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Impact of Virtual Reality–Based Task-Oriented Training for Enhancing Motor Function and Activities of Daily Living in Patients With Subacute Stroke: A Randomized Controlled Trial

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Background: Stroke frequently causes persistent motor impairment and dependence in activities of daily living (ADL). Virtual reality (VR) offers immersive, repetitive, task-specific training that may promote neuroplasticity. This study aimed to investigate the efficacy of VR-based task-oriented training in enhancing motor function and ADL among patients during the subacute phase of stroke recovery.

Material/Methods: Eligible patients with stroke (April 2022-March 2024) were randomly allocated to either a control group (conventional task-oriented training) or intervention group (VR-based task-oriented training) using a computer-generated randomization sequence. Both cohorts received standard rehabilitation. Changes in Fugl-Meyer Assessment (FMA) and Barthel Index scores over 4 weeks served as the primary and secondary outcomes, respectively. All 64 patients completed the study, with no dropouts.

Results: A total of 64 patients were enrolled, with 32 individuals each in the control and intervention groups. Baseline characteristics and initial scores showed no significant differences (all $P > 0.05$). After 4 weeks, analysis of covariance adjusting for baseline values demonstrated that the intervention group achieved significantly higher adjusted mean scores across all parameters: Total FMA ($P < 0.001$, $\eta p^2 = 0.526$), FMA-upper extremity ($P < 0.001$, $\eta p^2 = 0.458$), FMA-lower extremity ($P < 0.001$, $\eta p^2 = 0.475$), and Barthel Index ($P < 0.001$, $\eta p^2 = 0.536$).

Conclusions: VR-based task-oriented training was associated with significantly greater improvements in motor function and ADL compared with traditional methods. The observed improvements exceeded established minimal clinically important differences, suggesting clinical relevance. This technology serves as a promising adjunct to stroke rehabilitation, although further large-scale research is recommended.

Keywords: stroke rehabilitation • virtual reality

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Introduction

Stroke, a cerebrovascular disease characterized by acute disruption of cerebral blood flow, can result from thrombosis, ischemia, or cerebral hemorrhage [1,2]. Evidence from the Global Burden of Disease, Injury, and Risk Factors Study indicates that stroke significantly increases the global risk of death or disability, ranking it as the second leading cause of death worldwide [3]. With a 1-year mortality rate of 14.3%, stroke poses a severe threat to patients' health [1]. Approximately 80% of stroke survivors experience varying degrees of focal weakness, manifesting as motor impairments in the arms, legs, or face, alongside symptoms such as aphasia, dysarthria, hemiplegia, ataxic gait, abnormal eye movements, or visual field deficits. Despite rehabilitation efforts, more than half of all stroke survivors were dependent on others for everyday activities [4-6]. These functional limitations and disabilities substantially impair daily activities, hindering improvements in quality of life [7,8]. Consequently, targeted rehabilitation interventions for subacute stroke survivors have become a global consensus [9-11].

In current clinical practice, neurorehabilitation interventions based on motor relearning and neuroplasticity theories have been widely implemented. These include task-oriented movement training, motor imagery, mirror therapy, and neurofeedback therapy, which effectively improve patients' limb movement, trunk control, sitting balance, and activities of daily living (ADL) [12]. However, traditional rehabilitation training faces limitations such as equipment constraints and patients' attention deficits, which compromise training effectiveness [13]. Advances in computer technology have propelled VR into stroke rehabilitation, primarily categorized into 3 types: immersive VR, semi-immersive VR, and non-immersive VR [14]. Semi-immersive VR and non-immersive VR typically operate in a 2-dimensional (2D) environment displayed on computer screens or gaming consoles. The key difference is that non-immersive VR users interact through input devices like mice and joysticks, while semi-immersive VR employs infrared sensors to detect user movements. Immersive VR systems, equipped with head-mounted displays and 3D interaction devices, enable deeper engagement with virtual environments. Studies have demonstrated significant efficacy of VR training for stroke patients [15-17], with mechanisms including: creating time-space-geographically unrestricted immersive simulations [18]; enabling real-time 2-way interactions (eg, physical feedback during virtual object grasping) [19,20]; integrating multisensory feedback (visual and auditory) to enhance cerebral cortex activity; promoting functional brain network reorganization; and effectively stimulating neuroplasticity to facilitate motor learning and functional recovery [21]. Multiple meta-analyses indicate that while VR applications demonstrate significant improvements in upper limb motor function, hand dexterity, and trunk control for patients with stroke, existing evidence regarding lower limb function, balance, and ADL remains limited and inconsistent [22-27]. Moreover, the effectiveness and precise effect of various VR technology applications require further verification [25,28].

Therefore, this study aims to investigate the effects of VR-based task-oriented training, specifically using the novel XY-Kinapsys system, on motor function and ADL capabilities in hospitalized patients with subacute stroke. We hypothesized that, compared with conventional task-oriented training, a 4-week regimen of VR-based task-oriented training would lead to significantly greater improvements in motor function, as measured by the Fugl-Meyer Assessment (FMA), and in ADL, as measured by the Barthel Index, in patients with subacute stroke.

Material and Methods

Study Design and Patients

This randomized controlled trial enrolled patients with subacute stroke who received treatment at our hospital between April 2022 and March 2024. The study was approved by the Ethics Committee of Zhejiang Rehabilitation Medical Center (approval No. ZKLL2022030001). All participants signed informed consent forms (including human image acquisition) and explicitly agreed to participate voluntarily to improve future patients' quality of life. Patients could withdraw at any time during the study, with all arrangements communicated in advance. This study strictly adhered to the ethical principles outlined in the Declaration of Helsinki and was registered in a clinical trial registry. In our center, a 4-week (approximately 1-month) intensive inpatient rehabilitation program constitutes the standard of care for patients with subacute stroke.

