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A Review of the Effects and Mechanisms of VR Training on the Physical and Mental Health of Stroke Patients

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Abstract

To explore the effects of virtual reality (VR) training on the physical and mental rehabilitation of stroke (CVA) patients and its underlying mechanisms, to address issues such as monotonous training, low compliance, and limited environmental simulation in traditional rehabilitation. This study aims to provide a theoretical basis for optimizing clinical rehabilitation strategies. Databases such as PubMed (Medline), Web of Science, Cochrane Library, Google, CNKI, and Wan fang Data were used to search for literature published in core journals from both domestic and international sources over the past 10 years (2014-2024). Keywords included: virtual reality, VR training, stroke, cerebrovascular accident, physical and mental health, and mechanism of action. Inductive summarization and comparative analysis methods were applied to process the selected literature. Different VR training methods can not only improve the upper and lower limb strength and balance of stroke patients, but also significantly enhance their activities of daily living (ADL). Additionally, these training methods can alleviate anxiety and improve depression and other psychological issues in stroke patients. The improvement in physical and mental health due to VR training may be achieved through a synergistic effect of neuroplasticity and psychological immersion. VR training can effectively promote the recovery of motor function, improve ADL, and enhance psychological status in stroke patients. However, due to the limited number of long-term studies with rigorous intervention protocols, the current analysis of the mechanisms underlying the improvement of physical and mental health in CVA patients through VR training lacks persuasive power.

Keywords: *Mechanism of Action, Physical and Mental Health, Stroke, Virtual Reality, VR.*

A. Introduction

Stroke, also known as cerebral vascular accident (CVA), is the leading cause of disability and death among adults in China, as well as the primary cause of shortened life expectancy due to disease(Hu, J. & Chen, X., 2020). Among stroke survivors, 75% to 80% of patients experience varying degrees of functional impairment, including motor, sensory, and cognitive disorders, significantly affecting their daily life and social participation abilities (Henderson et al., 2007). Motor dysfunction, primarily manifested by changes in muscle strength, muscle tone, and abnormal walking patterns, leads to a decline in walking speed and gait stability (Saposnik et al., 2010). Stroke patients are also at a significantly higher risk of psychological health issues, with multiple factors such as physical condition, cognitive function, and social support often contributing to negative emotions (Guo et al., 2022). However, emotional disorders like anxiety and depression are often covert, and family members and healthcare professionals may prioritize the assessment of physical health indicators such as motor function and daily living abilities, overlooking the importance of psychological health evaluation (Brigadeiro et al., 2017).

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Furthermore, many patients lack the awareness or ability to express their emotional needs, which exacerbates feelings of depression and anxiety, ultimately lowering their quality of life (Baker et al., 2024).

Virtual Reality (VR) is defined as an advanced form of human-computer interface that allows users to "interact" and "immerse" themselves in computer-generated environments in a natural way (Schultheis & Rizzo, 2001). VR can be classified into immersive and non-immersive types based on the level of immersion. Immersive VR uses head-mounted devices, body motion sensors, real-time graphics, and advanced interface equipment to simulate a complete virtual environment that surrounds the user within the virtual world (W. Liu et al., 2024). In contrast, non-immersive VR allows users to interact via a keyboard, mouse, touchpad, or joystick, and view the VR environment on a digital screen (Carreon et al., 2024).

In addition to display devices, other input-output devices can be used in VR systems, such as motion trackers, exoskeletons, sensors, bionic gloves, and treadmills. These systems serve as effective tools to build realistic environments, offering personalized home physical therapy solutions by controlling content, duration, intensity, and feedback mechanisms (Tannus et al., 2024). In recent years, VR has become a multidisciplinary tool in clinical medicine for various purposes, such as pain management (Pourmand et al., 2018), neurocognitive disorder assessment (Yeh et al., 2012), medical skills training (Barteit et al., 2021), and physical rehabilitation (Pourmand et al., 2017). The application of VR in rehabilitation therapy is increasingly widespread. This new technology is used to achieve cognitive and motor function recovery, providing an immersive and interactive experience (Zhu et al., 2021). It transports patients into virtual environments where they perform physical actions in a nearly natural way, thereby improving cognitive functions (attention, memory, visual-spatial abilities, executive functions, etc.) (Mura et al., 2018) and physical activity abilities (activities of daily living - ADL, balance, gait function, etc.) (Subramaniam et al., 2014).

Existing studies have shown that VR training can improve the physical health of stroke patients by enhancing upper and lower limb muscle strength, balance ability, and activities of daily living (ADL). Psychologically, it can help alleviate depression, reduce anxiety, and increase treatment adherence, attention, executive function, and social participation willingness. Studies using magnetic resonance imaging (MRI) have found that VR training aids in the cortical remodeling of stroke patients' brains, which, in turn, enhances their motor functions. The likely reason for this is that during VR training, dynamic sensory feedback from multiple modalities, such as vision, vestibular sense, and proprioception, provides real-time self-correction to the premotor cortex and parietal cortex neural networks, thereby stimulating the activity of mirror neurons (Campbell et al., 2025). The application of VR technology also engages multiple sensory modes, such as visual and auditory stimuli, optimizing the interactions between cortical networks and promoting the reorganization of neuronal structures. This neuroplasticity is critical for repairing damaged brain functions, which helps alleviate the negative psychological symptoms in stroke patients (Gangemi et al., 2023).

In summary, VR training not only alleviates psychological issues such as anxiety and depression in stroke patients but also improves their physical functions, such as upper and lower limb strength and balance, thereby enhancing their activities of daily living (ADL). However, most current studies provide only superficial analyses of the mechanisms through which VR training impacts the physical and mental health of stroke patients. Most studies are limited to describing phenomena and failing to delve into the underlying mechanisms. Therefore, there is a need for more scientifically rigorous experimental designs that integrate insights from physiology, biology, and medicine to explore the deeper mechanisms by which VR training affects the physical and mental health of stroke patients. In the context of the "National Fitness" and "Healthy China 2030" strategies, improving the physical and mental health of stroke patients, reducing their anxiety and depression, and enhancing their physical fitness have become urgent tasks. Based on this, this study organizes relevant literature to explain the effects and mechanisms of VR training on the physical and mental health of stroke patients, providing a theoretical foundation for clinical translation and technological optimization.

