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EFFECT OF VIRTUAL REALITY TRAINING ON HAND FUNCTION IN SUBJECTS WITH STROKE- A pilot study.

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ABSTRACT:

PURPOSE: The study aims to find out the effect of virtual reality training on hand function with stroke subjects.
RELEVANCE: Stroke, a prevalent neurological issue, is a major cause of upper extremity and hand impairments, impacting components of the Barthel index such as holding, grasping, and manipulating objects. Training with a Leap Motion Controller (LMC) based device, coupled with Virtual Reality (VR), proves effective in enhancing upper limb function and motor skills in hand rehabilitation. The LMC precisely tracks fine movements of both hand and fingers, offering potential relief for the growing strain on stroke rehabilitation due to the increasing prevalence of stroke.
PARTICIPANTS: The study recruited 30 Sub acute stroke subjects meeting inclusion criteria, aged 35-70, both men and women with MMSE >24, Hand ROM >10, and Brunnstrom recovery stages 3 & 4 on both right and left sides, Ischemic and Haemorrhagic strokes are included.
METHOD: The study employs a double -blind, prospective randomized control design. Subjects were randomly assigned to two groups: Group A, received VR game-based exercise with an LMC device along with hand exercises, Group B, underwent conventional exercise solely for the hand. Both groups participated in 60 minutes of daily sessions, 3 days a week, over an 8-week period.

Arm and hand function was evaluated by Fuel-Meyer assessment (FMT), Action research arm test (ART)in additionally wrist movement analysis was done by Kinova software (KEA) and grip strength was measured by Hand-held Dynamometer (HD).

ANALYSIS: Pre and post-values were measured using paired t-tests within the groups. The individual t-test is used to measure the between group data.

RESULTS: Following treatment, both groups exhibited significant differences in FMT, ART, KEA, and HD ($p < 0.05$). Additionally, a comparison between the experimental and control groups revealed significant results across all parameters ($p < 0.05$).

CONCLUSION: This study showed that VR with LMC device training can be used as an effective adjuvant in improving hand function in stroke subjects.

KEYWORDS: Stroke, Hand Function, Dexterity, Virtual reality Training, Leap motion controller.

ABBREVIATION: VRT= virtual reality training, LMC= leap motion control device, FMT= Fugl Myer upper extremity TEST, ART= Action research arm test, KEA=Kinovea wrist extension analysis, HD= Hand held dynamometer, MMSE= mini mental scale, ROM= Range of motion.

INTRODUCTION:

Stroke is a common neurological problem and one of the leading causes of disability and death worldwide, as reported by the World Health Organization (WHO)[1]. It is an acute neurological event caused by an alteration in blood flow to the brain, leading to ischemia or infarction. Atherosclerosis, one of the major causes of stroke, disrupts brain circulation, hinders information flow across brain regions, and triggers a cascade of synaptic plasticity events from molecular to behavioural systems[2]. Several risk factors contribute to stroke, including tobacco use, atrial fibrillation, physical inactivity, unhealthy diet, alcohol consumption, hypertension, elevated blood lipid levels, obesity, male gender, old age, genetic predisposition, and psychological factors[3].

In India, the cumulative incidence of stroke ranges from 122 to 170 per 100,000 persons (2019 data), with approximately 46% of stroke survivors experiencing long-term effects[4]. The most common neurological impairment caused by stroke is partial weakness, which may manifest as paresis or plegia—conditions characterized by a reduced ability to voluntarily activate motor neurons. Plegia represents total paralysis, while paresis involves partial motor impairment [5,6]. These motor dysfunctions typically affect the side contralateral to the damaged brain tissue and frequently impair upper extremity function more than the lower extremities, significantly restricting activities of daily living.

Despite advancements in prevention and acute treatment, stroke remains a leading cause of adult disability worldwide[7]. Recovery of upper extremity impairments and activity limitations primarily occurs within the first 2–3 months after a stroke, although some patients continue to recover over a longer period. Approximately 70% of stroke survivors experience arm and hand weakness, and at six months post-stroke, 62% of these individuals do not regain dexterity in their arm and hand [8]. Studies by Kwakkel et al. reveal that 38% of severely disabled stroke patients regain some fine hand use, while only 12% recover complete fine hand use within six months[9]. Chronic motor problems pose challenges for functional activities such as grasping objects, buttoning shirts, or using tools, making arm and hand dysfunction a major concern for stroke survivors[10]. Early and intensive treatment is critical for recovery.

Recent advancements in neuroscience have reshaped our understanding of the human central nervous system (CNS). Once considered static, the CNS is now known to possess plasticity, the ability to restructure and reorganize throughout life. This property plays a crucial role in learning, memory, and the recovery of motor function after injury. Neurorehabilitation, a clinical sub-specialty, focuses on restoring and maximizing functions lost due to nervous system impairments. Stroke rehabilitation leverages the concept of neuroplasticity, with functional MRI studies over the past decade providing robust evidence of cerebral reorganization[11,12].