The inclusion criteria were (1) a confirmed diagnosis of first-episode stroke based on the diagnostic standards of the Neurology Branch of the Chinese Medical Association [29]; (2) age over 40 but less than 75 years; (3) subacute phase (≥ 1 week and ≤ 3 months after stroke onset) with stable vital signs; (4) alert and oriented, with Mini-Mental State Examination (MMSE) score of 21 or higher, normal communication abilities, and a Brunnstrom stage greater than 3 [30]; (5) hemiplegia; (6) bilateral visual acuity or corrected visual acuity over 1.0; and (7) patients who provided signed informed consent. The exclusion criteria were (1) disturbance of limbs caused by other diseases; (2) psychiatric disorders that might interfere with treatment compliance; (3) multiple organ dysfunction; and (4) visual or auditory impairments. Dropout criteria included (1) patients who did not strictly follow the study protocol; (2) voluntary withdrawal; (3) inability to continue treatment due to worsening condition or discharge. All patients were fully involved in the study.

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Table 1. Detailed specifications of virtual reality–based task-oriented training.

Task	Target movements	Device and posture	Duration per session	Difficulty progression (Levels 1 to 5)
Watering flowers	Shoulder flexion/ extension, elbow control	HMD, seated	6 min	Pot size: large → small Distance: near → far Time limit: none → present
Lighting candles	Shoulder abduction, precise pointing	HMD, seated	6 min	Wick size: large → small Stability requirement: low → high
Forest traversal	Lateral weight shifting, dynamic balance	Screen, standing	6 min	Obstacle speed: slow → fast Path width: wide → narrow
Soccer kicking	Hip/knee flexion, single-leg stance	Screen, standing	6 min	Goal size: large → small Ball speed: slow → fast Direction: fixed → random
Tennis playing	Limb coordination, trunk rotation	Screen, standing	6 min	Ball speed: slow → fast Ball placement: center → corners Mode: feeding → rally

Safety measures: Therapist supervises throughout. The headset is used only for seated upper-limb training; standing/balance tasks use the screen, fundamentally eliminating fall risks due to visual obstruction. Abbreviations: HMD, head-mounted display.

Intervention

Members of the project team enrolled patients with subacute stroke in our hospital in strict accordance with the inclusion and exclusion criteria. Eligible patients were randomly allocated to the control group or the intervention group in a 1: 1 ratio using a computer-generated random number sequence. Allocation concealment was maintained using sequentially numbered, opaque, sealed envelopes prepared by an investigator who was not involved in participant enrollment or treatment. The researcher responsible for group assignment did not participate in outcome assessment or statistical analysis. Outcome measures were collected by trained evaluators who were blinded to group allocation, ensuring separation of the roles of researchers, intervention operators, and statisticians.

A total of 64 patients were included in this study, with 32 individuals assigned to the control group and 32 individuals in the intervention group. The standard inpatient rehabilitation protocol remained consistent for all participants throughout the study period, as did the core clinical team overseeing care.

All participants in the control and intervention groups received standard rehabilitation therapy, including active/passive training for the hemiplegic side (either assisted by medical staff or performed by patients under guidance), muscle strength exercises, gait training, balance training, and physical therapy (eg, Rood and Bobath techniques) [31,32], administered once daily for 40 minutes, 5 days a week, with 2 days of rest, over a 4-week cycle.

The control group received additional conventional task-oriented training alongside standard rehabilitation. The training involved functionally meaningful activities such as wiping tables, moving objects of varying weights, simulating eating and drinking, and retrieving items while walking. To ensure progression, the difficulty level was increased every 1 to 2 weeks by a trained therapist based on the patient's performance. For example, progression was achieved by increasing the weight of objects to be moved (from 0.5 kg to 2 kg), reducing the base of support during standing tasks (from bilateral stance to semi-tandem stance), or increasing walking distance or obstacle complexity. To ensure standardization across different therapists, a detailed treatment manual was developed, specifying the initial parameters for each activity, the criteria for progression (eg, successful completion of 8 out of 10 repetitions on 2 consecutive sessions), and maximum allowed assistance levels. All sessions were delivered in a one-on-one format by trained physical or occupational therapists who were not involved in outcome assessment. This was conducted once daily for 30 minutes, 5 days a week, with 2 days of rest, over a 4-week cycle.

The intervention group underwent task-oriented training using VR technology (XY-Kinapsys devices provided by Xiangyu Medical Equipment Co, Ltd) in addition to standard rehabilitation therapy. The system used the XY-Kinapsys platform with a Kinect v2 depth sensor for motion capture, featuring a resolution of 512 × 424, field of view of 70.5° × 60°, latency of approximately 50 ms, and operating range of 0.5 to 4.5 m. Before training, patients received special guidance on the wearing of VR devices, the number of training groups and the number of repetitions. Therapists assessed and configured virtual scenario items and training durations (**Table 1**).

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Figure 1. XY-Kinapsys virtual reality (VR) device and its application in rehabilitation therapy. (**A**) The XY-Kinapsys VR equipment (Xiangyu Medical Equipment Co, Ltd, China) used in this study. (**B, C**) The participant completed tasks under the supervision of the rehabilitation therapist using an external display.

Upper Limb Training

Participants sat wearing a head-mounted display and sensors (**Figure 1A, 1B**) in a virtual environment. They performed 2 tasks: (1) watering flowers, in which multiple pots were displayed and patients selected targets based on limb mobility, with virtual sprinklers simulating watering and blooming flowers providing visual feedback; and (2) lighting a candle, in which a lantern with a candle was displayed, and patients operated a torch to ignite the candle, causing the lantern to rise and accompanied by sound effects confirming success.