B. Methods

This study adopts a qualitative systematic literature review design to comprehensively investigate the effects of virtual reality (VR) training on the physical and mental rehabilitation of stroke (cerebrovascular accident/CVA) patients, and to explore the underlying mechanisms of these effects. The design is intended to synthesize current empirical findings and theoretical perspectives from high-quality publications, providing a critical and integrative understanding of how VR contributes to stroke rehabilitation. This method allows for an in-depth exploration of both the physiological and psychological outcomes associated with VR interventions in clinical settings.

The review process involved a structured and comprehensive search of both international and domestic scientific databases. The databases consulted included PubMed (Medline), Web of Science, Cochrane Library, Google Scholar, CNKI (China National Knowledge Infrastructure), and Wan Fang Data. Literature published between 2014 and 2024 was considered. The inclusion criteria focused on peer-reviewed journal articles addressing the application of VR in stroke rehabilitation, particularly those evaluating physical and mental health outcomes and discussing potential mechanisms of action. Keywords used during the search included "virtual reality," "VR training," "stroke," "cerebrovascular accident," "physical and mental health," and "mechanism of action." Duplicate records were removed, and articles were screened based on relevance, methodological rigor, and reported outcomes.

The main data source consisted of secondary data derived from peer-reviewed journal articles, including experimental studies, clinical trials, and meta-analyses. Data extraction involved identifying recurring findings, intervention strategies, measurement tools (e.g., ADL scales, balance assessments, psychological scales), and reported outcomes. Special attention was given to studies detailing specific VR technologies, session durations, frequencies, and target rehabilitation outcomes. A coding sheet was used to classify articles based on study population, intervention type, physical and mental health indicators, and theoretical frameworks regarding neuroplasticity and psychological immersion.

The collected data were analyzed using inductive summarization and comparative analysis. Inductive summarization involved categorizing themes and trends emerging from the literature, such as improved limb strength, balance, ADL, anxiety reduction, and enhanced motivation. Comparative analysis was used to identify variations in intervention effects across different VR systems, training protocols, and patient populations. The analysis also considered the consistency and strength of evidence supporting neurophysiological mechanisms, including neuroplasticity and cognitive-behavioral immersion. Limitations and gaps, such as the scarcity of long-term randomized controlled trials (RCTs), were also critically evaluated to assess the credibility of the proposed mechanisms.

C. Results and Discussion

1. The Application of VR Training in Stroke Rehabilitation

There are many methods for physical therapy in stroke rehabilitation; however, traditional physical therapy often relies on the therapist to manually adjust the intensity and difficulty of the exercises. This approach lacks real-time dynamic data, making it difficult to precisely match the therapy with the patient's functional level. As a result, mild and severe balance disorder patients may end up using the same training regimen. Moreover, the exercises are often monotonous with low interactivity, and the high repetition of movements may cause patients to become bored, leading to decreased adherence and, ultimately, treatment interruptions or reduced effectiveness. Traditional physical therapy also struggles to simulate real-life environments and is limited in its capacity for multi-task training. Virtual Reality (VR) training addresses these issues by providing a safe and immersive environment for patients to perform functionally specific tasks, increasing repetitions, exercise intensity, and patient motivation to adhere to the intervention, thus promoting neuroplasticity(Wu, M. et al., 2019). In the field of stroke rehabilitation, VR training has been shown to effectively increase the range of motion in the upper limbs, improve sensation, enhance muscle strength, and reduce pain. VR training for stroke patients has proven to be safe and cost-effective in improving lower limb function, particularly in enhancing balance, stair-climbing speed, ankle muscle strength, range of motion, and gait speed. Compared to other traditional physical therapy methods, VR training may be more effective in improving dynamic balance control and preventing falls, especially in subacute and chronic stroke patients (Zheng et al., 2020). Currently, VR training for the physical and mental rehabilitation of stroke patients mainly involves task-oriented training or cognitive-motor integration training through immersive or non-immersive VR. Additionally, VR can be combined with other techniques such as repetitive transcranial magnetic stimulation (rTMS), brain-computer interfaces (BCI), and assistive robots for rehabilitation purposes.

Immersive VR provides a more realistic environmental design and precise object tracking. It also delivers real-time feedback through visual, tactile, and auditory cues, allowing for movements in real-life scenarios to rebuild bodily functions (Ögün et al., 2019). Immersive VR therapy has shown multiple benefits in restoring both upper and lower limb motor functions in stroke patients (Patsaki et al., 2022). Compared to traditional therapies, it allows patients to perform more repeated functional tasks (Demain et al., 2013) and can often feel more like a game rather than a treatment, thereby enhancing treatment adherence and motivation to continue therapy (Patsaki et al., 2022). Additionally, VR aids in providing augmented feedback, an important motor learning mechanism for patients with neurological conditions (Levin & Demers, 2021). By offering real-time information about performance and helping individuals improve and adjust their movements, VR supports the dynamic learning process, providing a more detailed understanding of their performance, and ultimately improving the effectiveness of rehabilitation strategies (Levin & Demers, 2021).

Non-immersive VR training can be considered a simple, low-cost, high-intensity, task-oriented, patient-centered, and community-based therapy aimed at optimizing motor function recovery. Additionally, it systematically overcomes interference with participants' movements and environmental limitations from the training environment, while minimizing risks (Saposnik et al., 2016). Compared to immersive VR, non-immersive VR training is more cost-effective, less complex, and more adaptable (Saposnik et al., 2016). Non-immersive VR training can improve balance and gait performance in subacute stroke patients and contribute to the appearance of a normal gait pattern. However, the effectiveness of non-immersive VR technology is not superior to traditional balance and motor function training. Non-immersive

VR can be used as a complementary clinical rehabilitation therapy alongside conventional treatment (Bian et al., 2022).

