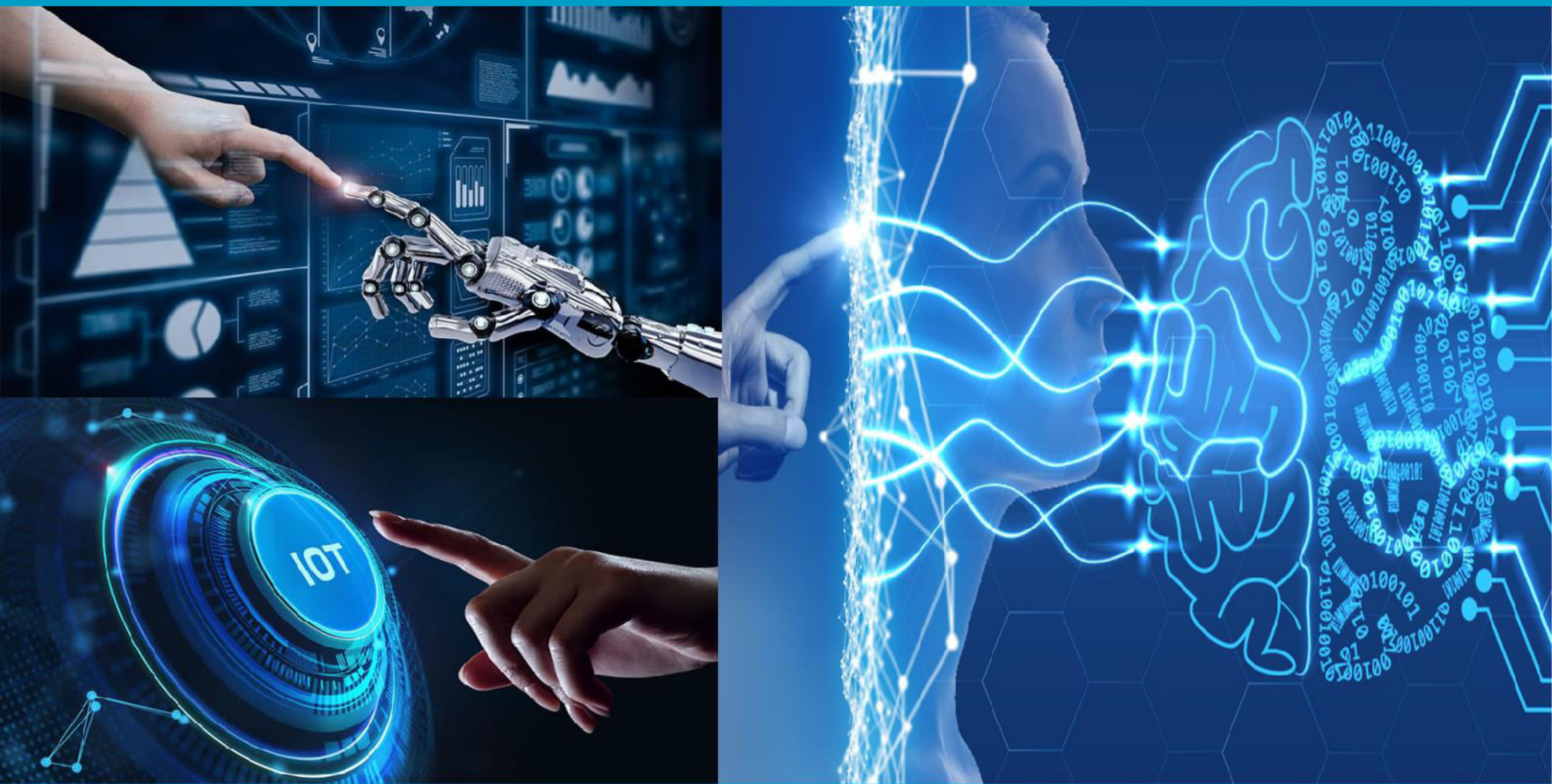
IJMRSETM

e-ISSN: 2395 - 7639



INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH

IN SCIENCE, ENGINEERING, TECHNOLOGY AND MANAGEMENT

Volume 12, Issue 1, January 2025

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 7.802

+91 99405 72462 +9163819 07438 ijmrsetm@gmail.com www.ijmrsetm.com

| ISSN: 2395-7639 | www.ijmrsetm.com | Impact Factor: 7.802 | A Monthly Double-Blind Peer Reviewed Journal |

| Volume 12, Issue 1, January 2025 |

The Role of Virtual Reality in Enhancing Cognitive and Psychosocial Recovery Post-Stroke Framework

