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Virtual Reality Gaming Applications in Healthcare

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Abstract. With the rapid advancement of digital technologies, Virtual Reality (VR) has emerged as a powerful tool in the field of healthcare. The paper, through a method of literature review, explores the integration of virtual reality gaming applications in healthcare, particularly focusing on exercise therapy, rehabilitation, psychological interventions, and medical education. The study reviews existing VR-based serious games that utilize gamification strategies to enhance physical and mental well-being. It analyzes their effectiveness in engaging users through immersive experiences, real-time feedback, and personalized adaptive systems. The paper concludes that VR games in healthcare not only improve patient adherence and rehabilitation outcomes but also hold significant potential in medical training and public health education. This paper provides a comprehensive reference for researchers, practitioners, and policy-makers aiming to harness VR technologies for better health outcomes.

Keywords: Virtual Reality, healthcare, games, gamification, serious games

1. Introduction

With the rapid advancement of digital technologies, Virtual Reality (VR) has increasingly permeated the field of healthcare, offering novel approaches across diagnosis, treatment, and rehabilitation. VR-based healthcare games are no longer solely designed for entertainment purposes; rather, they are developed as serious games aimed at enhancing health outcomes through gamification strategies. These applications are typically characterized by high interactivity, immersion, real-time feedback, and personalized adaptability.

A growing body of literature suggests that the application of VR in healthcare is evolving from conceptual exploration to practical implementation. For instance, Tao et al. [1] demonstrated the efficacy of VR in promoting physical activity, motor rehabilitation, and pain management. Similarly, Usmani et al. [2] provided empirical evidence supporting the utility of VR in the diagnosis and treatment of mental health disorders.

This study employs a comprehensive literature review methodology to examine recent developments in the application of VR games within healthcare contexts. By synthesizing existing research findings, this paper identifies innovative approaches to VR game design in healthcare and assesses their potential impact on health promotion, patient recovery, and medical education.

The significance of this research lies in its provision of a structured analytical framework for scholars, as well as actionable insights for healthcare practitioners. Moreover, the findings may

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inform policy-making processes and support technology developers in designing more effective and contextually appropriate VR-based healthcare interventions.

2. Functions and application scenarios of healthcare VR games

2.1. Physical exercise

2.1.1. Current applications of VR games in promoting physical exercise

With the continuous advancement of VR technology, its applications in the healthcare field have become increasingly widespread. In particular, VR games offer an engaging and highly interactive new approach to promote physical activity and improve both physical and mental health.

Research has shown that VR games have demonstrated positive effects in promoting physical exercise. For example, for individuals with obesity, exercise through VR games can increase physical activity levels and aid in weight management. [3] In addition, VR games can enhance participants' motivation to engage in exercise and improve their adherence to physical therapy. [4] However, current VR fitness games are mainly targeted at younger users. Considering the physiological, psychological, and cognitive characteristics of older adults—as well as their unique needs regarding exercise games—there is a growing need for VR fitness games specifically designed for the elderly.

2.1.2. Advantages of using VR games for physical exercise

In terms of interactivity, VR games encourage full-body movement through highly interactive user interfaces. With the use of handheld controllers or body tracking technology, users' physical movements are directly translated into interactive responses in the virtual environment, providing an immersive exercise experience.

Personalized settings are a key feature of many VR games, allowing the intensity and type of exercise to be tailored to the users' physical condition and rehabilitation needs. This individualized training approach helps users meet their specific health goals.

Compared with traditional exercise methods, VR games incorporate elements such as virtual storylines, reward systems, and visual effects to make exercise more enjoyable. This enhanced enjoyment significantly increases user engagement and motivation to maintain long-term exercise routines.

Real-time data feedback allows VR games to accurately track users' performance. Using biometric sensors and other hardware devices, VR systems can monitor physiological and movement data such as heart rate, respiration, and calorie consumption in real time. This data is fed back to the VR system, enabling automatic adjustments to game difficulty and intensity. At the same time, the data is presented to the user, allowing them to clearly understand their workout status and improve both the experience and effectiveness of exercise.

The ability to record long-term performance is another major advantage of VR systems. VR systems can log and analyze long-term training data, including real-time monitoring data from each session, frequency of gameplay, time of day, and more. This helps users better understand their long-term progress and develop more efficient, personalized workout plans. When integrated with modules like AI coaches, the system can provide scientific, data-driven evaluations and guidance, forming a comprehensive smart training ecosystem.

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The progress tracking feature allows users to monitor their exercise performance in real time. This design not only helps users recognize their improvement but also enables timely adjustments to their exercise plans to achieve better training outcomes.