VR and repetitive transcranial magnetic stimulation (rTMS) show promising potential in enhancing balance function in stroke patients. Task-oriented VR training can restore the balance of inhibitory signals between the two brain hemispheres, increase cortical motor neuron excitability on the affected side, promote functional reorganization within the central motor nervous system, and ultimately lead to improvements in motor function and balance(Liang, M., 2023). Research suggests that using virtual reality (VR) technology and multisensory stimulation can enhance activation of motor brain areas and reconstruct synaptic connections within the nervous system. By emitting pulsed magnetic fields through coils, rTMS can modulate excitability in specific cortical regions and blood flow in brain tissues(Wu, M. et al., 2019).Therefore, it aids in the neurofunctional reconstruction and repair within the infarcted area.

The combination of VR and Brain-Computer Interface (BCI) shows better rehabilitation effects. VR, through immersive virtual avatars, helps patients relearn lost motor functions due to illness—these avatars only perform and execute corresponding actions when the patient correctly imagines or attempts the target movement. The key is to create a "body ownership" experience for the subject, making the virtual limbs feel like the subject's own real limbs (N. Gao et al., 2023). The BCI system can record and analyze brain signals, which can then be used to control activities within the VR system. Connecting brain activity with motor tasks in VR can stimulate and enhance the reorganization of the central nervous system, thus promoting the rehabilitation process (Thi Chau et al., 2025). Furthermore, the VR-BCI system can be personalized and used at home, allowing patients to continue their rehabilitation after discharge.

Robot-assisted therapy uses computer-controlled systems to help individuals with various neurological diseases undergo rehabilitation. It can be categorized into therapeutic robots or assistive robots (Pignolo, 2009). Compared to traditional physical therapy, robot-assisted therapy can provide intensive, repetitive, and consistent movement training to restore motor functions post-stroke (Dobkin, 2004; Morone et al., 2020). The combination of VR and robot-assisted therapy can activate more neural circuits involved in motor learning, promoting neuroplasticity (Ranzani et al., 2020). The VR system, using immersive environments and real-time biofeedback, alleviates the monotony of training by transforming repetitive tasks into gamified, goal-oriented activities (e.g., simulating daily life scenarios). This can promote cortical reorganization through reward-based learning (Chen et al., 2025). When combined with robot devices that provide precise calibration of assistance or resistance, this hybrid approach enables data-driven personalization while reducing the physical workload for therapists (Voinescu et al., 2021).

2. Mechanisms of VR Training in Improving the Physical and Mental Health of Stroke Patients

Regulatory Mechanisms of VR Training on the Physical Health of Stroke Patients

The VR environment serves as a multifunctional platform for exploring the complex neurobiological mechanisms of neuroplasticity, encompassing sensory feedback integration, motor learning, and cognitive processing (Ettenhofer et al., 2019; Flores-Cortes et al., 2023; Katan & Luft, 2018). The neuroplasticity mechanisms it induces (as shown in Figure 2-1) are manifested in specific changes such as: enhanced regional activation of specific brain areas due to task activation, optimized inter-brain communication across regions, and strengthened brain-motor function connectivity through neuro-motor coupling enhancement (Wankhede et al., 2025). When individuals are immersed in these simulated environments, the central nervous system triggers molecular-cellular adaptive responses including structural reorganization (such as increased synaptic curvature and dendritic spine density), synaptic modulation (activation of NMDA receptors mediating calcium ion signaling pathways), and functional remodeling (elevated BDNF levels strengthening synaptic connections and promoting neuronal growth). These mechanisms, which enhance neural connectivity, play a key role in improving motor and cognitive function recovery outcomes (Colloca et al., 2020; Georgiev et al., 2021).

By immersing patients in interactive virtual environments, VR technology can enhance neuronal connectivity, activate NMDA receptors to trigger calcium ion-mediated signaling pathways, and increase brain-derived neurotrophic factor (BDNF) levels—these mechanisms collectively reinforce synaptic connections and promote neuronal growth, which is critical for brain function recovery, significantly improving motor and cognitive rehabilitation outcomes (Wankhede et al., 2025). The role of sensory feedback in modulating neuroplasticity changes within the VR environment is a core research area, shaping neural adaptability through multisensory integration, which is crucial for sensorimotor integration, perceptual learning, and environmental adaptation (Flores-Cortes et al., 2023; Han et al., 2022). The multisensory inputs integrated into VR, such as visual, auditory, and somatosensory feedback, trigger cascading molecular events, leading to synaptic modifications, dendritic spine reorganization, and neurochemical changes in brain sensory processing regions (Wankhede et al., 2025). Research based on animal models and clinical trials has revealed the molecular signaling pathway mechanisms involved in sensory-driven neural remodeling during VR exposure (Flores-Cortes et al., 2023; Han et al., 2022).

