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Effects of Virtual Reality (VR) for Cognitive Rehabilitation in Stroke Survivors

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ABSTRACT

Background: Stroke is a leading cause of long-term disability, significantly impacting cognitive functions such as memory, attention, and executive functioning in survivors. Traditional cognitive rehabilitation methods have limitations, necessitating innovative approaches like virtual reality (VR) to enhance recovery.

Objective: To determine the effects of VR-based cognitive rehabilitation in stroke survivors compared to traditional methods.

Methods: A randomized controlled trial was conducted at Mian Medical Complex from October 2023 to August 2024, involving 24 stroke survivors aged 40-80 years with cognitive impairments. Participants were randomly assigned to either the VR group, receiving 30-minute sessions three times weekly for 12 weeks, or the control group, receiving traditional cognitive rehabilitation. Cognitive functions were assessed using the Montreal Cognitive Assessment (MoCA), Trail Making Test (TMT), and Digit Span Test. Data analysis was performed using SPSS version 25.

Results: The VR group showed significant improvements in MoCA scores (22.3 ± 3.5 to 25.0 ± 2.8, $p < 0.01$), TMT Part A (50.2 ± 10.3 to 45.6 ± 9.2 seconds, $p < 0.05$), and Digit Span Test (6.4 ± 1.2 to 7.2 ± 1.0, $p < 0.01$), whereas the control group showed minimal changes.

Conclusion: VR-based cognitive rehabilitation significantly improves cognitive functions in stroke survivors and offers a more engaging alternative to traditional methods.

INTRODUCTION

Stroke is a major public health concern and a leading cause of long-term disability globally, significantly impairing survivors' cognitive functions and diminishing their quality of life. Cognitive impairments such as memory loss, attention deficits, and executive function disorders are common among stroke survivors, severely affecting their ability to perform daily activities and reintegrate into society (1). Despite advancements in medical treatment, the rehabilitation process for cognitive impairments remains challenging, necessitating the development of innovative and effective approaches to enhance recovery outcomes (2, 3). Traditional cognitive rehabilitation therapies, although beneficial to some extent, often have limitations related to patient engagement, accessibility, and adaptability. These conventional methods typically involve repetitive, monotonous tasks that may not sufficiently motivate patients or cater to their unique rehabilitation needs, leading to suboptimal adherence and outcomes (4, 5). Additionally, the delivery of traditional cognitive rehabilitation can be resource-intensive, requiring significant time and effort from healthcare professionals, which may restrict its availability to a broader population of stroke survivors (6).

In recent years, Virtual Reality (VR) has emerged as a promising tool in cognitive rehabilitation, offering an immersive and interactive environment that simulates real-life scenarios. This technology provides a novel approach to engaging patients in therapeutic exercises that target various cognitive functions, including memory, attention, and problem-solving skills (7, 8). VR's capacity to create customized rehabilitation programs tailored to the specific needs and progress of individual patients positions it as a valuable complement to conventional rehabilitation strategies. Engaging in virtual environments that mimic daily tasks lost due to stroke allows patients to repeatedly practice and master these skills at their own pace, enhancing cognitive recovery (9). Moreover, the interactive and engaging nature of VR-based interventions can significantly increase patient motivation and adherence to rehabilitation protocols, overcoming some of the common barriers associated with traditional methods (10, 11).

The potential impact of VR in cognitive rehabilitation extends beyond individual patient outcomes. By providing a highly engaging and adaptable platform, VR has the potential to revolutionize neurorehabilitation practices by making therapeutic exercises more accessible and enjoyable, thereby enhancing the overall rehabilitation experience. This aligns with the growing body of evidence suggesting that VR can improve cognitive outcomes by simulating complex, real-world tasks in a controlled and safe environment (12). Additionally, VR's ability to offer a standardized yet flexible approach allows for consistent

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delivery of rehabilitation interventions, which can be particularly beneficial in settings with limited resources or where traditional rehabilitation is less feasible (13). The integration of VR technology into mainstream clinical practice could pave the way for the development of standardized, evidence-based protocols that enhance cognitive rehabilitation for stroke survivors, ultimately aiming to improve their quality of life through innovative and accessible therapeutic solutions (14, 15).

MATERIAL AND METHODS

The study was conducted as a randomized controlled trial (RCT) to evaluate the effectiveness of virtual reality (VR)-based cognitive rehabilitation in stroke survivors. Participants were randomly assigned to either the VR intervention group or the control group receiving traditional cognitive rehabilitation methods. The study took place at Mian Medical Complex (MMC) from October 2023 to August 2024, with a total sample size of 24 participants, calculated using G*Power to ensure adequate power for detecting significant differences between the groups. Eligible participants were aged 40 to 80 years, diagnosed with stroke within the past 6 months to 2 years, and experiencing cognitive impairments as a result of the stroke. Exclusion criteria included severe physical disabilities that prevented VR use, severe cognitive impairments that hindered understanding of instructions, and a history of epilepsy or other conditions contraindicated for VR use.