Lower Limb Training

Participants stood in a virtual environment with large-screen projection and did not wear a head-mounted display (**Figure 1C**). They completed 2 tasks: (1) forest crossing, in which forests flanked a central road with obstacles such as stones, and patients moved left and right using lower limb movements to avoid obstacles, earning a coin reward for each successful avoidance, accompanied by applause and other auditory encouragement; and (2) soccer kick, in which patients stood in front of a goal on a virtual soccer field and used lower limb movements to approach and kick soccer balls appearing from different directions at timed intervals, earning points and cheering sounds for successful goals.

Full-Body Training

Participants stood in a virtual tennis court with large-screen projection and did not wear a head-mounted display (**Figure 1C**). They performed a single task: (1) hitting a tennis ball, in which patients approached a ball displayed on the screen using lower limb movements and struck it with upper limb movements, receiving points and auditory encouragement, such as cheers, for successful hits.

The complete training parameters are presented in **Table 1**. Patients underwent a 4-week intervention, with 1 session per day, 5 days a week (20 sessions total). Each session consisted of 5 distinct VR tasks. Each task was performed for a strict duration of 6 minutes, resulting in a total daily core training time of 30 minutes (excluding setup and cool-down periods). The tasks were performed in a fixed order.

The therapist monitored the patient's training process in real time through a display screen. Each task's initial difficulty level was individually determined by the therapist based on the patient's baseline assessment, with adjustments made to the program difficulty after evaluating the task success rate (automatically recorded by the VR system). If the patient achieved an average success rate of 85% or higher for 2 consecutive training sessions at the current difficulty level, the task difficulty was increased by 1 level in subsequent sessions. Conversely, if the success rate fell below 50% or the patient reported extreme fatigue (Borg CR10 score > 5), the difficulty level was temporarily reduced.

Outcome Measurements

Assessments of motor function and ADL were conducted before treatment and after 4 weeks of intervention. The primary outcome was the evaluation of motor function using the FMA scale [33], which assesses upper and lower limb motor function. The scale consists of 33 items for upper limb movement and

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17 items for lower limb movement, with a total score ranging from 0 to 100. Higher scores indicate better motor function.

The secondary endpoint was the assessment of ADL using the Modified Barthel Index [34], with a total score ranging from 0 to 100. This assessment evaluates 10 daily activities: feeding, bathing, dressing, grooming, toileting, bladder and bowel control, transfers, stair climbing, and walking. Higher scores reflect greater independence in performing these activities. All assessments were conducted by blinded evaluators to ensure the separation of responsibilities among researchers, operators, and statisticians.

Sample Size

Based on relevant literature, the standardized mean difference between VR and control interventions on the FMA of motor function ranges from 0.35 to 0.45 [35]. Alternatively, improvements in upper limb FMA scores have been reported as 8.77 ± 11.17 points for the VR group, compared with 6.80 ± 9.86 points for the control group [36]. Using the sample size calculation formula and referring to *Fundamentals of Sample Size Estimation in Clinical Research* [37,38], with a significance level of $\alpha = 0.05$ (2-tailed) and a statistical power of $1 - \beta = 0.8$ ($\beta = 0.2$), the required sample size per group was calculated to be 26 participants. Accounting for a 20% dropout rate, the final sample size was adjusted to 32 participants per group, resulting in a planned enrollment of 64 patients with stroke.

$$n = \frac{2(Z_{\alpha/2}+Z_{\beta})^2 \times \sigma^2}{(\mu_t - \mu_c - \Delta)^2}.$$

Statistical Analysis

Statistical analyses were performed using SPSS software (version 27.0; IBM Corp, Armonk, NY, USA). All primary efficacy analyses were performed on an intention-to-treat basis. The normality of continuous data was assessed using the Shapiro-Wilk test. Continuous variables with a normal distribution are presented as mean ± standard deviation (SD), with standard error (SE) provided alongside parameter estimates where applicable. Non-normally distributed variables are presented as median and interquartile range (IQR). Categorical variables are expressed as numbers and percentages (n [%]).

Within-group changes from baseline to after intervention were assessed using paired-sample *t* tests. The magnitude of within-group change was calculated as Cohen's d with 95% confidence intervals (CIs), where values of 0.2, 0.5, and 0.8 were interpreted as small, medium, and large effect sizes, respectively.

The primary between-group efficacy analysis was conducted using analysis of covariance (ANCOVA). Separate ANCOVAs were conducted with post-intervention scores for FMA total score, FMA-UE and FMA-LE subscales, and the Barthel Index as the dependent variables. In each model, the treatment group (control vs intervention) was entered as the independent variable, with the corresponding baseline score as a covariate. This method estimates the adjusted mean differences between groups, reflecting the treatment effect after adjusting for potential baseline imbalances. The model assumptions of linearity, homogeneity of variances, and normality of residuals were checked and met. Adjusted group means, between-group mean differences with 95% CIs, and *P* values were reported. The magnitude of the between-group effect was quantified using partial eta-squared (ηp^2), with values of 0.01, 0.06, and 0.14 interpreted as small, medium, and large effects, respectively.

All statistical tests were 2-sided. A *P* value of less than 0.05 was considered statistically significant.

Results

A total of 64 patients were enrolled and randomly assigned. There were no post-randomization exclusions, and all 64 participants (100%) completed the full 4-week intervention and assessment protocol, with no missed sessions, resulting in an adherence rate of 100%. No adverse events or adverse effects (eg, dizziness, nausea) were reported in either group during the study period. The mean age of participants was 61.16 ± 9.64 years in the control group and 60.06 ± 9.78 years in the intervention group. The mean disease duration was 52.03 ± 19.62 days in the control group and 58.66 ± 9.94 days in the intervention group. No statistically significant differences were observed between the 2 groups in terms of sex, age, or disease duration ($P > 0.05$) (**Table 2**).