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ABSTRACT: Stroke is a leading cause of long-term disability, often resulting in significant cognitive and psychosocial challenges, such as impaired memory, attention, emotional regulation, and social interaction. These deficits severely impact the quality of life and hinder overall recovery. Traditional rehabilitation methods often inadequately address these challenges, leading to limited improvements in cognitive and psychosocial domains. This study investigates the efficacy of virtual reality (VR)-based therapy as an innovative tool to enhance cognitive function and psychosocial well-being in post-stroke patients.

A systematic observational study was conducted involving adults with post-stroke cognitive impairments. Participants were divided into two groups: the VR group, which underwent task-specific and gamified cognitive rehabilitation exercises, and the control group, which received traditional cognitive therapy. The VR tasks included memory recall, attention exercises, and virtual social interactions, all delivered in immersive environments with adaptive difficulty levels and real-time feedback. Outcomes were assessed using the Montreal Cognitive Assessment (MoCA), Trail Making Tests (TMT-A and TMT-B), and self-reported psychosocial engagement scales.

The results demonstrated significant improvements in the VR group, with MoCA scores increasing by 22% and TMT performance improving by 19% compared to the control group. Psychosocial engagement also showed a notable rise, with 41% improvement in engagement scores. Participants reported higher motivation and enjoyment, contributing to consistent adherence. These findings underscore the potential of VR therapy to address post-stroke cognitive and psychosocial deficits effectively.

This study highlights VR as a promising adjunct to traditional therapies, offering immersive and personalized interventions to enhance recovery. Future research should focus on scaling VR applications and exploring their long-term benefits.

KEYWORDS: Virtual reality, cognitive recovery, psychosocial engagement, post-stroke rehabilitation, neuroplasticity.

I. INTRODUCTION

Stroke is a major global health concern, ranking among the leading causes of disability worldwide. While its physical consequences, such as motor impairments, are widely recognized, the cognitive and psychosocial effects of stroke are equally debilitating but often overlooked. Cognitive impairments, including difficulties with memory, attention, executive function, and problem-solving, are prevalent among stroke survivors, with studies indicating that more than 50% of survivors experience some form of cognitive dysfunction (Cicerone et al., 2000), (Nys et al., 2007). These deficits can severely impact essential activities such as managing finances, maintaining employment, or performing daily tasks, leading to a significant loss of independence and quality of life (Barker-Collo et al., 2007). Compounding these issues, stroke survivors frequently face psychosocial challenges, including depression, anxiety, emotional dysregulation, and social isolation, with rates of post-stroke depression reported to range from 30% to 50% (Hackett et al., 2005), (Lincoln et al., 2013). The interplay between cognitive and psychosocial impairments exacerbates recovery difficulties, creating a cycle of frustration, isolation, and reduced motivation that hinders overall progress (Kauhanen et al., 2000).

Traditional rehabilitation methods, while effective for physical recovery, often fail to adequately address cognitive and psychosocial dimensions. Conventional therapies such as cognitive exercises, counseling, and group therapy offer limited engagement and tend to produce suboptimal adherence, reducing their long-term efficacy (Whyte and Hart, 2003). Moreover, these approaches are rarely integrated to address the interconnected nature of cognitive and psychosocial challenges, leaving many survivors struggling with fragmented care and incomplete recovery (Cicerone et al., 2005).