2.1.3. Examples of VR games that promote physical exercise

VR games designed for younger audiences, such as Pokemón Ride [5], focus on creating engaging and immersive experiences that combine physical activity with entertainment. These games often incorporate popular cultural elements, like Pokémon, to attract and retain players' interest. The mechanics of these games, such as the reward system for capturing Pokémon, are designed to stimulate both passive and active engagement, fostering a state of flow. The dynamics involve increasing difficulty and scores, though they may lack complexity, leading to potential monotony. Aesthetically, these games leverage visually pleasing environments and beloved characters to enhance player enjoyment. The hardware setup for youth-oriented games is typically more advanced, offering a comprehensive and interactive experience.

VR games for the elderly, such as VRrowing [6], prioritize health benefits and cognitive training over entertainment. These games simulate real-world activities like rowing, supplemented by mini-games that target both physical and cognitive functions. The mechanics are straightforward, focusing on task completion and progression, while the dynamics involve simple yet functional interactions. Aesthetically, these games emphasize calm and relaxing environments, such as serene lakes, to create a pleasant experience. The hardware setup is simplified to avoid overwhelming elderly users, who may experience "technophobia" or physical limitations. Overall, these games are designed to be accessible, functional, and supportive of overall well-being.

2.2. Rehabilitation therapy

2.2.1. Exercise rehabilitation

Professional athletes often find it difficult to avoid musculoskeletal injuries throughout their careers, and even regular sports enthusiasts frequently face the risk of sports-related injuries. In response, exercise rehabilitation is commonly used as a treatment method.

Traditional rehabilitation therapy typically involves repeating specific rehabilitation movements in the same environment, which can quickly become monotonous and demotivating for patients, sometimes even affecting their mental health. This negative psychological state can further slow down the rehabilitation process.

In contrast, incorporating VR games into exercise rehabilitation allows patients to interact within a simulated environment while performing rehabilitation exercises. This approach is more enjoyable, dynamic, and personalized than traditional training. The immersive experience of VR games helps reduce the perceived duration of the treatment, while game-based reward mechanisms provide patients with enjoyment, motivation, and a sense of confidence.

Studies have shown that VR-based exercise rehabilitation games are effective in treating chronic neck pain and shoulder impingement syndrome [7]. These studies combined clinical assessments with self-reports to evaluate both the effectiveness of the treatment and the patients' satisfaction and adherence.

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2.2.2. Neurocognitive rehabilitation

In recent years, the application of VR technology in neurocognitive rehabilitation has attracted widespread attention, especially in the treatment of patients with brain injuries, strokes, Alzheimer's disease, and other cognitive disorders. Cognitive impairment is a common symptom among these patients, often manifesting as difficulties with attention, memory loss, limited decision-making ability, and impaired problem-solving skills. To address these issues, repeated practice of specific cognitive processes has become a key approach in rehabilitation therapy.

With VR technology, patients can engage in cognitive function training within an immersive environment. These trainings can effectively promote neuroplasticity, helping patients to restore or improve their cognitive functions.

Serious games based on virtual reality technology can significantly reduce cognitive decline by enhancing engagement and producing synergistic effects on cognitive functions [8]. Additionally, VR-assisted cognitive training offers a non-pharmacological treatment method, resulting in fewer side effects for patients.

VR technology can also provide a platform for social interaction, which helps patients regain their social skills. This not only aids in restoring basic cognitive functions but also facilitates the reintegration into normal life, thereby improving the overall effectiveness of treatment.

2.2.3. Balance function rehabilitation

In the study conducted by Jiao et al., researchers used an immersive VR system as a supplementary method for vestibular function rehabilitation [9]. They designed a VR game and recruited patients with vestibular dysfunction to participate in the experiment. The results showed that, compared to traditional rehabilitation training, patients who engaged in VR-based rehabilitation demonstrated more significant improvements in balance and anxiety relief. This indicates that virtual reality systems hold potential benefits in vestibular function rehabilitation and offer new possibilities for future therapeutic approaches.

2.3. Psychotherapy and psychological interventions

2.3.1. Immersive VR technology and Cognitive Behavioral Therapy

Cognitive Behavioral Therapy (CBT) is a core method for treating various psychological disorders. Its central concept focuses on regulating emotions and behaviors by identifying, challenging, and restructuring individuals' irrational cognitions [10]. The introduction of VR technology provides a novel platform for implementing CBT, particularly offering unique advantages in scenario simulation and behavioral rehearsal.

Exposure therapy is a key intervention within CBT used to address fear and avoidance responses. Its fundamental mechanism involves gradually exposing patients to the situations, objects, or internal experiences they fear, thereby breaking the vicious cycle of "fear-avoidance-reinforcement," reducing anxiety, and promoting functional recovery. However, traditional exposure therapy still faces several limitations in practice. On one hand, patients often lack treatment adherence due to overwhelming fear intensity; on the other hand, some exposure scenarios are difficult or unsafe to recreate in real life, such as heights or airplane crashes [11]. Moreover, the effectiveness of treatment also heavily depends on whether the therapist and patient can establish a strong task

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alliance [12], which involves sufficient trust and cooperation around the exposure tasks during therapy.