Participants in the VR group received a VR-based cognitive rehabilitation program administered for 30 minutes per session, three times a week, over a period of 12 weeks. The VR intervention involved engaging in immersive and interactive virtual environments designed to improve cognitive functions such as memory, attention, and executive skills. The control group received traditional cognitive rehabilitation methods, which included computer-based cognitive training, paper-and-pencil tasks, and therapist-led activities. The duration and frequency of the traditional rehabilitation sessions were matched to those of the VR intervention group to maintain consistency across groups. Cognitive functions were assessed using standardized tests, including the Montreal Cognitive Assessment (MoCA), Trail Making Test (TMT) Parts A and B, and the Digit Span Test. These assessments provided quantitative data on cognitive performance at baseline and after the intervention period. In addition to cognitive assessments, user experience and satisfaction surveys were administered to evaluate participants' perceptions of the rehabilitation interventions. All assessments were conducted by trained professionals who were blinded to group assignments to reduce bias.

The study adhered to ethical principles outlined in the Declaration of Helsinki. Informed consent was obtained from all participants before the commencement of the study, ensuring that they were fully aware of the study procedures, potential risks, and benefits. Confidentiality was maintained throughout the study, and participants were informed of their right to withdraw from the study at any time without consequence. Ethical approval for the study was obtained from the institutional review board of Mian Medical Complex.

Data analysis was performed using SPSS version 25. Descriptive statistics were used to summarize demographic and baseline characteristics of the participants. Paired t-tests and independent t-tests were used to compare cognitive test scores within and between the VR and control groups, respectively. The significance level was set at $p < 0.05$ for all statistical tests. Results were reported as means with standard deviations for continuous variables, and the differences in outcomes between the groups were analyzed to assess the effectiveness of the VR intervention in comparison to traditional cognitive rehabilitation methods (1).

RESULTS

The study included 24 participants, evenly distributed between the VR intervention group (n = 12) and the control group (n = 12). The mean age of participants in the VR group was 62.5 years (±8.3), while the control group had a mean age of 63.2 years (±7.9). The gender distribution was relatively balanced, with the VR group consisting of 6 males and 6 females, and the control group comprising 5 males and 7 females. The average time since stroke was 8.5 months (±4.2) for the VR group and 9.0 months (±4.0) for the control group. Baseline cognitive scores, as measured by the Montreal Cognitive Assessment (MoCA), were similar between the groups, with the VR group scoring 22.3 (±3.5) and the control group scoring 22.0 (±3.8).

Table 1: Participant Demographics

Demographic Variable	VR Group (n=12)	Control Group (n=12)
Mean Age (years)	62.5 (±8.3)	63.2 (±7.9)
Gender (Male/Female)	6/6	5/7
Time Since Stroke (months)	8.5 (±4.2)	9.0 (±4.0)
Baseline Cognitive Score (MoCA)	22.3 (±3.5)	22.0 (±3.8)

The VR group demonstrated significant improvements in all cognitive tests post-intervention compared to their baseline scores. The MoCA scores increased from 22.3 (±3.5) at baseline to 25.0 (±2.8) post-intervention ($p < 0.01$). The Trail Making Test (TMT) Part A time reduced from 50.2 seconds (±10.3) to 45.6 seconds (±9.2) ($p < 0.05$), and TMT Part B time decreased from 85.3 seconds (±15.7) to 75.8 seconds (±14.3) ($p < 0.05$). The Digit Span Test score improved from 6.4 (±1.2) to 7.2 (±1.0) ($p < 0.01$). In contrast, the control group showed negligible changes in these cognitive measures, with MoCA scores increasing from 22.0 (±3.8) to 23.5 (±3.6) ($p = 0.10$), TMT Part A time decreasing from 49.8 seconds (±11.0) to 48.2 seconds (±10.8) ($p = 0.20$), TMT Part B time reducing from 83.5 seconds (±16.0) to 80.7 seconds

Table 2: Baseline and Post-Intervention Cognitive Scores

Cognitive Test	Group	Baseline Mean (±SD)	Post-Intervention Mean (±SD)	p-value (Pre vs. Post)
MoCA	VR	22.3 (±3.5)	25.0 (±2.8)	<0.01
	Control	22.0 (±3.8)	23.5 (±3.6)	0.10
TMT Part A (seconds)	VR	50.2 (±10.3)	45.6 (±9.2)	<0.05
	Control	49.8 (±11.0)	48.2 (±10.8)	0.20
TMT Part B (seconds)	VR	85.3 (±15.7)	75.8 (±14.3)	<0.05
	Control	83.5 (±16.0)	80.7 (±15.6)	0.25
Digit Span Test	VR	6.4 (±1.2)	7.2 (±1.0)	<0.01
	Control	6.5 (±1.3)	6.7 (±1.2)	0.40

(±15.6) (p = 0.25), and Digit Span Test score increasing from 6.5 (±1.3) to 6.7 (±1.2) (p = 0.40). User satisfaction and engagement scores were also assessed, indicating higher levels in the VR group compared to the control group. Participants in the VR group reported a mean satisfaction score of 8.4 (±1.2) and an engagement level of 8.7 (±1.1). Conversely, the control group reported a satisfaction score of 6.5 (±1.5) and an engagement level of 6.2 (±1.7), highlighting the enhanced motivational and immersive experience provided by the VR intervention.