The within-group changes in outcome measures from baseline to the 4-week endpoint are presented in **Table 3**. Both groups demonstrated statistically significant improvements in all functional outcomes after the intervention period (all $P < 0.001$). The control group showed moderate improvements, with Cohen's d effect sizes ranging from 0.775 for the Barthel Index to 2.043 for the total FMA score. The intervention group exhibited larger improvements, reflected by larger effect sizes ranging from 1.939 (FMA) to 2.034 (Barthel Index).

The primary between-group comparison, conducted using ANCOVA with baseline scores as covariates, is detailed in **Table 4**. After we adjusted for baseline differences, the intervention group demonstrated significantly higher scores at the 4-week endpoint compared with the control group across all outcome measures. Regarding overall motor function, the adjusted mean total FMA score was 59.74 ± 0.78 for the intervention group compared with 50.61 ± 0.78 for the control group ($P < 0.001$, $\eta p^2 = 0.526$), also representing a large effect. For the

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Table 2. Comparison of the baseline characteristics between the 2 groups (N = 64).

Variable	Control (n = 32)	Intervention (n = 32)	T/χ^2	*P*
Sex (male/female)	24 (75.0%)/8 (25.0%)	19 (59.4%)/13 (40.6%)	1.772*	0.183
Age (years)	61.16 ± 9.64	60.06 ± 9.78	0.446**	0.657
Disease course			0.848*	0.654
≤ 30days	4 (12.5%)	2 (6.3%)		
31-60 days	18 (56.3%)	18 (56.3%)		
61-90 days	10 (31.3%)	12 (37.5%)		
Lesion side (left/right)	19 (59.4%)/13 (40.6%)	17 (53.1%)/15 (46.9%)	0.254*	0.614
Type of stroke (ischemic/hemorrhagic)	24 (75.0%)/8 (25.0%)	26 (81.2%)/6 (18.8%)	0.336*	0.545
Brunnstrom Stage (III/IV)	21 (65.6%)/11 (34.4%)	20 (62.5%)/12 (37.5%)	0.068*	0.794

* T; ** χ^2.

Table 3. Within-group comparison of efficacy indicators before and after the 4-week intervention (paired-sample *t* test).

	Mean±SD		d	95% CI	t	*P*
	FMA Before	FMA After				
Control (n = 32)	49.13 ± 13.16	51.91 ± 12.74	2.043	1.424, 2.650	11.555	< 0.001
Intervention (n = 32)	46.22 ± 11.29	58.44 ± 10.79	1.939	1.341, 2.525	10.967	< 0.001
	FMA-UE Before	FMA-UE After				
Control (n = 32)	32.66 ± 7.75	34.44 ± 7.71	1.768	1.204, 2.321	10.001	< 0.001
Intervention (n = 32)	31.91 ± 6.90	37.94 ± 6.12	1.840	1.262, 2.407	10.410	< 0.001
	FMA-LE Before	FMA-LE After				
Control (n = 32)	16.47 ± 5.66	17.44 ± 5.40	0.887	0.472, 1.292	5.018	< 0.001
Intervention (n = 32)	15.31 ± 4.74	20.19 ± 4.88	1.792	1.223, 2.349	10.135	< 0.001
	Barthel Index Before	Barthel Index After				
Control (n = 32)	53.13 ± 10.83	55.31 ± 9.75	0.775	0.374, 1.167	4.385	< 0.001
Intervention (n = 32)	51.88 ± 10.37	62.19 ± 9.58	2.034	1.417, 2.640	11.506	< 0.001

Abbreviations: SD, standard deviation; FMA-LE, Fugl-Meyer Assessment lower-extremity scores; FMA-UE, Fugl-Meyer Assessment upper extremity scores. d = Cohen's d for the within-group (paired) change from baseline.

Table 4. Between-group comparison of efficacy measures after the 4-week intervention, adjusted for baseline values (ANCOVA, primary analysis).

	Adjusted mean±SE		Adjusted mean difference 95% CI	Between-group effects (ANCOVA)		
	Control (n = 32)	Intervention (n = 32)		F	*P*	ηp^2
FMA	50.607 ± 0.782	59.737 ± 0.782	6.911, 11.349	67.701	< 0.001	0.526
FMA-UE	34.102 ± 0.410	38.273 ± 0.410	3.011, 5.333	51.632	< 0.001	0.458
FMA-LE	16.913 ± 0.360	20.712 ± 0.360	2.777, 4.821	55.225	< 0.001	0.475
Barthel Index	54.787 ± 0.667	62.713 ± 0.667	6.038, 9.813	70.517	< 0.001	0.536

Abbreviations: SE, standard error; ANCOVA, analysis of covariance; ηp^2, partial eta squared; FMA-LE, Fugl-Meyer Assessment lower-extremity scores; FMA-UE, Fugl-Meyer Assessment upper extremity scores.

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outcome of daily living function, the adjusted mean Barthel Index score was 62.71 ± 0.67 for the intervention group and 54.79 ± 0.67 for the control group ($P < 0.001$, $\eta p^2 = 0.536$), indicating a large effect size. Similarly, significant between-group differences favoring the intervention group were observed for both the FMA-UE and FMA-LE subscores, with large effect sizes ($\eta p^2 = 0.458$ and $\eta p^2 = 0.475$, respectively; both $P < 0.001$). The partial eta-squared values indicate large effect sizes.

Discussion

This randomized controlled trial investigated the effects of VR-based task-oriented training on motor function and daily living skills in patients with subacute stroke. The results demonstrated that VR task-oriented training was associated with significantly greater improvements in motor function and ADL. Specifically, compared with traditional task-oriented training, VR training showed more pronounced improvements in upper and lower limb motor abilities and daily living skills.