Motor training for the paretic hand during rehabilitation not only increases somatosensory input but also results in well-documented behavioural improvements[13]. Animal models have demonstrated positive outcomes in neural substrates undergoing rehabilitation, and parallel clinical advances have emerged[14]. Non-invasive physiotherapy techniques, such as mirror therapy, repetitive transcranial stimulation, constraint-induced movement therapy, robotic-assisted devices, and virtual reality training, have shown promising results in addressing arm and hand functional limitations in stroke rehabilitation. These approaches underscore the potential of neuroplasticity-driven strategies to enhance recovery and improve quality of life for stroke survivors[15].

Virtual reality: Virtual Reality Training (VRT) is a modern rehabilitation approach that serves as a complementary or alternative method to conventional therapy for upper limb functional impairments, especially in stroke patients. VRT leverages advanced technologies to enhance motor recovery by providing rich, controllable, and customizable multimodal simulations that actively engage patients in their recovery process.[15,16]

While several VRT devices have demonstrated promising outcomes for upper limb rehabilitation, many fail to address wrist and finger movements—critical for functional tasks like reaching, grasping, and manipulating objects. To address this gap, the Leap Motion Controller (LMC) has gained attention as a cost-effective and innovative device specifically tailored for neurorehabilitation. Developed by David Holza, the LMC tracks fine hand and finger movements with sub-millimetre precision, enabling users to interact with virtual environments. This system is composed of three components: a personal laptop, the LMC device, and a USB cable for connectivity. Its motion-capture capabilities allow for the monitoring of multiple hand and finger movements, supporting tasks requiring arm and hand coordination in an engaging game-like format[17,18]. Research highlights the potential of the Leap Motion Controller in facilitating motor recovery and promoting neural reorganization in stroke patients. Its affordability, precision, and ability to immerse users in tailored therapeutic environments make it a valuable tool in stroke rehabilitation[19], helping address upper limb functional impairments and enhancing overall recovery outcomes.

NEED OF THE STUDY:

Stroke affects arm and hand function in up to 85% of patients initially, with 55–75% still experiencing deficits three to six months later [20], significantly impairing daily living activities like grasping and manipulating objects. While therapies such as constraint-induced movement therapy, mirror therapy, and task-specific training have shown some success in upper limb recovery, they often lack focus on hand-specific impairments, face challenges in maintaining patient motivation, and can be costly. Motivation plays a crucial role in performance, as described by the Yerkes-Dodson law[21], which highlights the need for optimal arousal levels during therapy[22].

Virtual Reality Training (VRT), particularly with the Leap Motion Controller (LMC), offers an engaging, cost-effective solution, enabling repetitive, task- oriented training tailored to maximize arousal and performance. VRT enhances motor relearning and brain plasticity by providing a virtual environment that supports sensorimotor representation and transformation[23]. However, limited research has specifically addressed hand function recovery in stroke patients using LMC-based VRT. Thus, this study aims to evaluate the effect of VRT on hand function in stroke patients.

OBJECTIVES OF THE STUDY:

i. To evaluate the effect of Virtual Reality based Leap Motion Controller training on affected hand grip strength by using Hand held dynamometer (HD) in a subjects with stroke.

ii. To evaluate the effect of Virtual Reality based Leap motion controller training on affected Upper extremity capacity (function) by using Action Research Arm Test (ART) in a subject with stroke.

iii. To evaluate the effect of Virtual Reality based Leap Motion Controller training on affected hand motor recovery by using Fugl-Meyer Upper Extremity test (FMT-UE) in a subjects with stroke.

iv. To evaluate the effect of Virtual Reality based Leap Motion Controller training on affected wrist and hand kinematics by using kinovea wrist extension analysis software in a subjects stroke.

METHODS:

STUDY DESIGN: This study is double – blinded prospective randomized control trail with assessment administered pre and post 8 -weeks intervention. Ethical committee approval was obtained from Sri Venkateswara institute of medical sciences (SVIMS) and Study set-up at SVIMS college of physiotherapy, Tirupati, A.P.

PARTICIPANTS: The 30 stroke patients have taken to the study and who met inclusion and exclusion criteria were eligible for the study:

Inclusion criteria-

- Sub-acute stroke (hemodynamically stable -7thday after stroke).
- Stroke subjects age:40-70years.
- Both men and women stroke subjects are included.
- Stroke subjects with right and left hemiplegic are included.
- Stroke subjects whose mini-mental state examination score > 22.
- Stroke subjects who have hand range of motion should be minimum 5-10 degree
- Patient should acquire stage-3 and 4 of Brannstrom stages of stroke recovery.

Ischemic stroke and haemorrhagic stroke subjects are include

Exclusion criteria-

- Stroke subjects who have Spastic hand
- Stroke subjects unwilling to participate.
- Stroke subjects with Shoulder hand syndrome
- Stroke subjects who have Visual impairments.
- Stroke subjects who have sensory deficit
- Sever aphasia and psychiatric illness.