Table 3: User Satisfaction and Engagement Scores

Survey Question	Group	Mean Score (±SD)
Satisfaction with VR	VR	8.4 (±1.2)
Engagement Level	VR	8.7 (±1.1)
Satisfaction with Traditional Method	Control	6.5 (±1.5)
Engagement Level	Control	6.2 (±1.7)

Overall, the VR group exhibited significant improvements in cognitive functions, satisfaction, and engagement compared to the control group, supporting the efficacy of VR as an innovative approach to cognitive rehabilitation in stroke survivors. The findings suggest that VR not only enhances cognitive outcomes but also improves patient experience, potentially leading to better adherence to rehabilitation programs.

DISCUSSION

The study demonstrated that virtual reality (VR) is an effective approach for cognitive rehabilitation in stroke survivors, showing significant improvements in cognitive functions such as memory, attention, and executive function compared to traditional rehabilitation methods. The VR group exhibited notable enhancements in MoCA scores, TMT Part A and B times, and Digit Span Test results, highlighting the potential of VR to provide a more engaging and effective rehabilitation experience (1). These findings align with previous research, such as Chen et al. (2022), which reported that VR-based cognitive rehabilitation improved daily living activities and cognitive function in patients with post-stroke cognitive impairments (16). The interactive and immersive nature of VR likely contributed to the observed benefits by maintaining patient engagement and motivation, which are critical factors in the success of rehabilitation programs (12).

However, the results contrasted with some studies, such as Wiley et al.'s systematic review and meta-analysis, which found that VR therapy was not significantly more effective than control measures in improving global cognition, memory, attention, or language in stroke patients (1). This discrepancy may be attributed to differences in study design, sample size, intervention protocols, or the severity of cognitive impairments among participants. Furthermore, Oliveira et al. suggested that VR-based exercises focusing on daily activities could provide short-term cognitive benefits post-stroke, supporting the notion that task-specific VR interventions may yield different outcomes depending on the targeted cognitive domains (17). The present study adds to the growing body of evidence supporting VR as a viable tool for cognitive rehabilitation, emphasizing the need for tailored VR programs that address the unique needs and challenges of stroke survivors.

One of the strengths of this study was the randomized controlled design, which helped minimize biases and provided a robust comparison between VR and traditional rehabilitation methods. Additionally, the use of standardized cognitive assessments allowed for objective measurement of cognitive improvements, enhancing the reliability of the results. However, the study also had limitations, including a relatively small sample size, which may limit the generalizability of the findings to a broader population of stroke survivors. Moreover, the study duration was relatively short, focusing on immediate post-intervention outcomes without assessing the long-term sustainability of cognitive improvements. Future research should include larger sample sizes and extended follow-up periods to better understand the long-term effects of VR-based cognitive rehabilitation.

Another limitation was the potential variability in participants' familiarity and comfort with VR technology, which could have influenced their engagement and performance. Addressing this, future studies should consider incorporating familiarization sessions to reduce the potential impact of the learning curve associated with VR use. Additionally, the study did not account for individual differences in stroke severity, cognitive impairments, and rehabilitation goals, which could affect the responsiveness to VR interventions. Personalized VR programs that adapt to the progress and specific needs of each patient may further enhance the effectiveness of this approach.

Despite these limitations, the study's findings have important implications for clinical practice. The integration of VR into cognitive rehabilitation protocols offers a novel and promising avenue to enhance patient engagement, motivation, and outcomes. Given the increasing accessibility and affordability of VR technology, its incorporation into mainstream rehabilitation services could provide a cost-effective alternative to traditional methods, especially in settings with limited resources. Future research should explore the development of standardized VR-based rehabilitation protocols and investigate their application across diverse patient populations and settings. Overall, this study highlighted the potential of VR as an innovative and valuable tool for cognitive rehabilitation in stroke survivors, with the capacity to improve both clinical outcomes and patient experience. The positive results underscore the need for continued exploration of VR in neurorehabilitation, with an emphasis on optimizing intervention strategies to maximize benefits for stroke survivors.

CONCLUSION

The study concluded that virtual reality (VR) is an effective and innovative approach for cognitive rehabilitation in stroke survivors, demonstrating significant improvements in cognitive functions, patient engagement, and satisfaction compared to traditional rehabilitation methods. These findings suggest that VR has the potential to enhance clinical outcomes and overall rehabilitation experience, making it a valuable addition to conventional neurorehabilitation strategies. The integration of VR into cognitive rehabilitation protocols could address the limitations of traditional methods by providing a more engaging, adaptable, and patient-centered approach, ultimately improving the quality of life for stroke survivors. The broader implications for human healthcare include the potential for VR to be incorporated into standard rehabilitation practices, offering a cost-effective and scalable solution that can be tailored to meet the specific needs of individuals, thereby expanding access to effective cognitive rehabilitation for a diverse population of stroke patients.

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