VR has become an important tool in the field of stroke rehabilitation, enhancing patients' motor function recovery, functional reconstruction, and quality of life through innovative methods. Its application is based on a systematic understanding of the neurobiological mechanisms of motor recovery and neural reorganization following brain damage from stroke (Cortés-Pérez et al., 2020). The core neurobiological perspective of VR rehabilitation focuses on neuroplasticity—the brain's remarkable ability to reorganize and adapt after injury (Kang et al., 2012). VR interventions utilize principles of neuroplasticity to promote the activation of residual neural circuits, enhance synaptic reorganization, and accelerate motor learning and relearning processes in individuals with post-stroke motor impairments (Hao et al., 2022; Maier et al., 2019).VR-based interventions provide an immersive interactive environment that drives repetitive task-oriented training, stimulates sensory-motor feedback, motor planning, and coordination abilities, thereby activating motor-related brain regions and promoting motor function reconstruction (Darekar, 2023; Rodríguez-Hernández et al., 2023). The application of VR technology in stroke rehabilitation is rooted in principles of motor learning and skill acquisition: VR-based interventions integrate customizable training programs for specific motor tasks and functional activities, allowing patients to engage in goal-oriented movements within a safe, controlled virtual environment (Maier et al., 2019; Rodríguez-Hernández et al., 2023).Through the integration of real-time feedback, adaptive task difficulty, and performance monitoring, VR interventions promote motor skill acquisition, coordination ability, and motor sequence learning, thereby accelerating the consolidation of motor memory and optimizing the relearning process for post-stroke motor impairments (Maier et al., 2019; Muratori et al., 2013). Additionally, VR rehabilitation integrates sensory stimulation and motor imagery techniques, emphasizing the value of multisensory input and cognitive engagement in motor function reconstruction. The multimodal perceptual environment it provides—comprising visual, auditory, and somatosensory feedback—enhances sensorimotor integration and perceptual-motor coordination (Amini Gougeh & Falk, 2022; Choy et al., 2023). The incorporation of motor imagery and action observation tasks further activates the mirror neuron system, enhancing motor planning and execution abilities through imitation and internalization (Errante et al., 2022; Xiong et al., 2022).

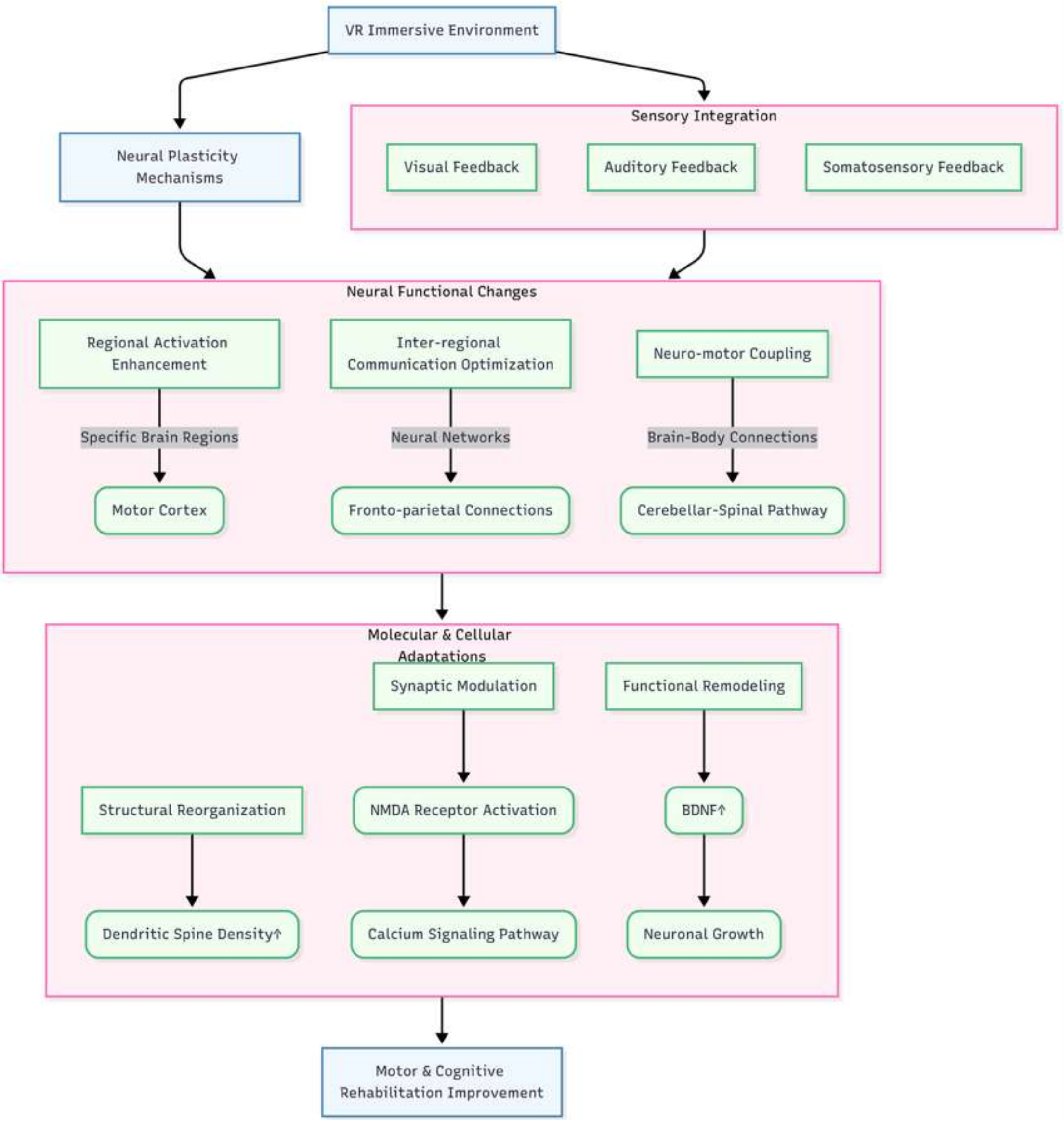

Figure 1. The mechanism of the effects of VR training on the physical health of stroke patients.