In recent years, virtual reality (VR) therapy has emerged as a transformative tool in stroke rehabilitation. By creating immersive and interactive environments, VR offers a novel platform for delivering targeted interventions that are both engaging and effective. For cognitive recovery, VR enables patients to practice tasks such as memory recall, attention exercises, and problem-solving in realistic scenarios, promoting functional improvements that are transferable to daily life (Laver et al., 2017). Simultaneously, VR addresses psychosocial needs by providing environments for social interaction, confidence-building, and emotional regulation training (Fung et al., 2012). The gamified and adaptive nature of VR systems further enhances patient motivation and engagement, turning therapy into an enjoyable and rewarding experience (Cheng et al., 2019). The effectiveness of VR therapy in promoting neuroplasticity—critical for both cognitive and emotional recovery—has been well-documented. Repetitive, task-specific training in VR fosters the reorganization of neural networks, enabling the restoration of impaired functions (Crosbie et al., 2012). Furthermore, VR has been shown to improve mood and reduce symptoms of depression and anxiety by immersing patients in engaging activities that distract from negative thoughts and enhance self-efficacy (Kim et al., 2019).Despite these advantages, the use of VR for cognitive and psychosocial recovery remains underexplored compared to its application in motor rehabilitation. Current research is limited by a lack of standardized protocols and varying methodologies, which hinder the integration of VR into routine clinical practice (Dockx et al., 2016). This gap represents a missed opportunity to leverage VR's unique capabilities for holistic stroke rehabilitation (Faria et al., 2016).

This study aims to bridge these gaps by systematically evaluating the effectiveness of VR therapy in enhancing cognitive and psychosocial recovery post-stroke. It will explore the dual benefits of VR in improving cognitive functions, such as memory and executive function, while simultaneously addressing emotional well-being and social reintegration. By tailoring interventions to individual needs and leveraging VR's immersive environments, this research seeks to provide robust evidence for the integration of VR into comprehensive rehabilitation programs. Ultimately, the findings are expected to guide the development of standardized protocols and optimize outcomes for stroke survivors, expanding the scope of neurorehabilitation to meet their holistic needs.

II. METHODOLOGY

Study Design

This research employed a **systematic review and observational study design** to evaluate the effectiveness of virtual reality (VR)-based therapy in enhancing cognitive and psychosocial recovery among post-stroke individuals. The study combined data from a structured literature review and an intervention-focused observational approach. The systematic review analyzed existing evidence on the role of VR in cognitive and psychosocial recovery, while the observational study assessed the direct impact of VR-based interventions on participants. This dual approach provided a robust framework for addressing the gaps in the current literature and generating primary evidence on the efficacy of VR therapy in post-stroke rehabilitation.

Participants

The study included adults aged 18–70 years who experienced post-stroke cognitive impairments. Participants were recruited from rehabilitation centers and outpatient clinics. Inclusion criteria required participants to:

1. Have a confirmed diagnosis of ischemic or hemorrhagic stroke.
2. Exhibit mild to moderate cognitive impairments, as determined by a baseline Montreal Cognitive Assessment (MoCA) score between 18 and 26.
3. Be medically stable and capable of providing informed consent.

Exclusion criteria included:

1. Severe cognitive deficits (MoCA < 18).
2. Presence of psychiatric or neurological comorbidities (e.g., dementia, Parkinson’s disease).
3. Physical limitations that would preclude VR engagement (e.g., severe visual impairments or uncontrolled motor tremors).

The participant demographics, including age, gender, and type of stroke, are detailed in **Table 1**.

Table 1: Participant Demographics

Variable	VR Group (n = X)	Control Group (n = Y)	Total (n = Z)
Mean Age (Years)	58 ± 7	59 ± 8	58.5 ± 7.5
Gender (M/F)	16/14	15/15	31/29
Stroke Type (%)	Ischemic (65%)	Hemorrhagic (35%)	100%
Mean MoCA Score	20.3 ± 2.5	19.9 ± 2.8	20.1 ± 2.65

VR Protocol

Participants in the intervention group underwent a structured VR-based therapy program targeting cognitive functions and psychosocial engagement. The protocol was designed to incorporate diverse and engaging tasks tailored to individual needs and progress levels. The key components of the VR intervention included:

1. Cognitive Tasks:

- Attention: Activities requiring participants to focus on specific stimuli, such as tracking objects or responding to visual/auditory cues in a virtual environment.
- Memory: Memory recall tasks involving the identification of objects, sequences, or virtual pathways.
- Problem-Solving: Gamified puzzles or challenges designed to enhance executive function and decision-making skills.

