocols rely on physicians' experience, making standardized promotion difficult; long-term efficacy data are insufficient, and research on applicability to special populations is still incomplete [9, 11].

Industrially and ethically, there is a shortage of interdisciplinary talents, and insufficient professionals with both psychiatric and VR technical backgrounds; virtual scenes involve traumatic memories, posing ethical risks such as data privacy leakage and excessive stimulation, with imperfect supervision and protection mechanisms [13, 14]; VR treatment has not been fully covered by medical insurance, resulting in high out-of-pocket costs for patients and limiting popularization [8].

4.2. Comprehensive analysis

VR technology provides an innovative solution for PTSD treatment, effectively compensating for the shortcomings of traditional treatment, with clear clinical value and application prospects, but it is still in the stage of development and improvement. Technological maturity, clinical standardization, and industrial supporting integrity restrict large-scale implementation. Current research and application are mostly concentrated in large medical and scientific research institutions, and there is still much room for improvement towards inclusive and primary-level application [8, 12, 15].

5. Conclusion

Centered on virtual reality exposure therapy, VR technology has advantages in PTSD treatment such as controllable scenes, strong immersion, high compliance, and good safety. Global clinical studies have confirmed that it can effectively alleviate core symptoms including intrusive traumatic recollections, avoidance behaviors, and hyperarousal, representing an important innovative direction in psychiatric treatment. At present, the technology still faces problems such as high hardware cost, lack of clinical specifications, shortage of professional talents, imperfect ethical supervision, and low popularity, and a complete and mature clinical application system have not yet been formed.

In the future, VR PTSD treatment will break through in multiple directions: in terms of technology integration, VR will combine with AI, biosensing, and brain-computer interface to realize intelligent scene adaptation, real-time physiological monitoring, and automatic protocol adjustment, improving precision; in terms of clinical standardization, unified treatment procedures, evaluation standards, and operational guidelines will be established to promote it as a routine intervention; in terms of application popularization, hardware and service costs will be reduced, medical insurance coverage will be promoted, and it will be extended to primary medical and rehabilitation institutions; in terms of ethical safety, data protection and ethical specifications will be improved, and a talent training system will be established to ensure safe and compliant application.

With technological iteration and deepening clinical research, VR technology will play a more important role in PTSD treatment, providing more efficient, inclusive, and personalized solutions for post-traumatic psychological rehabilitation.

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