STUDY PROCEDURE AND INTERVENTION: After giving informed consent, eligible subjects allocated in to two groups according a simple randomization technique with Sealed opaque envelopes: two groups were named as experimental group (n=15) received virtual reality based leap motion control training and the other group control group (n=15) received conventional physiotherapy for 3 session per week for 8-weeks with each session lasting 60 –min.

Virtual reality training

Virtual Reality Therapy (VRT) games, integrated with Leap Motion Controller (LMC) technology, offer an innovative solution for stroke rehabilitation by targeting motor and cognitive impairments through engaging and task-specific interventions. To play these games, first ensure the Leap Motion Controller (LMC) is properly connected to laptop and Install the leap motion Inc. software for LMC and the VRT games. Position the controller on a flat surface and patient made to sit on the chair with free open space for plying hand games. Five unique games have been developed for this purpose. The **Petal Picking Game** immerses patients in a virtual garden, requiring them to use pinching gestures to pick lotus petals, thereby enhancing fine motor skills, finger dexterity, and hand-eye coordination. Each session involves at least 30 repetitions within 10 minutes. The **Robot Assembly Game** challenges patients to assemble a virtual robot, promoting forearm pronation/supination, pinching skills, and spatial awareness, with 30 assembly tasks completed in a 10-minute session. The **Plasma Ball Game** focuses on hand extension/flexion, forearm rotation, and gripping strength as patients manipulate a virtual plasma ball using gestures like sweeping and pinching, also performed for 30 repetitions in 10 minutes. The **Flocking Game** requires dynamic hand gestures to guide a virtual flock, improving finger extension/flexion and hand coordination, with 30 movements executed in a 5-minute session. Lastly, the **King of Juice Game** engages patients in virtual juice preparation tasks, including squeezing and pouring, to increase the range of motion (ROM) in the hand, elbow, and shoulder, while strengthening wrist muscles. This game also involves 30 repetitions within a 5-minute session. Along with conventional hand exercise also performed in this group for minute of 10 -15 min.

Conventional exercise

In this group subjects will be made to sit comfortably on chair and perform the following hand exercises . It includes Hand and Finger exercises: Band exercise, Making a fist, Finger stretch, Wide open, Ball squeezing, Claw hand, Grip strengthening, Pinch strengthening, Finger lift, Thumb extension, Thumb flex, Thumb touch, Thumb stretches. 60 min a day /3 times a week for 8-weeks.

Outcome measures: Affected hand grip strength measured by using Hand held dynamometer, Affected Upper extremity motor function by using Action Research Arm Test, Affected hand motor recovery measured by using Fugl-Meyer Upper Extremity test (FM-UE), Affected wrist and hand kinematics measured by using kinovea wrist extension analysis. These have been validated for use in the stroke population. These were completed at base line, post intervention and 8- weeks follow-up.

Study algorithm:

Assed for eligibility n=30

Randomization (n=30)

Experimental group (VRT group) (n=15) 50 -min a day /3 times a week for 8-weeks.10-min conventional hand exercises.

Pre - test measures by FMT, ART, HD, KEA.

Drop out n=0, follow- up (n=15)

Data analysis n=15

Results and conclusion

Control group (n=15) (Conventional physiotherapy treatment) (n=15). 60 -min a day /3 times a week for 8-weeks.

Pre - test measures by FMT, ART, HD KEA.

Drop out n=0 Follow-up n=15

Data analysis n=15

Results and conclusion

DATA ANALYSIS: Data were analysed by using SPSS version (10.0;SPSS Inc.Chicago.) confident limit set 95% with margin of error 5% and level significant was set at $P<0.05$. Pre and post-values were measured using paired t-tests within the groups. The individual t-test is used to measure the between group data.

Table -1: Base line characteristics of study population.

(Comparison of Demographic Variables between control and experimental groups)

Variables	Control Group (N=15)	Experimental Group (N=15)	P -Value (2-Tailed)
Age: Years	49.46 ±9.35	47.61 ±8.51	0.621
Gender: Male: Female	9:6	8:7	X^2 =1.32 P=0.461
Side Stroke: R: L	6:9	9:6	X^2=0.43 P=0.756

The demographic comparison between the control and experimental groups revealed no significant differences. The control group had a mean age of 49.46 ± 9.35 years, while the experimental group had a mean age of 47.61 ± 8.51 years ($p = 0.621$). Gender distribution was also similar, with 9 males and 6 females in the control group, and 8 males and 7 females in the experimental group ($\chi^2 = 1.32$, $p = 0.461$). Regarding stroke side, the control group had 6 right- sided and 9 left-sided strokes, while the experimental group had 9 right-sided and 6 left-sided strokes ($\chi^2 = 0.43$, $p = 0.756$). These findings indicate no significant differences in age, gender, or stroke side between the two groups.