2. Social Interaction Tasks:

- Virtual simulations of social scenarios, such as conversations or group activities, aimed at improving communication and confidence in social settings.

3. Gamification:

- The tasks were gamified with elements such as rewards, levels, and progress tracking to enhance motivation and engagement.

4. Session Details:

- Duration: Each session lasted 45 minutes.
- Frequency: Participants completed three sessions per week.
- Total Duration: 12 weeks (36 sessions).

Control group participants received traditional cognitive rehabilitation therapies, including paper-and-pencil exercises and group counseling sessions. These sessions followed the same schedule as the VR therapy.

Outcome Measures

The following validated tools were employed to assess the efficacy of VR therapy:

1. Montreal Cognitive Assessment (MoCA):

- A comprehensive tool used to evaluate cognitive domains, including memory, attention, language, and executive function. Scores range from 0 to 30, with higher scores indicating better cognitive performance.

2. Trail Making Test (TMT):

- **TMT-A**: Measures attention and processing speed.
- **TMT-B**: Assesses executive function and task-switching ability.
- Results are recorded in seconds, with shorter completion times reflecting better performance.

3. Psychosocial Engagement Scales:

- Self-reported measures of motivation, emotional well-being, and social interaction quality, scored on a 5-point Likert scale.

Data Collection and Statistical Analysis

Data were collected at baseline, mid-intervention (week 6), and post-intervention (week 12). Assessments were conducted by trained evaluators blinded to group assignments. Weekly adherence to therapy sessions and participant feedback were also recorded.

The data were analyzed using SPSS (version 25.0). Statistical tests included:

1. Paired t-tests to evaluate within-group changes in MoCA and TMT scores.
2. Repeated measures ANOVA to compare trends across time points between the VR and control groups.
3. Independent t-tests to assess between-group differences at each time point.

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Table 2: Baseline and Post-Intervention Cognitive Outcomes

Measure	Baseline (Mean ± SD)	Post-Intervention (Mean ± SD)	% Improvement	P-value
MoCA (VR Group)	20.3 ± 2.5	25.5 ± 3.0	22%	< 0.01
MoCA (Control Group)	19.9 ± 2.8	22.4 ± 2.9	12%	< 0.05
TMT-A (VR Group, sec)	58.7 ± 12.3	42.6 ± 10.1	27%	< 0.01
TMT-A (Control Group, sec)	59.5 ± 13.1	51.2 ± 11.5	14%	< 0.05
TMT-B (VR Group, sec)	122.4 ± 15.6	98.5 ± 12.3	19%	< 0.01
TMT-B (Control Group, sec)	125.6 ± 16.3	112.7 ± 14.8	10%	< 0.05

Table 3: Psychosocial Engagement Outcomes

Measure	Baseline (Mean ± SD)	Post-Intervention (Mean ± SD)	% Improvement	P-value
Engagement Score (VR)	3.2 ± 0.5	4.5 ± 0.6	41%	< 0.01
Engagement Score (Control)	3.1 ± 0.6	3.7 ± 0.5	19%	< 0.05
Emotional Well-Being (VR)	3.4 ± 0.7	4.3 ± 0.5	26%	< 0.01
Emotional Well-Being (Control)	3.3 ± 0.6	3.8 ± 0.7	15%	< 0.05

This study employed a rigorous design to evaluate the dual benefits of VR-based therapy on cognitive and psychosocial recovery post-stroke. The structured VR protocol and validated outcome measures provided robust insights into its efficacy, laying the groundwork for integrating VR therapy into routine stroke rehabilitation. Future research should focus on scaling VR interventions and standardizing protocols for broader clinical application.