To address these limitations, Virtual Reality Exposure Therapy (VRET) has gradually emerged as a powerful supplement to traditional exposure therapy. A meta-analysis by Powers and Emmelkamp covering 13 VRET studies showed [13] that VRET had a significantly large effect size compared to control groups (Cohen's d = 1.11) and was slightly more effective than standard (in vivo) exposure (d = 0.35). This advantage stems from VRET's enhanced sense of safety, autonomy, and environmental controllability, which encourages patients to comply with exposure tasks, thereby indirectly strengthening task alliance and improving treatment adherence.

Another major strength of VRET is its ability to evoke presence. Presence refers to the sense of "being there" that virtual environments provide, and this perception is closely related to the activation of the patient's fear structures [14]. Although current research on the assessment of presence is still limited, experiments have shown that using head-mounted displays (HMDs) or immersive virtual environments (such as CAVE systems) can effectively trigger emotional responses and have a positive impact on phobic symptoms [15].

Overall, immersive VR exposure therapy not only preserves the core mechanism of exposure strategies in traditional CBT but also enhances scenario realism and task engagement, providing a more immersive and sustainable intervention pathway for alleviating anxiety symptoms. Powers and Emmelkamp highlighted that VRET shows particularly high cost-effectiveness and personalization advantages in treating acrophobia and fear of flying, enabling the safe and repeated reproduction of complex scenarios in a therapy room that would be difficult to achieve in traditional exposure settings. As technology matures and empirical evidence grows, VRET is expected to expand its clinical applicability to a broader range of anxiety disorders.

2.3.2. VR technology and psychological interventions

As an immersive medium, VR technology demonstrates cross-diagnostic and cross-technical integration potential in psychological interventions. Beyond exposure therapy and CBT, VR is increasingly used in areas such as emotion regulation, mindfulness training, and self-awareness enhancement, making it a versatile platform supporting various psychological intervention models.

First, VR's application in emotion regulation is gaining attention. Studies have found that natural scenes presented via head-mounted displays (e.g., beaches, rural meadows) can effectively promote relaxation and positive emotions [16]. Researchers compared the emotional and physiological effects of two VR nature scenes versus a neutral indoor environment. Results showed that participants exposed to nature scenes exhibited significantly reduced electrodermal activity (EDA), indicating decreased sympathetic nervous system activation and a higher level of relaxation. Subjective feedback further suggested that nature scenes were more enjoyable than neutral environments, especially when scene content aligned with individual preferences. This indicates that VR nature scenes can serve as an effective stress management tool, particularly for psychological interventions in isolated and confined environments (ICE) such as long-haul seafarers and astronauts.

Second, VR is widely used in mindfulness training. Through visual and audio guidance, individuals can focus on breathing, body scanning, or environmental awareness in a virtual space, reducing cognitive distractions and improving attentional stability. Compared to traditional mindfulness training, which often struggles with achieving immersive states, VR provides a more structured and sensory-guided environment, especially beneficial for populations with attention deficits, chronic pain, or obsessive-compulsive disorders [17].

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Additionally, VR can enhance individuals' self-awareness. Some systems use mirrored feedback or virtual character interactions to allow users to observe and recognize their own behavioral responses, emotional fluctuations, and even tone changes in specific situations. This approach is particularly suitable for individuals with low self-perception or significant emotional recognition difficulties, such as those with borderline personality disorder, autism spectrum disorder, or neurodegenerative diseases like Alzheimer's.

2.4. Surgical simulation and medical education

2.4.1. Surgical simulation training (professional medical education)

With the rapid advancement of VR technology in medical education, particularly in surgical training, VR has become a vital simulation tool. VR provides an immersive, interactive, and risk-free training environment that allows surgical residents to repeatedly practice operational skills across diverse virtual cases, effectively improving learning efficiency and knowledge transfer.

More importantly, VR simulations offer real-time interactivity: the system can instantly provide visual, auditory, and even haptic feedback based on the learner's actions, making the learning process more proactive and targeted. For example, systems can record and provide feedback on key performance indicators such as surgical paths, operation times, and error rates, assisting instructors in objectively assessing students' technical proficiency.

However, despite VR systems' strong technical potential, surgical skill training still requires expert supervision to provide timely and effective feedback. To reduce reliance on human experts, recent research has explored automating feedback mechanisms. For instance, Ma et al. proposed a "follow-me ghost demonstration" method [18], where expert operation paths are pre-recorded as "virtual images" to guide learners. However, novices may struggle to synchronize with the expert's pace.