Regulatory Mechanisms of VR Training on the Psychological Health of Stroke Patients

VR-based neurorehabilitation interventions can enhance patients' engagement in virtual interaction and training processes (Bell et al., 2024), thereby boosting treatment motivation and promoting their active participation in diverse rehabilitation activities (Postolache et al., 2021). The specificity of this effect is manifested in the significant increase in the activation levels of specific brain regions, such as the prefrontal cortex and the mirror neuron system. This type of neural regulation is clearly associated with behavioral improvements (Hao et al., 2022). VR technology integrates sensory modalities such as visual and auditory feedback, optimizing brain-cortex network interactions and promoting neuronal structural reorganization (Gangemi et al., 2023). This neuroplasticity plays a key role in the rehabilitation of impaired brain functions and can alleviate negative psychological symptoms in stroke patients.Additionally, VR supports dynamic adjustment of task difficulty based on individual abilities and allows for flexible switching between various safe training scenarios (Weber et al., 2019). The immersive characteristics of VR, through multisensory engagement, interactive feedback, and repetitive practice, enhance learning outcomes, induce cognitive resonance, and promote psychological immersion (Jongbloed et al., 2024). Ultimately, this leads to a positive feedback loop that strengthens functional compensation abilities (Li et al., 2025).

There are strategic differences in the application of VR interventions for post-stroke depression (PSD) and post-stroke anxiety (PSA): VR technology aimed at PSD promotes stress relief and the reconstruction of positive emotions through predefined virtual scene interactions (Hao et al., 2022). For PSA, VR simulates anxiety-inducing sources in the virtual environment, helping patients develop strategies to remain calm and manage stress responses. The focus is on replicating reactions in anxiety-inducing scenarios and training coping mechanisms (R.-C. Lin et al., 2020).The simulated environment, through multi-modal scenario customization and practice, effectively improves psychological disorders. As a novel therapy in stroke rehabilitation (M. Lee et al., 2016), studies have shown that VR interventions significantly reduce negative emotions in patients with psychological disorders, alleviate social and psychological pain, and enhance overall quality of life (Wiebe et al., 2022).

3. VR Training Effects on the Physical and Mental Health of Stroke Patients

Physical Function

The impact of training on the physical health of stroke patients is highly significant, particularly through rehabilitation training and targeted physical therapy. Stroke patients often experience varying degrees of motor dysfunction, speech impairments, and cognitive damage. Appropriate training and rehabilitation therapy can help patients regain some functions, improve physical health, and in certain cases, achieve near-normal levels of daily living. As shown in Table 1, VR-based training has been proven to enhance the physical health of stroke patients.

VR Training for the Recovery of Motor Function in Stroke Patients

VR-based training for the recovery of motor function in stroke patients has been shown to be an effective supplementary tool to traditional rehabilitation methods. Several studies indicate that VR therapy can significantly promote the physical recovery of stroke patients (Errante et al., 2022; Fang et al., 2022; Ikbali Afsar et al., 2018; Kiper et al., 2018). For instance, Lee et al. (2023) discussed how integrating VR rehabilitation training in a hospital setting improved upper limb function, daily activity performance, and cognitive function (L.-J. Lee et al., 2023). Hao et al. (2023) explored the impact of home-based VR rehabilitation, finding that this approach significantly improved patients' upper limb mobility and walking ability (Hao et al., 2023). Bian (2022) examined the VR-based intervention's effect on lower limb motor function, balance, and gait performance, noting improvements in these areas.

These studies suggest that incorporating VR technology into traditional therapies offers targeted repetitive practice, which is crucial for promoting neuroplasticity and motor learning. Korkusuz (2024) compared VR training with conventional physical therapy and found that VR training effectively improved dynamic balance in patients. This was attributed to the efficient stimulation of rapid postural adjustments and multi-joint coordination abilities in VR tasks (Korkusuz et al., 2024). However, the effectiveness of VR in improving static balance remains controversial. In a meta-analysis by Lyu (2023), compared with control groups, gait training (including weight-bearing treadmills and virtual reality gait training) did not show any significant effects on static balance. Static posture maintenance might rely more on proprioceptive reinforcement, with VR's visual feedback contributing less to this aspect (Lyu et al., 2023).

Table 1: Literature List on the Adjustment Effects of VR Training on the Physical Health of Stroke Patients

Author	Treatment Duration & Intervention Frequency	Group Intervention Measures	Outcome Indicators	Main Results
Vitor Antônio dos Santos Junior et al. (2019) [79]	50min per session, twice a week for two months	VR Group (n=16); PNF Group (n=16); VR+PNF Group (n=16)	FM	Significant improvements in passive movement and pain scores observed in the PNF group and PNF+VR group; Similar results were seen in upper limb motor function, lower limb motor function in the VR group, and balance in the PNF and PNF+VR groups.
Carlos Luque-Moreno et al. (2021) [80]	2h per session, five times a week for three weeks	VR+CP Group (n=10); CP Group (n=10)	FAC, FIM, FM, BBS, TCT	Only the VR+CP group showed significant improvement in FAC. In FIM, the CP group showed a tendency toward significance, while VR+CP showed significant results. Both groups showed significant improvement in FM (especially in VR+CP's amplitude, pain, and CP's sensitivity) and BBS. No significant improvements were observed in TCT.

Continuation of Table 1: Literature List on the Adjustment Effects of VR Training on the Physical Health of Stroke Patients

Author	Treatment Duration & Intervention Frequency	Group Intervention Measures	Outcome Indicators	Main Results
Hyun-min Moon et al. (2024) [81]	30 minutes per session, twice a week for eight weeks	VR Group; TPT Group; VR+TPT Group (n=54)	BBS, TUG, 10MWT, Gait Analysis, ABC	Compared to the TPT group, both the VR group and VR+TPT group had significant impacts on spatial-temporal 4variables a5nd co6nfidence (p<70.05). Spec8ifically, the V9R group showed superior results in TUG, 10MWT, speed, stride, single-leg stance, and ABC (p<0.05).
Naveed Anwar et al. (2022) [82]	1h per session, three times a week for six weeks	VR Group (n=37); CP Group (n=37)	BBS, FM	Significant differences in BBS (P<.001), motor function FMA (P=.03), joint pain, and joint range FM (P<.001); however, no significant difference in upper limb sensation FM (P=0.19).