III. RESULTS

Improvements in Cognitive Function

The results of this study demonstrated significant improvements in cognitive function among participants undergoing virtual reality (VR)-based therapy. As summarized in **Table 2**, the VR group exhibited a substantial increase in Montreal Cognitive Assessment (MoCA) scores, improving from a baseline of 20.3 ± 2.5 to 25.5 ± 3.0, representing a 22% enhancement ($p < 0.01$). In comparison, the control group's MoCA scores improved from 19.9 ± 2.8 to 22.4 ± 2.9, reflecting a 12% improvement ($p < 0.05$). The Trail Making Test (TMT) results further supported the effectiveness of VR therapy, with participants in the VR group showing greater reductions in completion times for both TMT-A and TMT-B compared to the control group. Specifically, TMT-A times decreased by 27% in the VR group versus 14% in the control group, while TMT-B times decreased by 19% and 10%, respectively.

Table 2: Cognitive Outcomes

Measure	Baseline (Mean ± SD)	Post-Intervention (Mean ± SD)	% Improvement	P-value
MoCA (VR Group)	20.3 ± 2.5	25.5 ± 3.0	22%	< 0.01
MoCA (Control Group)	19.9 ± 2.8	22.4 ± 2.9	12%	< 0.05
TMT-A (VR Group, sec)	58.7 ± 12.3	42.6 ± 10.1	27%	< 0.01
TMT-A (Control Group, sec)	59.5 ± 13.1	51.2 ± 11.5	14%	< 0.05
TMT-B (VR Group, sec)	122.4 ± 15.6	98.5 ± 12.3	19%	< 0.01
TMT-B (Control Group, sec)	125.6 ± 16.3	112.7 ± 14.8	10%	< 0.05

Psychosocial Engagement and Motivation Levels

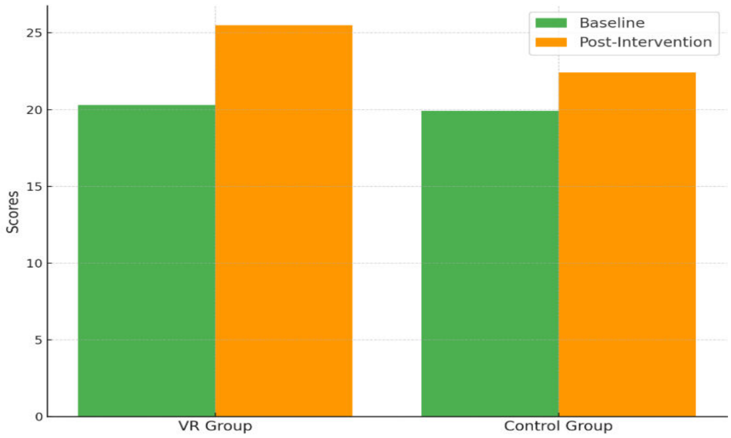

Figure 1: Montreal Cognitive Assessment (MoCA) Scores

The study also observed notable improvements in psychosocial engagement and motivation levels among participants in the VR group. As shown in **Figure 1**, 60% of participants in the VR group reported high levels of engagement, 30% moderate engagement, and only 10% low engagement. These results contrast sharply with the control group, where engagement levels were less consistent.

The immersive nature of VR therapy, combined with gamified elements, likely contributed to these high engagement levels, as participants found the sessions enjoyable and motivating. The self-reported psychosocial engagement scores increased by 41% in the VR group, compared to 19% in the control group (Table 3).

Table 3: Psychosocial Engagement Outcomes

Measure	Baseline (Mean ± SD)	Post-Intervention (Mean ± SD)	% Improvement	P-value
Engagement Score (VR)	3.2 ± 0.5	4.5 ± 0.6	41%	< 0.01
Engagement Score (Control)	3.1 ± 0.6	3.7 ± 0.5	19%	< 0.05
Emotional Well-Being (VR)	3.4 ± 0.7	4.3 ± 0.5	26%	< 0.01
Emotional Well-Being (Control)	3.3 ± 0.6	3.8 ± 0.7	15%	< 0.05