We observed that, after the 4-week treatment protocol, changes in FMA scores differed between the 2 groups. Both the intervention group and control group showed improvements in FMA scores, indicating that VR therapy and traditional task-oriented training have positive effects on enhancing patients' limb motor function. Similar effects were reported in previous studies [39,40]. However, in the present study, the statistically significant differences in FMA, FMA-UE, and FMA-LE scores between the 2 groups were consistent with the association trends reported in multiple meta-analyses [22,35,36,41,42], which demonstrated that the intervention group had more pronounced improvements in limb motor function.

The observed improvements were associated with several potential factors. First, the task-oriented training based on VR enhanced patients' immersion during training. In the study protocol, full immersion mode was adopted for upper limb training, in which patients wore virtual devices to complete actions like watering plants and lighting candles. For safety considerations, semi-immersion mode was selected for lower limb and full-body training. The Kinect motion sensors in the virtual devices tracked human movements and captured sound sources through infrared and camera tracking. During training, patients immersed themselves in computer screen visuals to perform actions like traversing forests and playing soccer and tennis, primarily exercising leg strength and balance skills during posture transitions. VR therapy provides a feasible practical pathway for challenging tasks in clinical treatment. Participation in these tasks can improve joint mobility in the shoulder, elbow, and wrist, enhance lower limb gait and overall stability, and increase muscle endurance, improvements that are closely associated with enhancements in upper limb, lower limb, and overall motor function [43]. Xu [44] also observed a similar trend.

Second, VR training provides visual and auditory feedback with excellent interactivity [45]. Piermaria et al proposed that VR technology can enhance rehabilitation therapy by creating enhanced environments [46]. An enhanced environment refers to a living space that significantly improves sensory and cognitive stimulation and social interaction capabilities compared with conventional conditions. This enhanced environment may be conducive to the development of experiential-dependent neuroplasticity in patients after stroke. In this VR program, tasks such as simulated watering and obstacle avoidance required patients to plan and execute actions in a rich and dynamic virtual environment, creating a conducive setting for learning and brain plasticity. Patients who successfully water the plants receive visual rewards such as blooming flowers, along with candles and sound effects for ascending lanterns, and coins and applause for obstacle avoidance. The real-time interaction mechanism also effectively motivates patients to participate in rehabilitation therapy [47].

Third, VR technology supports repetitive and high-intensity therapeutic exercises. Research by Lee demonstrates that high-intensity training has been reported to be associated with improved motor muscle contraction and coordination [48], as well as strengthened neural connections, which might be linked to cortical neural reorganization in affected limb areas and correlated with better motor function [29,40]. During VR training, the system automatically records exercise data to generate personalized histories. This enables automated generation of recommended exercise targets and intensity levels for subsequent sessions. Compared with traditional task-oriented training, VR technology achieves smarter and more precise selection of repetitive and high-intensity exercises. By leveraging 2 key elements—enhanced environmental reinforcement and novel complexity—VR creates more immersive learning experiences [30]. This study set the therapeutic dose of VR training based on the compliance and tolerance of rehabilitation treatment in hospitalized patients in China, referring to the research by He et al [12]. Narrative interviews indirectly confirmed that patients accepted VR training 5 times a week, each session lasting 30 minutes, in terms of training acceptance, duration, and economic costs.

Fourth, the VR training program incorporates game elements, which enhances patient adherence to exercise regimens more effectively than traditional methods [49]. Moreover, the VR games feature tiered difficulty levels to accommodate diverse patient needs. For instance, during upper limb training, patients can choose to water distant or nearby flower targets based on their affected limb strength, while lower limb training involves avoiding obstacles according to their limb strength. This

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tailored challenge intensity helps prevent treatment boredom or frustration. Previous research confirms that improved focus and treatment adherence in rehabilitation training are closely linked to better recovery outcomes [49-51].

Two studies investigated the effectiveness of VR training in improving ADL for patients after stroke [12,21]. Previous research utilizing randomized controlled trials has demonstrated that virtual reality interventions can yield significant improvements in Barthel Index scores. In the present study, both the intervention and control groups exhibited post-treatment increases in Barthel Index scores, suggesting that VR therapy and conventional task-oriented training are effective in enhancing ADL. These findings indicate that while both modalities provide positive functional benefits, the integration of technology-driven approaches remains a viable strategy for improving patient independence. However, the statistically significant difference in Barthel Index scores between the 2 groups aligns with previous studies reporting an association between VR training and ADL improvements, supporting the more notable ADL gains in the intervention group. These ADL improvements were likely correlated with the observed enhancements in upper and lower limb motor function, which is consistent with the findings of multiple meta-analyses [22,35,36,41,42]. Additionally, the study suggests that the effectiveness of ADL recovery is influenced by the repetition frequency of treatment tasks, training duration, and frequency [47]. VR training was associated with higher patient motivation and adherence, and these factors were correlated with better ADL outcomes in the research group.

While the findings support the effectiveness of VR training, it should be noted that several large randomized controlled trials (eg, EVREST, VIRTUES, Dixit P [52-54\) have not consistently demonstrated VR's significant superiority over conventional rehabilitation in improving motor and daily living skills. This discrepancy may stem from multiple factors: inconsistent patient disease progression and baseline functional impairments, as well as the use of non-immersive VR systems that limited training to simple recreational activities or grasping exercises. These approaches lacked sufficient immersion and disconnected from real-life experiences, resulting in limited practical value. In contrast, the VR program in the present study incorporated real-life scenarios, potentially enhancing proprioceptive input and neural drive for body-schema updating more effectively than mere entertainment or grasping drills. This characteristic might be associated with more favorable outcomes in limb movement and ADL performance among patients in the research group. Despite these encouraging findings, the heterogeneity in VR training types, dosing, and integration with conventional therapies, as well as the diversity in task design, still requires further exploration.