Roberto Llorens et al. (2021) [83]	30 minutes per session, three to five times a week	tDCS+VR Group (n=16); CP Group (n=16)	FM-UL, WMFT, NSA	After the experimental intervention, all motor measurements showed clinically significant improvements in upper limb motor function, which was not observed after conventional physical therapy. Similar limited effects were detected in both groups for sensory function.
Chan Wai Yin et al. (2014) [84]	30 minutes per session, five times a week for two weeks	VR Group (n=11); CP Group (n=12)	FM	All participants' FM scores improved (mean change (SD) = 11.65 (8.56), P<0.001). All other outcome indicators showed a similar pattern. No significant difference between the two groups in improvement. Most participants found VR training useful and interesting, with no serious adverse reactions reported.

Continuation of Table 1: Literature List on the Adjustment Effects of VR Training on the Physical Health of Stroke Patients

Author	Treatment Duration & Intervention Frequency	Group Intervention Measures	Outcome Indicators	Main Results
Keng HeKong et al. (2016) [85]	1h per session, four times a week for three weeks	VR Group (n=33); CP Group (n=35)	FM-UL, ARAT, FIM, SIS	No statistical significance in changes between the two groups after intervention.
Yoon-Hee Choi et al. (2016) [86]	30 minutes per session, five times a week for two weeks	VR Group (n=12); CP Group (n=12)	FM-UL, MWS, MMT, MBI, EQ-5D, BDI	Significant statistical differences between FM-UL, MWS, and MMT between the two groups.
Ho-Suk Choi et al. (2021) [77]	30 minutes per session, three times a week for four weeks	VR+LeapMotion Training Program (n=12); Conventional USN-Specific Training (n=12)	LBT, CBS, MBI, MVPT-V, Head Horizontal Motion	Compared to the control group, the VR group showed more responses to left-side visual tasks (P=0.024), more correct responses in left and right visual tasks (P=0.024 and P=0.014), and faster response times (P=0.014). Additionally, in VR-based exercises, VR group had significantly higher levels of rotational and speed horizontal head movements than the control group (P=0.007 and P=0.001).
Yu Bai et al. (2022) [78]	40-60 minutes per session, five times a week for ten weeks	VR+AI (n=25); TPT (n=250)	FMA-UL, FMA-LE, FTHUE-HK, BI, ADL Activities, BBS	The control group had lower scores in FMA-UE, FMA-LE, FTHUE-HK, BI, ADL activities, and BBS compared to the experimental group, but had higher MWS scores (P<0.05).

Note: *PNF = Proprioceptive Neuromuscular Facilitation, CP = Conventional Physical Therapy, TPT = Traditional Training, FM = Fugl-Meyer Assessment, FAC = Functional Ambulation Classification, FIM = Functional Independence Measure, BBS = Berg Balance Scale, TCT = Trunk Control Test, TUG = Timed Up and Go Test, 10MWT = 10-Meter Walk Test, ABC = Activities-specific Balance Confidence Scale, FM-UL = Fugl-Meyer Assessment Upper Limb Subscale, WMFT = Wolf Motor Function Test (Time and Ability Subscales), NSA = Nottingham Sensory Assessment, ARAT = Action Research Arm Test, SIS = Stroke Impact Scale, tDCS = Transcranial Direct Current Stimulation, MMT = Manual Muscle Test, MBI = Modified Barthel Index, EQ-5D = EuroQol Five-Dimensional Scale, BDI = Beck Depression Inventory, LBT = Line Bisection Test, CBS = Catherine Bergego Scale, MVPT-V = Motor-Free Visual Perception Test Vertical Version, FMA-LE = Fugl-Meyer Assessment Lower Limb Subscale, FTHUE-HK = Fugl-Meyer Assessment Hong Kong Version, BI = Barthel Index, ADL Activities = Activities of Daily Living,MWS Score = Brunnstrom Stages of Motor Recovery.*

VR Training for Improving Activities of Daily Living (ADL) in Stroke Patients

VR training may offer advantages over traditional therapies in ADL rehabilitation. Firstly, VR platforms allow individuals to practice real-world tasks that are difficult to implement in the physical world (e.g., crossing the street) in a safe and controlled manner (Katz et al., 2005). Such interventions are more engaging and motivating, which can enhance rehabilitation participation (Thornton et al., 2005). Secondly, compared to conventional treatments, VR enhances the ecological validity of rehabilitation by simulating real environments (Rizzo & Kim, 2005). Therapists can adjust task difficulty according to the patient's functional capacity and gradually increase the challenge as rehabilitation progresses, thus enabling customizable, individualized rehabilitation (Grewal et al., 2024). Finally, the technology supports task repetition, providing an effective pathway for reinforcing practice and skill transfer (Brunner et al., 2016; Levin, 2011).

VR training can guide participants through simulated daily life scenarios and provide timely feedback. The skills gained during VR training may be better transferred to real-world activities. In a single-blind randomized controlled trial by Choi (2021), the effects of VR training versus unilateral spatial neglect (USN) specific training on subacute stroke patients' rehabilitation were compared. The study concluded that both groups showed improvements over time in tests such as the line bisection test, the Catherine Bergego Scale, the Modified Barthel Index, the MVPT-V (Motor-free Visual Perception Test-Vertical), and head tracking sensor data (H.-S. Choi et al., 2021).In a study by Bai (2022) comparing a VR-based AI rehabilitation system with traditional drug treatments, the effects on long-term health management were assessed based on motor function and ADL. The results showed that the control group had lower scores on the Fugl-Meyer Upper Extremity Scale (FMA-UE), Fugl-Meyer Lower Extremity Scale (FMA-LE), Hong Kong version of the Fugl-Meyer Upper Extremity Test (FTHUE-HK), Barthel Index (BI), ADL, and the Berg Balance Scale (BBS) compared to the experimental group. This suggests that the VR-based AI rehabilitation system significantly improves long-term health management in stroke patients and is more effective than traditional drug treatments, making it valuable for clinical promotion (Bai et al., 2022).