To overcome this limitation, recent developments have introduced feedback mechanisms based on data mining, Random Forest, and Integer Linear Programming (ILP) that can detect skill deficiencies and provide efficient, concise, real-time guidance within one second. These algorithms balance feedback effectiveness, timeliness, and computational efficiency, representing a key future direction for automated feedback in surgical simulation [19].

2.4.2. Emergency skills training (non-professional medical education)

VR technology also shows great potential in emergency skills training for non-professionals. Common emergency training, such as CPR and AED, typically relies on face-to-face courses and mannequin simulations. However, this traditional method often faces high equipment costs, logistical challenges, and low training frequency. A randomized controlled trial by Aksoy et al. demonstrated [20] that in basic life support training, VR-based serious gaming modules outperformed tablet-based modules in knowledge retention, operational accuracy, and learner motivation. Trainees were more likely to transfer emergency response strategies learned in virtual environments to real-life scenarios, especially in sudden emergencies where they could make quicker and more effective decisions.

Another advantage of VR is its controllable and diverse scenario simulations. The system can adjust scenario complexity based on user performance, such as simulating patients of different ages or various types of cardiac arrest, enhancing training adaptability. Additionally, VR platforms can

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collect user operation data and generate visual reports to help trainers monitor learning progress and identify weaknesses.

In public health promotion, VR's educational and interactive features make it especially suitable for schools, workplaces, and community settings, with great potential to become an effective tool for widespread emergency response training.

3. Evaluation of VR applications in healthcare

Evaluating healthcare VR applications involves assessing both physiological and psychological effects, user experience, and clinical outcomes. Physiological data, such as heart rate, EEG, and posture, are often monitored with biofeedback tools and can be analyzed using deep learning to quantify physical responses, useful in areas like pain management. Psychological impact is typically measured through self-report scales assessing anxiety, depression, and stress, with VR-based relaxation therapies showing positive effects.

User experience and satisfaction are evaluated via interviews and questionnaires, focusing on interaction design, content appeal, and immersion. These factors influence user acceptance and rehabilitation outcomes.

Finally, clinical effectiveness is assessed through studies like randomized controlled trials. Systematic reviews and meta-analyses help identify which VR applications are most effective for specific conditions, supporting evidence-based use and guiding future research.

4. Challenges and prospects of healthcare VR applications

Despite the promising applications of healthcare VR games in rehabilitation training and health management, they still face several challenges in widespread adoption and practical implementation.

First, technical challenges and cost issues remain significant barriers to large-scale application. These systems require high interactivity and realism in their design and development, which depend on advanced technologies such as graphics rendering, user input response, and physics engine simulation, necessitating substantial research and development resources. Additionally, the high cost of medical-grade VR equipment makes improving cost-effectiveness while maintaining efficacy a key industry concern.

Second, data security and privacy protection must be prioritized. As these systems handle large amounts of sensitive personal health information, strict security mechanisms and data de-identification procedures must be established throughout data collection, transmission, and access to prevent privacy breaches and ensure the safe and compliant use of patient data.

Moreover, medical regulation and legal frameworks pose significant practical challenges. Since healthcare VR products directly impact patient health and treatment outcomes, they are subject to stringent regulatory requirements during development, approval, and market launch. Variations in laws and regulations across countries and regions further complicate international expansion, while outdated legal frameworks may also hinder innovation in emerging technologies.

Finally, user acceptance plays a crucial role in the promotion and widespread adoption of this technology. Differences in familiarity with emerging technologies among patients and healthcare providers may influence their willingness to use VR, while cultural background, education level, and age also affect how different user groups perceive and accept VR health interventions. Therefore, in addition to technological improvement and policy support, enhancing user education and optimizing user experience are essential for increasing overall user satisfaction and promoting the sustainable development of VR in healthcare.

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5. Conclusion

This paper systematically reviews the main applications of virtual reality games in the healthcare field, including physical rehabilitation, psychological interventions, medical education, and elderly health support. Research shows that VR games enhance patient engagement, provide personalized treatment, and create safe and controllable training environments, thereby improving the quality of medical services and treatment outcomes.

However, this study is primarily based on a literature review and has not yet conducted empirical investigations or clinical experiments. The discussion on some specific application scenarios and technological effects is also relatively limited. Future research can further verify the effectiveness and user acceptance of VR games in various healthcare settings through surveys and experimental studies.

As technology advances and costs decrease, the application prospects of virtual reality games in healthcare are vast. Future efforts should focus on strengthening interdisciplinary collaboration, promoting the standardization, personalization, and intelligent development of VR games in the medical field, and contributing to the creation of a more efficient and user-centered digital healthcare system.

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