Table-2: Comparison of mean score of outcome measures at baseline and on follow-up in Experimental Group

Categories	**N**	**Mean**	**SD**	**t- value**	**p-value**
FMT Pre-value	15	89.60	21.67	4.25	0.001
FMT post-value	15	101.17	26.19		
ART pre- values	15	22.23	4.67	9.53	0.000
ART post value	15	47.81.	7.38		
HD pre -value	15	2.01	0.61	2.11	0.010
HD post-value	15	4.67	1.42		
KEA pre-value	15	14.20	4.47	5.61	0.000
KEA post- value	15	20.26	5.49		

N = sample, SD = Standard deviation, t= t-test, p= level significance, FMT- Fugl-Meyer Upper Extremity Test, ART= Action research arm Test, HD= Kinovea wrist extension analysis

The within-group analysis of the experimental group revealed significant improvements across all outcome measures following the intervention. The FMT showed a notable increase from 89.60 ± 21.67 to 101.17 ± 26.19 ($p = 0.001$), indicating enhanced upper extremity function. Similarly, the ART demonstrated a substantial improvement, with scores rising from 22.23 ± 4.67 to 47.81 ± 7.38 ($p < 0.0001$) with HD also improved significantly, from 2.01 ± 0.61 to 4.67 ± 1.42 ($p = 0.010$), suggesting better grip strength. Finally, the KEA revealed a significant increase from 14.20 ± 4.47 to 20.26 ± 5.49 ($p < 0.0001$).

TABLE-3 Comparison of mean score of outcome measures at baseline and on follow-up in Control Group.

Categories	N	Mean	SD	t- value	p-value
FMT Pre	15	92.80	16.55	4.94	0.000
FMT Post	15	99.00	18.31		
ART pre	15	22.41	5.26	5.66	0.001
ART post	15	30.01	7.59		
HD pre	15	2.01	0.61	2.11	0.010
HD post	15	4.67	1.42		
KEA pre	15	14.20	4.47	5.61	0.000
KEA post	15	20.26	5.49		

The results for the control group showed significant within-group improvements across all outcome measures following the intervention. The FMT scores increased from 92.80 ± 16.55 to 99.00 ± 18.31, with a mean difference of 6.20 ($p < 0.0001$), indicating a substantial improvement in upper extremity function. The ART also demonstrated significant improvement, rising from 22.41 ± 5.26 to 30.01 ± 7.59**,** with a mean difference of 7.60 ($p = 0.001$), reflecting enhanced arm function. The HD scores increased from 2.01 ± 0.61 **to** 4.67 ± 1.42**,** resulting in a mean difference of 2.66 ($p = 0.010$). Finally, the KEA scores improved from 14.20 ± 4.47 to 20.26 ± 5.49**,** with a mean difference of 6.06 **(**$p < 0.0001$).

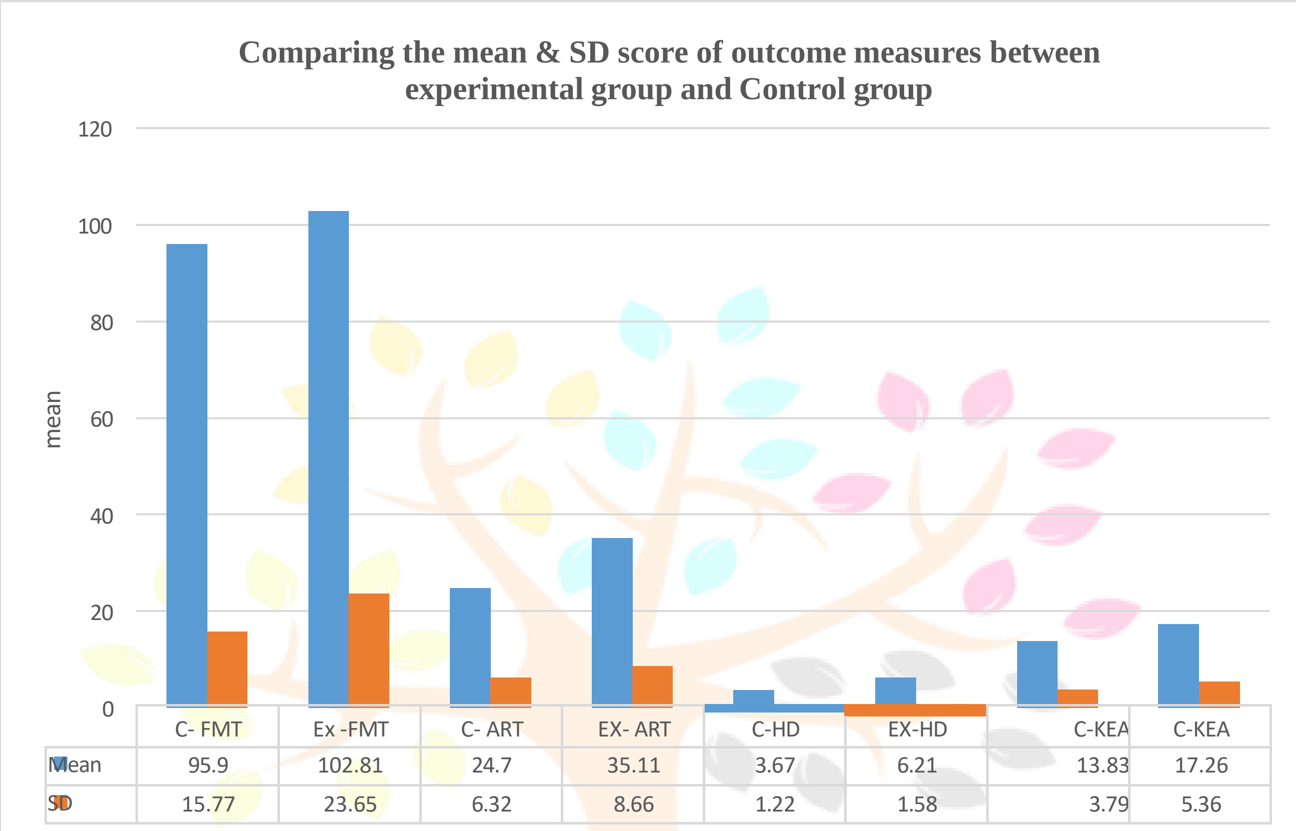
Table -4: Comparing the mean score of outcome measures between experimental group and Control group.