Psychological Well-being

VR training also has a significant positive impact on the psychological health of stroke patients. Stroke not only leads to physical impairment but is often accompanied by emotional, cognitive, and psychological health issues, such as depression, anxiety, mood swings, and social isolation. Therefore, psychological rehabilitation and appropriate training can help patients recover their mental health, improve emotional and cognitive function, and promote overall recovery. As shown in Table 2, multiple studies have demonstrated that VR-based training can enhance the psychological health of stroke patients.

VR Training Can Alleviate Negative Emotions in Stroke Patients

VR training can significantly alleviate the negative emotions of stroke patients. The VR environment can activate the parasympathetic nervous system, trigger intense emotional responses, and effectively reduce psychological stress. By constructing realistic multisensory environments, VR promotes motor function recovery and improves daily activity capabilities, thus benefiting psychological health (Li et al., 2025). A systematic review by Qian (2020) demonstrated the potential value of exercise-based VR interventions in improving psychological outcomes (Qian et al., 2020).VR interventions have shown potential in alleviating depressive symptoms in stroke survivors (Blázquez-González et al., 2024; Y. Gao et al., 2021; C. Lin et al., 2023). Stroke-related physical and motor impairments require a long rehabilitation period, imposing a heavy burden on both the patient and their family. This extended recovery process can lead to negative psychological states and increase the risk of depression (Medeiros et al., 2020). The new model of exercise rehabilitation based on gamified VR technology can significantly enhance the enjoyment and immersion of therapy (Jongbloed et al., 2024), increasing patient compliance and participation, encouraging them to actively engage in their rehabilitation program.Additionally, VR technology promotes neuroplasticity through exercise training and reduces neuroinflammation (Kayabinar et al., 2021), optimizing brain neural tissue structure and alleviating negative emotions. A meta-analysis by Li (2025) confirmed that VR interventions are effective for post-stroke depression (PSD) but noted high heterogeneity in the results. The analysis revealed that VR interventions were more effective in patients younger than 60, showing a more significant improvement in their ADL (Li et al., 2025). This may be because older patients experience age-related declines in visual and auditory abilities, which reduce their ability to adapt to new treatment methods (Dermody et al., 2020), limiting the benefits of VR interventions. In contrast, younger patients typically have better physical function and recovery potential, with higher motivation to restore motor function and improve quality of life through VR training (Halldorsson et al., 2021). They also exhibit higher acceptance and better ability to operate new technologies, thus utilizing VR more efficiently for rehabilitation.

VR interventions lasting more than 6 weeks showed more significant improvements in depressive symptoms (Blázquez-González et al., 2024) because stroke rehabilitation is a long-term process involving both physical and psychological adaptation. Patients not only need to readjust to their post-stroke physical condition but also face the reality of reduced ADL (Dworzynski et al., 2015). Additionally, the psychological problems resulting from functional impairments require enough intervention time to accumulate therapeutic effects. Li (2025) also found that VR was effective for moderate depression, but no significant differences were observed in cases of mild depression (Li et al., 2025).However, a meta-analysis on anxiety revealed no significant effect of VR intervention. Anxiety may stem from multiple specific triggers, such as psychological adaptation difficulties, reduced social participation, and the decline in life skills (Knapp et al., 2020). While VR can simulate a variety of scenarios, it may not accurately replicate the anxiety triggers that patients actually experience, limiting its effectiveness in alleviating anxiety.

Table 2: Literature List on the Psychological Health Adjustment Effects of VR Training for Stroke Patients

Author	Treatment Duration & Frequency	Group Intervention Measures	Measurement Tools	Main Results
Pawel Kiper et al. (2022) [87]	1 hour per session, 6 weeks	VR (n=30); SAT (n=30)	Geriatric Depression Scale, General Self-Efficacy Scale, Disease Acceptance Scale, Visual Analog Scale for Pain, Hospital Anxiety and Depression Scale, BI, Lawton ADL Scale, Rivermead Motor Assessment	VR group showed significant reduction in depression symptoms ($\eta p^2=0.13$, $p<0.01$) compared to SAT.
Ta-Chung Chao et al. (2024) [88]	60 minutes per session, 5 sessions per week, 3 weeks	Early rehabilitation + VR (n=16); Early rehabilitation (n=17)	PASS, FIM, Barthel Scale, HADS	VR group showed a more significant reduction in depression at discharge compared to early rehabilitation group (ß=3.77, p=0.011). No difference in muscle strength and functional recovery post-intervention.
Hsin-Chieh Lee et al. (2017) [89]	90 minutes per session, 2 sessions per week, 6 weeks	VR + Standard Treatment (n=25); Standard Treatment (n=25)	BBS, TUG-cog, BI, Functional Range Test	Significant improvements in BBS (P=0.000) and TUG-cog (P=0.005) over time for both groups. VR group found the intervention more enjoyable (P=0.027). No significant difference in other outcome measures. No severe adverse events reported in both groups.
Gui Bin Song et al. (2015) [90]	30 minutes per session, 5 sessions per week, 8 weeks	VR (n=20); ETG (n=20)	BDI, RCS	Both VR and ETG groups showed significant differences in weight distribution and balance on the paralyzed side. Significant improvement in BDI and RCS for both groups, with VR showing a more significant BDI improvement.