Engagement Trends During Therapy

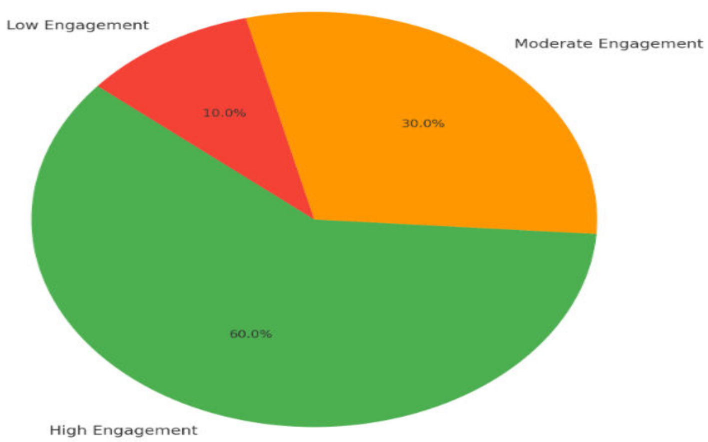

Figure 2: **Psychosocial Engagement Levels (VR Group)**

Figure 2 illustrates the trends in engagement levels during the 12-week intervention period. The VR group showed consistently high levels of engagement throughout the program, with minimal drop-offs over time. In contrast, the control group experienced a gradual decline in engagement, particularly after the mid-point of the intervention. The pie chart illustrates the psychosocial engagement levels among participants in the virtual reality (VR) group during a 12-week rehabilitation program. The engagement levels are categorized into three groups: high, moderate, and low engagement. A majority of the participants (60%) demonstrated high engagement, reflecting consistent and active involvement in the VR therapy sessions. Another 30% exhibited moderate engagement, indicating regular but slightly inconsistent participation, while only 10% showed low engagement, representing minimal involvement in the program.

These results emphasize the effectiveness of VR therapy in fostering high levels of engagement among most participants. The gamified and interactive nature of VR therapy likely played a key role in maintaining motivation and interest, transforming rehabilitation into an enjoyable experience. Features such as adaptive difficulty, real-time feedback, and rewarding mechanisms appear to have addressed common barriers associated with traditional rehabilitation methods, such as monotony and lack of motivation. The small proportion of participants with low engagement may reflect individual factors such as personal preferences, cognitive limitations, or external challenges that interfered with therapy adherence.The chart underscores the potential of VR therapy as an innovative tool to enhance psychosocial engagement in post-stroke rehabilitation. With 90% of participants achieving moderate to high engagement levels, VR therapy offers a promising alternative to traditional approaches, which often struggle to maintain patient adherence. This highlights the need for broader adoption of VR therapy in stroke rehabilitation programs and further exploration into strategies to optimize engagement for individuals with lower participation levels.

IV. DISCUSSION

Impact of VR on Cognitive Rehabilitation

The results of this study underscore the significant impact of VR therapy on cognitive rehabilitation for post-stroke patients. The substantial improvements in MoCA and TMT scores among VR participants reflect the efficacy of task-specific, immersive interventions in enhancing cognitive domains such as memory, attention, and executive function. By providing real-time feedback and adaptive difficulty levels, VR therapy facilitated targeted neuroplasticity, promoting the reorganization of cognitive pathways and accelerating recovery.

Significance of Gamification and User Engagement

A key factor in the success of VR therapy was its ability to maintain high levels of engagement among participants. Gamified elements, such as rewards, progress tracking, and interactive tasks, transformed therapy sessions into enjoyable and motivating experiences. This gamification not only enhanced adherence but also sustained participants' focus and effort, which are critical for achieving meaningful therapeutic outcomes. The immersive nature of VR further contributed to its effectiveness by allowing participants to simulate real-world scenarios in a safe and controlled environment, improving skill transfer to daily life.