Categories	N	Mean	SD	t- value	p-value
C- FMT	30	95.90	15.77	5.17	0.000
Ex -FMT	30	102.81	23.65		
C- ART	30	24.70	6.32	4.69	0.000
Ex- ART	30	35.11	8.66		
C-HD	30	3.67	1.22	2.55	0.012
Ex-HD	30	6.21	1.58		
C-KEA	30	13.83	3.79	3.11	0.004
Ex -KEA	30	17.26	5.36		

C -FMT= control group Fugl Myer upper extremity test, Ex= Experimental group Fugl Myer upper extremity test, C-ART= Control group Action Research arm test, Ex= Experimental Action Research arm test, C-HD= control group Hand held dynamometer, Ex-HD= experimental group Hand held dynamometer, C-KEA= control group kinovea wrist extension analysis, Ex-KEA= Experimental group Kinovea writs extension analysis, SD= Standard deviation , p= significance.

The comparison of outcome measures between the control group and the experimental group (Ex) revealed significant differences, such as FMT scores significantly improved in both groups, with the control group showing a mean of 95.90 ± 15.77 and the experimental group achieving a mean of 102.81 ± 23.65. The difference in scores between the groups was statistically significant ($t = 5.17$, $p < 0.0001$), indicating that the experimental group experienced a greater improvement in upper extremity function compared to the control group. Similarly, the ART scores for the control group increased from 24.70 ± 6.32 to 35.11 ± 8.66 in the experimental group. The difference between the two groups was significant ($t = 4.69$, $p < 0.0001$), with the experimental group showing a mean difference of 10.41, suggesting greater enhancement in arm reach. For HD, the control group scored 3.67 ± 1.22, while the experimental group had a mean score of 6.21 ± 1.58. The difference was statistically significant ($t = 2.55$, $p = 0.012$), with the experimental group showing a mean difference of 2.54, indicating superior improvement in fine motor skills.

Graph-1 : Mean and SD analysis between in the groups



C -FMT= control group Fugl Myer upper extremity test, Ex= Experimental group Fugl Myer upper extremity test, C-ART= Control group Action Research arm test, Ex= Experimental Action Research arm test, C-HD= control group Hand held dynamometer, Ex-HD= experimental group Hand held dynamometer, C-KEA= control group kinovea wrist extension analysis, Ex-KEA= Experimental group Kinovea writs extension analysis, SD= Standard deviation, p= significance.

c- FMT= Control group,

Lastly, the KEA results revealed a significant improvement in the experimental group (mean = 17.26 ± 5.36) compared to the control group (mean = 13.83 ± 3.79). This difference was statistically significant ($t = 3.11$, $p = 0.004$), with a mean difference of 3.43, indicating greater improvement in wrist extension in the experimental group.

Discussion:

The primary objective of this randomized controlled trial (RCT) was to evaluate the effect of Virtual Reality Training (VRT) using the Leap Motion Controller (LMC) on hand function in stroke patients. A total number of 30 subjects participated in the study and randomized into 15 subjects for VRT (experimental) group and 15 subjects in the conventional physiotherapy (control) group. The findings revealed significant improvements in multiple measures of hand and upper extremity function, including grip strength (Handheld Dynamometer – HD), upper extremity capacity (Action Research Arm Test – ART), motor recovery (Fugl-Meyer Upper Extremity – FMT), and wrist/hand kinematics (Kinovea Wrist Extension Analysis – KEA). Importantly, subjects in the experimental group, who underwent VRT, exhibited greater improvements than those in the conventional physiotherapy control group, supporting the hypothesis that VRT using the Leap Motion Controller is more effective in promoting motor recovery following stroke.