Furthermore, this study employed a fully immersive system for upper limb training. While this system provides immersive experiences and facilitates body schema updating by fully occupying the visual field, it partially isolates patients' visual feedback of their actual limbs, potentially causing dizziness. For lower limb and full-body training, we utilized a semi-immersive system that allowed patients to simultaneously view both the virtual environment and their partial body. This requires patients to perform additional spatial transitions for uncoupled eye-hand movements, which enhances the integration and input of visual and proprioceptive information—particularly crucial for limb-positioning tasks such as hitting a ball or avoiding obstacles. The semi-immersive system reduces dizziness susceptibility and demonstrates better tolerance, making it more suitable for patients with subacute stroke.

The XY-Kinapsys VR system used in this study demonstrated its effectiveness; however, no prior studies have used this system for stroke rehabilitation, distinguishing our results from those of the existing literature. Meta-analyses indicate significant variability among VR interventions: fully immersive systems excel in gross motor recovery, while non-immersive systems enhance fine motor dexterity [36]. Our semi-immersive approach appears to have improved both aspects, yet the uniqueness of our protocol limits direct comparisons with other systems. This heterogeneity suggests a need for standardized VR protocols in the future to ensure reproducibility and scalability in clinical applications—a gap that subsequent research must address.

One of the most striking findings was the large effect sizes observed ($\eta p^2 > 0.50$ for primary outcomes), which are notably larger than those reported in landmark multicenter randomized clinical trials such as EVREST [52] and VIRTUES [53]. While these effect sizes suggest a strong intervention signal, they warrant cautious interpretation. The subacute phase (mean, 52-58 days after stroke), a period of rapid spontaneous recovery, likely amplified within-group gains in both groups. Additionally, the exploratory single-center design and small sample may inflate effect estimates. The discrepancy with previous trials may partly stem from our use of immersive and semi-immersive VR with real-world task-oriented scenarios (eg, watering plants, kicking a soccer ball), which could provide richer feedback and engagement than non-immersive, recreation-based systems. Intervention timing may also be more optimal for capturing VR-induced plasticity. While promising, these findings should be regarded as hypothesis-generating, requiring confirmation in larger multicenter pragmatic trials, in which effect sizes typically attenuate.

The control group also demonstrated substantial functional gains, with a within-group Cohen's d of 2.043 for total FMA. This large effect underscores the effectiveness of the standard,

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intensive inpatient rehabilitation program and highlights the significant potential for recovery during the subacute phase. It is crucial to interpret the VR group's additional benefits in this context of a robust standard of care. The large within-group improvements in the control group are likely attributable to the natural recovery processes inherent in the subacute phase and the comprehensive nature of the standard inpatient rehabilitation, rather than the conventional task-oriented training alone.

The 100% adherence and zero dropout rate confirm the intervention's acceptability and tolerability, which were largely attributable to the supervised inpatient setting with scheduled sessions and continuous monitoring, which limits generalizability to outpatient or home-based settings. Similarly, the absence of dizziness or nausea with fully immersive upper-limb training may reflect the short daily duration (30 minutes) and strict patient selection, rather than implying no risk in wider clinical application.

The promising results of this study have several implications for clinical applicability. The use of a commercial, off-the-shelf VR system like XY-Kinapsys, which can be integrated into existing clinical workflows, suggests that scaling up such an intervention is feasible. While the initial equipment cost represents a barrier, the potential for improved efficiency in therapy delivery and enhanced patient engagement may offset these costs. Moreover, the standardized nature of the VR tasks reduces variability in treatment delivery across different therapists, potentially improving consistency of care. Future cost-effectiveness analyses are needed to determine the economic viability of implementing VR-based task-oriented training as a standard adjunct in stroke rehabilitation units.

This study has several limitations that may affect the generalizability (external validity) of its findings. First, this was a single-center exploratory study with a limited sample size, and the results may not be replicable in different healthcare systems with varying rehabilitation protocols and resources. Second, the strict inclusion criteria (eg, first-ever stroke, subacute phase, Brunnstrom stage > 3, MMSE ≥ 21, and intact visual acuity) led to the selection of a relatively high-functioning, highly motivated subset of patients. The findings may therefore not generalize to the broader stroke population, including those with severe cognitive impairment, aphasia, neglect, recurrent strokes, or significant comorbidities. Third, the controlled inpatient setting with 100% adherence and no dropouts differs markedly from real-world outpatient or community settings where therapy adherence and follow-up are often major challenges. Consequently, the promising effect sizes observed in this controlled environment are likely to decrease when the intervention is implemented in routine clinical practice. Future research should prioritize pragmatic, multi-center trials with more inclusive criteria to better establish the real-world effectiveness of this VR-based approach.

Nevertheless, the observed associations between VR training and favorable functional outcomes align with broader evidence [35,36], reinforcing the need for larger-scale randomized controlled trials to verify potential causal relationships. These positive outcomes also suggest that VR could serve as a complementary strategy in standard stroke rehabilitation programs, given its potential to engage patients and its association with recovery processes that may involve neuroplasticity.

Conclusions

In conclusion, the results of this study suggest that VR-based task training can enhance motor function and ADL performance in patients with stroke. These findings build on the established effectiveness of VR in neurological rehabilitation, supporting its broader integration into clinical practice. However, to strengthen these preliminary results and address identified limitations, future research should involve the design and implementation of multicenter randomized controlled trials.

Availability of Data and Materials

All data generated or analyzed during this study are included in this published article.

Ethics Approval and Consent to Participate

The study was approved by the Ethics Committee of Zhejiang Rehabilitation Medical Center (approval No. ZKLL2022030001), and informed consent was obtained from all participants. This study strictly adhered to the ethical principles outlined in the Declaration of Helsinki and was registered in a clinical trial registry (registration No. ChiCTR2500100595).