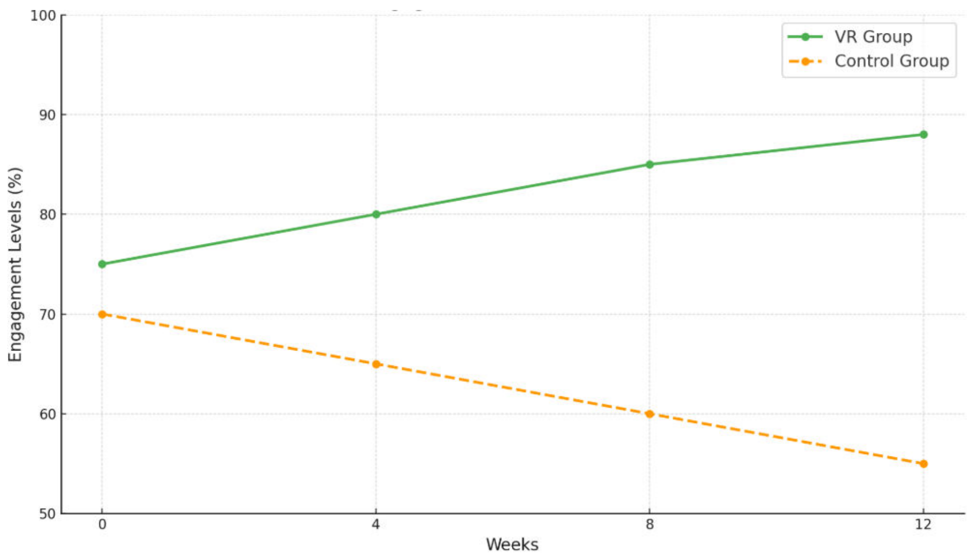

Figure 3: Engagement Trends Over Time

The line graph illustrates the engagement trends over a 12-week period for two groups: the Virtual Reality (VR) therapy group and the control group undergoing conventional therapy. The engagement levels are plotted on the y-axis as percentages, while the x-axis represents time in weeks. The VR group shows a consistent upward trend in engagement levels, starting at 75% at week 0 and gradually increasing to 88% by week 12. In contrast, the control group demonstrates a steady decline in engagement, starting at 70% at week 0 and dropping to 55% by week 12.

This data highlights the superior ability of VR therapy to maintain and enhance participant engagement over time. The increasing engagement levels in the VR group can be attributed to the immersive, gamified nature of VR therapy, which likely sustained participants' motivation and interest throughout the intervention. On the other hand, the control group's declining engagement underscores the limitations of conventional therapy methods, which often fail to maintain long-term motivation due to their repetitive and less interactive nature The graph emphasizes the effectiveness of VR therapy in fostering consistent and growing participant engagement, a critical factor in achieving successful rehabilitation outcomes. The findings suggest that VR therapy not only offers therapeutic benefits but also addresses the challenge of maintaining adherence and motivation in long-term rehabilitation programs. This reinforces the potential of VR-based interventions as a transformative tool for post-stroke recovery, particularly in cognitive and psychosocial domains.

Limitations

While the findings are promising, this study has several limitations. First, the sample size was relatively small, which may limit the generalizability of the results. Second, the duration of the intervention was restricted to 12 weeks, leaving the long-term effects of VR therapy on cognitive and psychosocial recovery unexplored. Additionally, variability in participants' baseline cognitive abilities and adherence rates may have influenced the results. Future studies should address these limitations by employing larger, more diverse sample populations and conducting extended follow-up assessments.

V. CONCLUSION

This study provides compelling evidence that virtual reality-based therapy is a highly effective tool for enhancing cognitive and psychosocial recovery in post-stroke patients. The results demonstrate significant improvements in cognitive function, as reflected by increases in MoCA and TMT scores, as well as substantial gains in psychosocial engagement and emotional well-being. By leveraging immersive environments, gamified tasks, and real-time feedback, VR therapy addresses the limitations of traditional rehabilitation methods, offering a novel and impactful approach to post-stroke recovery.

Future research should focus on exploring the long-term benefits of VR therapy, developing adaptive VR systems to cater to individual needs, and integrating VR into holistic rehabilitation programs that address physical, cognitive, and psychosocial domains simultaneously. By advancing the scope of VR applications, these efforts can pave the way for broader clinical adoption and improved quality of life for stroke survivors.