These results align with previous studies that have demonstrated the effectiveness of virtual reality (VR) and interactive technologies in stroke rehabilitation. For instance, Iosa et al. (2015) observed similar outcomes in stroke patients, where VR-based rehabilitation showed higher engagement and more significant improvements compared to traditional therapy methods[24]. Similarly, our findings underscore the enhanced engagement provided by interactive VR platforms, such as the Leap Motion-based system, which allows patients to perform task- oriented exercises while receiving real-time visual and auditory feedback. Such features contribute to greater motivation, which is a critical element in stroke rehabilitation, as emphasized by the Yerkes-Dodson Law (Yerkes & Dodson, 1908). This law suggests that optimal levels of motivation, facilitated by engaging and interactive tasks, are crucial for improving rehabilitation outcomes. Therefore, VRT not only promotes neuroplasticity through repetitive task-specific training but also enhances patient motivation, leading to more consistent and effective rehabilitation[25].

The observed improvements in motor function can be attributed to the principles of neuroplasticity, particularly in the context of high-intensity, repetitive, and task- oriented training, as suggested by previous research (Barreca et al., 2003; Wolf et al., 2006; Dobkin, 2008). Stroke rehabilitation is heavily reliant on the brain's ability to reorganize and form new neural connections. The VRT protocol using the Leap Motion Controller encourages the repetition of arm and hand movements, which are critical in stimulating the affected sensorimotor cortex. The intensity of this practice is likely to induce neuroplastic changes, as suggested by Kopp et al. (1999) and Nudo (2011), who emphasized the importance of repetitive practice in modifying neural organization[27].

Moreover, virtual reality has been shown to support the activation of brain regions involved in sensorimotor function. According to Zun-rong Wang et al. (2017), VR-based training significantly improved motor functional recovery in sub -acute stroke patients, demonstrating a shift in sensorimotor cortical activity as observed through functional MRI (fMRI)[28]. This shift is particularly notable in the experimental group, which underwent VRT. The greater shift in the sensorimotor cortex between the hemispheres of the brain in the VR group compared to the control group suggests that VRT can facilitate a more pronounced neuroplastic response, likely contributing to superior functional recovery. The VR environment's ability to simulate real-life tasks and provide visual and proprioceptive feedback further supports the process of motor learning. The Leap Motion Controller enables patients to control virtual avatars with their hands, which enhances motor learning through imitation and coordination. Studies such as those by Rizzolatti et al. (1999) and Holden and Dyar (2002) have highlighted the role of mirror neurons in motor learning and neuroplasticity, especially in rehabilitation[30]. Virtual reality training, by engaging the user in tasks where they mimic movements of a virtual avatar, may stimulate mirror neural networks, enhancing motor recovery. This process likely underpins the significant improvements seen in the present study, especially in fine motor skills like hand grip strength and wrist extension[40].

The comparison between the experimental and control groups further strengthens the study for incorporating virtual reality into stroke rehabilitation. While both groups showed improvements across all outcome measures (FMT, ART, HD, and KEA), the experimental group demonstrated more substantial gains. The ART score in the experimental group, for example, increased from 22.23 ± 4.67 to 47.81 ± 7.38, compared to a rise from 22.41

$\pm$ 5.26 to 30.01 ± 7.59 in the control group. Similarly, the HD and KEA results also favoured the experimental group, with significant improvements in grip strength and wrist extension. These findings suggest that VRT using the Leap Motion Controller is more effective than conventional therapy in promoting upper extremity function, grip strength, and wrist/hand kinematics in stroke patients.

The superiority of the experimental group is consistent with the idea that VR-based interventions provide a richer, more engaging, enjoyable environment for patients. Conventional therapies, while beneficial, may not offer the same level of engagement or intensity, which can limit patient adherence and progress. The VRT platform allows for individualized, repetitive practice with continuous feedback, making it more conducive to neuroplastic changes and motor learning[41] (Saposnik et al., 2010, 2011; Laver et al., 2015).

Conclusion:

This study provides strong evidence for the positive impact of Virtual Reality Training based on the Leap Motion Controller on hand and upper extremity function in stroke patients. The results suggest that VRT can significantly improve motor recovery, grip strength, and wrist/hand kinematics, offering a more engaging and effective alternative to conventional physiotherapy. The benefits of VRT are likely due to its ability to provide high-intensity, repetitive, and task-specific training, as well as its capacity to stimulate neuroplasticity and enhance motivation through interactive feedback mechanisms. While the findings are promising, further research with larger sample sizes, longer follow-up periods, and more diverse outcome measures is needed to fully establish the long-term efficacy of VRT in stroke rehabilitation.

Limitations of the Study

This study has several limitations, including a small sample size that may affect the generalizability of the results, a short duration of the study that limits assessment of long-term follow-up, and the lack of evaluation on other aspects of recovery such as cognitive function or quality of life. Additionally, the specific features of the Leap Motion-based VR system used may have influenced the outcomes, warranting further research into different VR platforms. Future studies should address these limitations for a more comprehensive understanding of VRT's efficacy in stroke rehabilitation.