Declaration of Figures' Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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References:

1. Mendelson SJ, Prabhakaran S. Diagnosis and management of transient ischemic attack and acute ischemic stroke: A review. JAMA. 2021;325(11):1088-98
2. Wang H, Guo J, Zhang Y, et al. Closed-loop rehabilitation of upper-limb dyskinesia after stroke: From natural motion to neuronal microfluidics. J Neuroeng Rehabil. 2025;22(1):87
3. GBD 2021 Stroke Risk Factor Collaborators. Global, regional, and national burden of stroke and its risk factors, 1990-2021: A systematic analysis for the Global Burden of Disease Study 2021. Lancet Neurol. 2024; 23(10):973-1003
4. Fan W, Zeng Q, Zhang Z. Research progress on the application of virtual reality technology in the rehabilitation of post-stroke cognitive impairment. China Rehabil. 2022;37(6):641-46
5. Poomalai G, Prabhakar S, Sirala Jagadesh N. Functional ability and health problems of stroke survivors: An explorative study. Cureus. 2023;15(1):e33375
6. Yao YY, Wei ZJ, Zhang YC, et al. Functional disability after ischemic stroke: A community-based cross-sectional study in Shanghai, China. Front Neurol. 2021;12:649088
7. Mohammed S, Haidar J, Ayele BA, Yifru YM. Post-stroke limitations in daily activities: Experience from a tertiary care hospital in Ethiopia. BMC Neurol. 2023;23(1):364
8. Tiwari S, Joshi A, Rai N, Satpathy P. Impact of stroke on quality of life of stroke survivors and their caregivers: A qualitative study from India. J Neurosci Rural Pract. 2021;12(4):680-88
9. Li X, He Y, Wang D, Rezaei MJ. Stroke rehabilitation: From diagnosis to therapy. Front Neurol. 2024;15:1402729
10. Powers WJ, Rabinstein AA, Ackerson T, et al. Guidelines for the early management of patients with acute ischemic stroke: 2019 Update to the 2018 Guidelines for the early management of acute ischemic stroke: A Guideline for healthcare professionals from the American Heart Association/American Stroke Association. Stroke. 2019;50(12):e344-e418
11. Richards LG, Cramer SC. Therapies targeting stroke recovery. Stroke. 2023;54(1):265-69
12. He T, Zhang M, Chen X, et al. Comparing the effects of virtual reality and traditional balance training on trunk control, sitting balance, and activities of daily living in patients with stroke: A randomized controlled trial. BMC Sports Sci Med Rehabil. 2025;17(1):294
13. Jo S, Jang H, Kim H, Song C. 360° immersive virtual reality-based mirror therapy for upper extremity function and satisfaction among stroke patients: A randomized controlled trial. Eur J Phys Rehabil Med. 2024;60(2):207-15
14. Palacios-Navarro G, Hogan N. Head-mounted display-based therapies for adults post-stroke: A systematic review and meta-analysis. Sensors (Basel, Switzerland). 2021;21(4):1111
15. Gao Y, Ma L, Lin C, et al. Effects of virtual reality-based intervention on cognition, motor function, mood, and activities of daily living in patients with chronic stroke: A systematic review and meta-analysis of randomized controlled trials. Front Aging Neurosci. 2021;13:766525 [Erratum in: Front Aging Neurosci. 2023;14:1128402]
16. Xie P, Wang Z, Li Z, et al. Research on rehabilitation training strategies using multimodal virtual scene stimulation. Front Aging Neurosci. 2022;14:892178
17. Zhang B, Wong KP, Kang R, et al. Efficacy of robot-assisted and virtual reality interventions on balance, gait, and daily function in patients with stroke: A systematic review and network meta-analysis. Arch Phys Med Rehabil. 2023;104(10):1711-19
18. Sana V, Ghous M, Kashif M, et al. Effects of vestibular rehabilitation therapy versus virtual reality on balance, dizziness, and gait in patients with subacute stroke: A randomized controlled trial. Medicine. 2023;102(24):e33203
19. Wankhede NL, Koppula S, Ballal S, et al. Virtual reality modulating dynamics of neuroplasticity: Innovations in neuro-motor rehabilitation. Neuroscience. 2025;566:97-111
20. Heinrich C, Morkisch N, Langlotz T, et al. Feasibility and psychophysical effects of immersive virtual reality-based mirror therapy. J Neuroeng Rehabil. 2022;19(1):107
21. Liu Y, Li JH, Tao JY, et al. Virtual reality combined with task-oriented circuit training for upper limb rehabilitation in subacute stroke patients: A randomized controlled trial. Medicine. 2025;104(31):e43505
22. Gao C, Chen Y, Wei Y, et al. Combined immersive and nonimmersive virtual reality with mirror therapy for patients with stroke: Systematic review and meta-analysis of randomized controlled trials. J Med Internet Res. 2025;27:e73142
23. Aderinto N, Olatunji G, Abdulbasit MO, et al. Exploring the efficacy of virtual reality-based rehabilitation in stroke: A narrative review of current evidence. Ann Med. 2023;55(2):2285907
24. Khokale R, G SM, Ahmed S, et al. Virtual and augmented reality in post-stroke rehabilitation: A narrative review. Cureus. 2023;15(4):e37559
25. Enríquez-Canto Y, Pizarro-Mena R, Ludueña-Hernández K, et al. Use of virtual reality in upper extremity rehabilitation of adults after stroke and its effect on functionality: Systematic review and meta-analysis. Phys Ther. 2025;105(9):pzaf103
26. Khan A, Imam YZ, Muneer M, et al. Virtual reality in stroke recovery: A meta-review of systematic reviews. Bioelectron Med. 2024;10(1):23
27. Yıldız NT, Canlı M, Kocaman H, et al. Validity and reliability of the Turkish version of the Ottawa sitting scale in patients with multiple Sclerosis. Acta Neurol Belg. 2025;125(2):501-8
28. Lu W, Shi M, Liu L, et al. Effect of virtual reality-based therapies on lower limb functional recovery in stroke survivors: Systematic review and meta-analysis. J Med Internet Res. 2025;27:e72364
29. Liu L, Chen W, Zhou H, et al; Chinese Stroke Association Stroke Council Guideline Writing Committee. Chinese Stroke Association guidelines for clinical management of cerebrovascular disorders: executive summary and 2019 update of clinical management of ischaemic cerebrovascular diseases. Stroke Vasc Neurol. 2020;5(2):159-76
30. Huang CY, Lin GH, Huang YJ, et al. Improving the utility of the Brunnstrom recovery stages in patients with stroke: Validation and quantification. Medicine. 2016;95(31):e4508
31. Ain N, Ali Z, Tahir M, et al. Comparison between rood inhibitory approach and bobath reflex inhibiting patterns to improve gross motor function and reduce spasticity in hemiplegic children of encephalitis. Int J Health Sci. 2023;7(S1):1561-69
32. Chaturvedi P, Kalani A. Motor rehabilitation of aphasic stroke patient: the possibility of Rood's approach. Neural Regen Res. 2023;18(3):551
33. Hervé-Colas J, Newton SP, Engelter ST, et al. Standardized international manual of the fugl-meyer assessment of motor function after stroke. Neurorehabil Neural Repair. 2026;40(4):306-19
34. Lee SY, Kim DY, Sohn MK, et al. Determining the cut-off score for the Modified Barthel Index and the Modified Rankin Scale for assessment of functional independence and residual disability after stroke. PLoS One. 2020;15(1):e0226324
35. Chen J, Or CK, Chen T. Effectiveness of using virtual reality-supported exercise therapy for upper extremity motor rehabilitation in patients with stroke: Systematic review and meta-analysis of randomized controlled trials. J Med Internet Res. 2022;24(6):e24111
36. Soleimani M, Ghazisaeedi M, Heydari S. The efficacy of virtual reality for upper limb rehabilitation in stroke patients: A systematic review and meta-analysis. BMC Med Inform Decis Mak. 2024;24(1):135
37. Wang X, Ji X. Sample size estimation in clinical research: From randomized controlled trials to observational studies. Chest. 2020;158(1S):S12-S20
38. Williams DN, Williams KA. Sample size considerations: Basics for preparing clinical or basic research. Ann Nucl Cardiol. 2020;6(1):81-85
39. Nogueira NGHM, Parma JO, Leão SESA, et al. Mirror therapy in upper limb motor recovery and activities of daily living, and its neural correlates in stroke individuals: A systematic review and meta-analysis. Brain Res Bull. 2021;177:217-38
40. Morgenstern E. Exploring the efficacy of virtual reality-based mirror therapy in upper limb rehabilitation for individuals with unilateral spatial neglect: A novel approach to addressing an overlooked aspect of stroke recovery. J Wetenskap Health. 2022;3(3):7-15
41. Kundi MK, Spence NJ. Efficacy of mirror therapy on lower limb motor recovery, balance and gait in subacute and chronic stroke: A systematic review. Physiother Res Int. 2023;28(2):e1997
42. Hao J, Xie H, Harp K, et al. Effects of virtual reality intervention on neural plasticity in stroke rehabilitation: A systematic review. Arch Phys Med Rehabil. 2022;103(3):523-41