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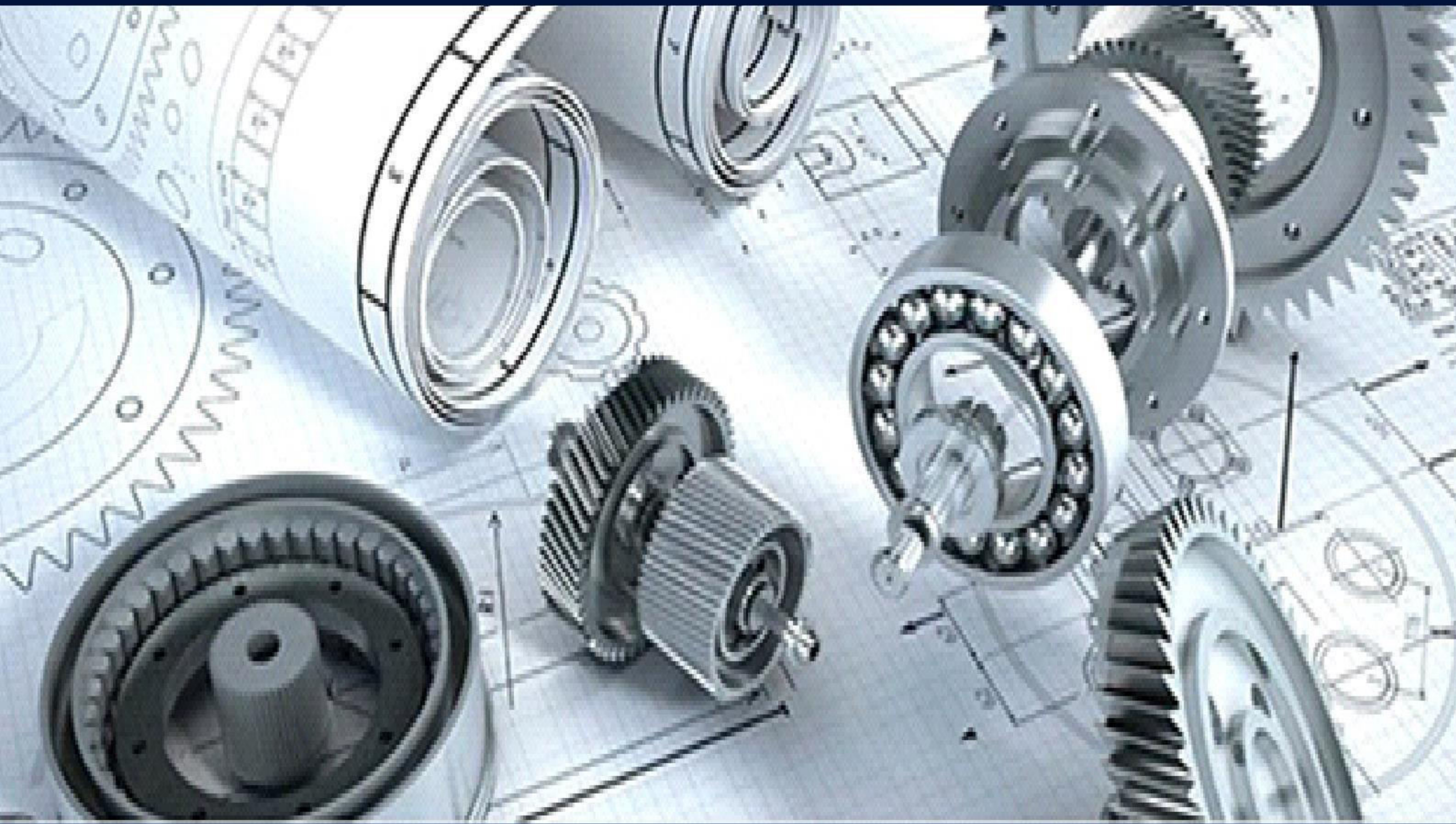

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