References

1. World Health Organization. Stroke. Geneva: World Health Organization; 2019 Jan 9.
2. Langhorne P, Coupar F, Pollock A. Motor recovery after stroke: a systematic review. Lancet Neurol. 2009;8(8):741–754.
3. Kwakkel G, Wagenaar RC, Kollen BJ, Lankhorst GJ. Predicting disability in stroke: a critical review of the literature. Age Ageing. 1996;25(6):479–489
4. Das SK, Banerjee TK, Biswas A, Roy T, Raut DK, Mukherjee CS, et al. A prospective community-based study of stroke in Kolkata, India. Stroke. 2007;38(3):906–910.
5. Barreca S, Wolf SL, Fasoli S, Bohannon R. Treatment interventions for the paretic upper limb of stroke survivors: a critical review. Neurorehabil Neural Repair. 2003;17(3):220–226.
6. Brunnstrom S. Motor testing procedures in hemiplegia: based on sequential recovery stages. Phys Ther. 1966;46(5):357–375.
7. Donnan GA, Fisher M, Macleod M, Davis SM. Stroke. Lancet. 2008;371(9624):1612– 1623.
8. Adamovich SV, Merians AS, Boian R, Tremaine M, Burdea GC, Recce M, Poizner H. A virtual reality (VR)-based exercise system for hand rehabilitation after stroke. Presence. 2005;14(2):161–174.
9. Kwakkel G, Wagenaar RC, Kollen BJ, Lankhorst GJ. Predicting disability in stroke: a critical review of the literature. Age Ageing. 1996;25(6):479–489.
10. Saposnik G, Levin M, Outcome Research Canada (SORCan) Working Group. Virtual reality in stroke rehabilitation: a meta-analysis. Stroke. 2011;42(2):514–520.
11. Merians AS, Poizner H, Boian R, Burdea GC, Adamovich S. Sensorimotor training in a virtual reality environment: Does it improve functional recovery poststroke? Neurorehabil Neural Repair. 2006;20(2):252–267.
12. Li WJ, Hsieh CY, Lin LF, Chu WC. Hand gesture recognition for post-stroke rehabilitation using Leap Motion. In: Meen T-H, Lam ADK-T, Prior SD, editors. Proceedings of the 2017 IEEE International Conference on Applied System Innovation: Applied System Innovation for Modern Technology; 2017 May 13-15; Chiba, Japan. Piscataway (NJ): IEEE; 2017. p. 386–388.
13. Deutsch JE, Merians AS, Adamovich SV, Poizner HP, Burdea GC. Development and application of virtual reality technology to improve hand use and gait of individuals post-stroke. Restor Neurol Neurosci. 2004;22(4):341–386.
14. Kopp B, Kunkel A, Muhlnickel W, Villringer K, Taub E, Flor H. Plasticity in the motor system related to therapy-induced improvement in chronic stroke patients. J Neurosci. 1999;19(17):6992–7000.
15. You SH, Jang SH, Kim YH, Hallett M, Ahn SH, Kwon YH, Kim JH, Lee MY. Virtual reality induced cortical reorganization and associated locomotor recovery in chronic stroke: an experimenter-blind randomized study. Stroke. 2005;36(6):1166–1171.
16. You SH, Jang SH, Kim YH, Kwon YH, Barrow I, Hallett M. Cortical reorganization induced by virtual reality therapy in a child with hemiparetic cerebral palsy. Dev Med Child Neurol. 2005;47(9):628–635.
17. Li WJ, Hsieh CY, Lin LF, Chu WC. Hand gesture recognition for post-stroke rehabilitation using Leap Motion. In: Meen T-H, Lam ADK-T, Prior SD, editors. Proceedings of the 2017 IEEE International Conference on Applied System Innovation: Applied System Innovation for Modern Technology; 2017 May 13-15; Chiba, Japan. Piscataway (NJ): IEEE; 2017. p. 386–388.
18. Deutsch JE, Merians AS, Adamovich SV, Poizner HP, Burdea GC. Development and application of virtual reality technology to improve hand use and gait of individuals post-stroke. Restor Neurol Neurosci. 2004;22(4):341–386.
19. Li WJ, Hsieh CY, Lin LF, Chu WC. Hand gesture recognition for post-stroke rehabilitation using Leap Motion. In: Meen T-H, Lam ADK-T, Prior SD, editors. Proceedings of the 2017 IEEE International Conference on Applied System Innovation: Applied System Innovation for Modern Technology; 2017 May 13-15; Chiba, Japan. Piscataway (NJ): IEEE; 2017. p. 386–388.
20. Merians AS, Poizner H, Boian R, Burdea GC, Adamovich S. Sensorimotor training in a virtual reality environment: Does it improve functional recovery poststroke? Neurorehabil Neural Repair. 2006;20(2):252–267.
21. Yerkes RM, Dodson JD. The relation of strength of stimulus to rapidity of habit- formation. J Comp Neurol Psychol. 1908;18(5):459–482.
22. Vanbellingen T, Filius SJ, Nyffeler T, van Wegen EE. Usability of videogame-based dexterity training in the early rehabilitation phase of stroke patients: A pilot study. Front Neurol. 2017 Dec 8;8:654.