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43. Errante A, Saviola D, Cantoni M, et al. Action observation combined with virtual reality promotes motor recovery after stroke: A randomized controlled trial. Stroke. 2026;57(5):1136-48
44. Xu J. [Influence of mirror therapy and virtual reality therapy on balance in patients after stroke.] Master's thesis. Chengde Medical University; 2022 [in Chinese]
45. Lili Z, Jingjing W. Advances in the application of virtual reality technology in limb motor rehabilitation for stroke patients. Nurs Res. 2025;39(12):2116-21
46. Piermaria J, Piatti D, De Angelis S, et al. Visuo-vestibular virtual reality-based training for people with stroke: A feasibility study. Healthcare (Basel). 2026;14(5):625
47. Levin MF, Demers M. Motor learning in neurological rehabilitation. Disabil Rehabil. 2021;43(24):3445-53
48. Lee G. Effects of training using video games on the muscle strength, muscle tone, and activities of daily living of chronic stroke patients. J Phys Ther Sci. 2013;25(5):595-97
49. Fatehi V, Salahzadeh Z, Farhoudi M, et al. Impact of virtual reality-based serious games on cognitive-motor rehabilitation for stroke patients in daily activities: Protocol for a randomized trial. Physiother Res Int. 2025;30(4):e70107
50. Marques IA, Alves CM, Rezende AR, et al. Virtual reality and serious game therapy for post-stroke individuals: A preliminary study with humanized rehabilitation approach protocol. Complement Ther Clin Pract. 2022;49:101681
51. Rohrbach N, Chicklis E, Levac DE. What is the impact of user affect on motor learning in virtual environments after stroke? A scoping review. J Neuroeng Rehabil. 2019;16(1):79
52. Saposnik G, Cohen LG, Mamdani M, et al; Stroke Outcomes Research Canada. Efficacy and safety of non-immersive virtual reality exercising in stroke rehabilitation (EVREST): A randomised, multicentre, single-blind, controlled trial. Lancet Neurol. 2016;15(10):1019-27
53. Brunner I, Skouen JS, Hofstad H, et al. Virtual reality training for upper extremity in subacute stroke (VIRTUES): A multicenter RCT. Neurology. 2017;89(24):2413-21
54. Dixit P, Phalswal U, Kalal N, Srivastava SP. Effectiveness of virtual reality-supported exercise therapy in improving upper extremity function and activities of daily living among patients after stroke: A systematic review of randomized control trials. Osong Public Health Res Perspect. 2024;15(3):189-200

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