Continuation of Table 2: Literature List on the Psychological Health Adjustment Effects of VR Training for Stroke Patients

Author	Treatment Duration & Frequency	Group Intervention Measures	Measurement Tools	Main Results
De Luca, R et al. (2018) [91]	45 minutes per session, 3 sessions per week, 8 weeks	VR (n=6); Cognitive Therapy Group (n=6)	TCT, MoCA, SAT, Language Memory, RCFT	The VR group showed greater improvement in TCT (p=0.03), MoCA (p=0.01), SAT (p=0.01), language memory (p=0.03), and RCFT (p=0.01) compared to the cognitive therapy group. The improvement in the VR group persisted at T2.
Yi Long et al. (2020) [92]	45 minutes per session, 5 sessions per week, 3 weeks	VR (n=30); CP (n=30)	COPM, SSEQ, MBI, FM-UL, PUL	Significant group differences in SSEQ (median difference=8, P=0.043) and MBI (median difference=10, P=0.030). No significant differences in COPM, FM-UL, and PUL. No severe adverse events reported.
Dong-Rae Cho et al. (2019) [93]	30 minutes per session, 5 sessions per week, 4 weeks	VR + Cognitive Therapy (n=21); Cognitive Therapy (n=21)	LOTCA, CNT, FIM	Both groups showed improvements in attention and memory, cognitive function, and daily life activities.

***Note**: SAT= Schultz's Autogenic Training, BI = Barthel Index, PASS = Postural Assessment Scale for Stroke Patients, FIM = Functional Independence Measure, HADS = Hospital Anxiety and Depression Scale, BBS = Berg Balance Scale, TUG-cog = Timed Up and Go Test with Cognitive Component, BDI = Beck Depression Inventory, RCS = Rehabilitation Coping Scale, TCT = Trunk Control Test, MoCA = Montreal Cognitive Assessment, RCFT = Rey–Osterrieth Complex Figure Test, COPM = Canadian Occupational Performance Measure, SSEQ = Simplified Social Adaptation Scale, MBI = Modified Barthel Index, FM-UL = Fugl-Meyer Assessment Upper Limb Subscale, PUL = Purdue Pegboard Test, LOTCA = Lowenstein Occupational Therapy Cognitive Assessment, CNT = Cognitive Neurotherapy Test.*

However, a meta-analysis focusing on anxiety indicated that VR intervention did not have a significant effect. This may be due to anxiety being caused by multiple specific factors such as psychological adaptation issues, reduced social participation, and decline in life skills [103]. While VR can simulate various scenarios, it is difficult to authentically replicate the anxiety triggers that patients experience in real life, which limits its effectiveness in alleviating anxiety.

VR Training Can Improve Cognitive-Behavioral Function in Stroke Patients

Cognitive function encompasses a wide range of complex concepts such as attention, executive function, memory, and psychomotor speed (Zhang et al., 2019). According to a literature review by Zhang (2021), VR training has been found to improve executive function, memory, and visuospatial abilities in stroke patients, suggesting that VR is an effective therapy for enhancing specific cognitive domains (Zhang et al., 2021). VR demonstrates great potential as a methodological approach to improve specific cognitive-behavioral functions, including executive function, attention, spatial cognition, memory, and language.A systematic review by Alexander (2019) and colleagues also supports the positive outcomes for these specific cognitive areas (Moreno et al., 2019). Flannery (2002) noted that VR training activates brain metabolism, increases cerebral blood flow, and stimulates neurotransmitter release, all of which contribute to cognitive improvement. Carrieri et al. (2019) confirmed that VR can promote the reactivation and improvement of various cortical functions, optimize sensory cortical efficiency and effectively enhancing cognitive functions (Park et al., 2019).

In clinical practice, VR training simulates real-life scenarios and demonstrations, providing real-time guidance and feedback for participants (Weiss et al., 2006). The abilities gained through VR training are more effectively transferred to daily activities. Additionally, VR integrates participants' physical movements, vocal and visual feedback, and provides immediate encouragement from therapists and family members (Merians et al., 2002). This helps participants better understand their performance, boosting their sense of accomplishment (Demain et al., 2013), and subsequently increases their enthusiasm and confidence in daily activities. The characteristics of VR interventions align with the four principles of self-efficacy enhancement (direct experience mastery, vicarious experience, verbal persuasion, and physiological state regulation). In a 3-week study by Long (2020), it was found that VR training can increase self-efficacy and improve ADL (Long et al., 2020). Numerous studies have confirmed that VR training significantly enhances stroke patients' confidence and self-efficacy, both of which are key psychological factors influencing post-stroke social participation. By conducting basic motor function training in a safe, controlled virtual environment, patients can rebuild their confidence in physical abilities during VR training, making them more likely to reengage in daily life activities and outdoor exercises (Woodman et al., 2014).

D. Conclusion

VR training not only enhances patients' upper and lower limb strength, balance, and other physical functions, thereby improving their ability to perform daily activities, but it also alleviates anxiety and improves depression and other psychological issues in stroke patients. Currently, VR training for the physical and mental rehabilitation of stroke patients primarily involves immersive or non-immersive VR for task-oriented training or cognitive-motor integration training. Additionally, VR can be combined with interventions such as transcranial magnetic stimulation (rTMS), brain-computer interfaces (BCI), and assistive robots to support stroke rehabilitation. The current research on VR training for the physical and mental health of stroke patients mainly presents descriptive phenomena and lacks in-depth analysis of underlying mechanisms. Further scientific and rigorous experimental designs are needed to explore the internal mechanisms of VR interventions in stroke patients' physical and mental health, incorporating deeper insights from fields such as physiology, biology, and medicine.

Current studies often suffer from small sample sizes and lack consideration of stroke type (ischemic or hemorrhagic) and disease progression stages (acute, subacute, or chronic), which limits the generalizability of the findings. Future research should increase sample sizes and stratify random groups based on stroke type and disease progression stages. Most current studies on VR training for stroke patients use traditional control designs, comparing conventional rehabilitation with VR-based interventions. This approach makes it difficult to isolate the specific contributions of VR. Future research should adopt more rigorous designs that better differentiate the unique effects of VR from other interventions. Existing studies often focus on short-term outcomes and lack long-term follow-up data, making it challenging to assess the lasting effects of VR training. Future studies should incorporate a stepwise assessment framework and track the maintenance of functional improvements over extended periods.

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