23. Nudo RJ. Recovery after brain injury: Mechanisms and principles. In: Gazzaniga MS, editor. The Cognitive Neurosciences. 4th ed. Cambridge (MA): MIT Press; 2011. p. 951–963.
24. Li WJ, Hsieh CY, Lin LF, Chu WC. Hand gesture recognition for post-stroke rehabilitation using Leap Motion. In: Meen T-H, Lam ADK-T, Prior SD, editors. Proceedings of the 2017 IEEE International Conference on Applied System Innovation: Applied System Innovation for Modern Technology; 2017 May 13-15; Chiba, Japan. Piscataway (NJ): IEEE; 2017. p. 386–388.
25. Kurth T, Moore SC, Gaziano JM, et al. Healthy lifestyle and the risk of stroke in women. Arch Intern Med. 2006;166(13):1403–1409.
26. Banerjee T, Mukherjee CS, Sarkhel A. Stroke in the urban population of Calcutta: An epidemiological study. Neuroepidemiology. 2001;20(3):201–207.
27. Das SK, Banerjee TK, Biswas A, Roy T, Raut DK, Mukherjee CS, et al. A prospective community-based study of stroke in Kolkata, India. Stroke. 2007;38(3):906–910.
28. Vanbellingen T, Filius SJ, Nyffeler T, van Wegen EE. Usability of videogame-based dexterity training in the early rehabilitation phase of stroke patients: A pilot study. Front Neurol. 2017 Dec 8;8:654.
29. Langhorne P, Coupar F, Pollock A. Motor recovery after stroke: A systematic review. Lancet Neurol. 2009;8(8):741–754.
30. Kwakkel G, Wagenaar RC, Kollen BJ, Lankhorst GJ. Predicting disability in stroke: A critical review of the literature. Age Ageing. 1996;25(6):479–489.
31. Barreca S, Wolf SL, Fasoli S, Bohannon R. Treatment interventions for the paretic upper limb of stroke survivors: A critical review. Neurorehabil Neural Repair. 2003;17(3):220–226.
32. Brunnstrom S. Motor testing procedures in hemiplegia: Based on sequential recovery stages. Phys Ther. 1966;46(5):357–375.
33. Nudo RJ. Recovery after brain injury: Mechanisms and principles. In: Gazzaniga MS, editor. The Cognitive Neurosciences. 4th ed. Cambridge (MA): MIT Press; 2011. p. 951–963.
34. Veerbeek JM, van Wegen EE, van Kordelaar J, et al. Effects of robot-assisted therapy for the upper limb after stroke: A systematic review and meta-analysis. Neurorehabil Neural Repair. 2014;28(3):231–238.
35. Sehatzadeh S. Effectiveness of repetitive task practice on upper limb rehabilitation after stroke. Neurorehabilitation. 2015;37(2):161–169.
36. French B, Thomas LH, Leathley MJ, et al. Repetitive task training for improving functional ability after stroke: A Cochrane systematic review and meta-analysis. Clin Rehabil. 2016;30(7):629–642.
37. Olsen T. Arm and leg paresis as outcome predictors in stroke rehabilitation. Stroke. 1990;21(2):247–251.
38. Hiaraoka K. Rehabilitation effort to improve upper extremity function in post-stroke patients: A meta-analysis. J Phys Ther Sci. 2001;13:5–9.
39. Adamovich SV, Merians AS, Boian R, Tremaine M, Burdea GC, Recce M, Poizner H. A virtual reality (VR)-based exercise system for hand rehabilitation after stroke. Presence. 2005;14(2):161–174.
40. Merians AS, Poizner H, Boian R, Burdea GC, Adamovich S. Sensorimotor training in a virtual reality environment: Does it improve functional recovery poststroke? Neurorehabil Neural Repair. 2006;20(2):252–267.
41. Merians A, Jack D, Boian R, Tremaine M, Burdea GC, Adamovich SV, Reece M, Poizner H. Virtual reality-augmented rehabilitation for patients following stroke. Phys Ther. 2002;82(9)
42. Olsen T. Arm and leg paresis as outcome predictors in stroke rehabilitation. Stroke. 1990;21(2):247–251.
43. Hiaraoka K. Rehabilitation effort to improve upper extremity function in post-stroke patients: A meta-analysis. J Phys Ther Sci. 2001;13:5–9.
44. Adamovich SV, Merians AS, Boian R, Tremaine M, Burdea GC, Recce M, Poizner H. A virtual reality (VR)-based exercise system for hand rehabilitation after stroke. Presence. 2005;14(2):161–174.
45. Merians AS, Poizner H, Boian R, Burdea GC, Adamovich S. Sensorimotor training in a virtual reality environment: Does it improve functional recovery poststroke? Neurorehabil Neural Repair. 2006;20(2):252–267.
46. Merians A, Jack D, Boian R, Tremaine M, Burdea GC, Adamovich SV, Reece M, Poizner H. Virtual reality-augmented rehabilitation for patients following stroke. Phys Ther. 2002;82(9):898–912