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Immersive Versus Non-Immersive Virtual Reality in Enhancing Upper Limb Functions Among Individuals with Subacute Stage Hemiplegia-A Preliminary Randomized Controlled Trial

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***Abstract*— Objectives:** *To compare the effectiveness of immersive and non-immersive VR, in conjunction with conventional therapy, on upper limb motor recovery in individuals with subacute stage hemiplegia and to assess the feasibility of these interventions in clinical settings.*

Methods: *This single-blinded, randomized controlled trial included 8 participants with subacute stage hemiplegia, randomly assigned to either the immersive VR group (Oculus Quest 3) or the non-immersive VR group (Neofect Smart Board and Tyromotion device). Both groups participated in a 6-week rehabilitation program, which included 15 minutes of conventional therapy followed by 45 minutes of VR therapy, three times per week. Upper limb motor function was assessed pre- and post-intervention using the Fugl-Meyer Assessment (FMA-UE) and the Wolf Motor Function Test (WMFT). Qualitative feedback on usability and patient engagement was also collected.*

Results: *Both groups demonstrated significant improvements in upper limb motor function post-intervention. However, participants in the immersive VR group reported higher levels of engagement as well as satisfaction with the therapy compared to the non-immersive VR group. Qualitative feedback indicated that immersive VR provided a more motivating and immersive experience, contributing to increased adherence and enjoyment during sessions.*

Conclusions: *This preliminary trial suggests that immersive VR may offer superior qualitative benefits in terms of patient engagement and therapy adherence compared to non-immersive VR, while both modalities effectively enhance upper limb motor function. The study supports the feasibility of using VR as an adjunct to conventional rehabilitation for stroke patients and highlights the potential of immersive VR as a more engaging and motivating intervention for motor recovery in individuals with subacute stage hemiplegia.*

Index Terms: *"Stroke", "upper limb function", "immersive virtual reality", "non-immersive virtual reality", "motor recovery", "rehabilitation" "Oculus Quest 3".*

I. INTRODUCTION

Stroke, a serious cerebrovascular disease marked by a sudden and abrupt onset stands as the primary cause of disability worldwide and is the second leading cause of mortality (1). While Global incident strokes and prevalent strokes rates increased by 18.51% and 31.97% respectively, there was a a decrease in disability-adjusted life-years as a result of stroke and deaths due to stroke by 60.18% and 65.03%, respectively, from 1990 to 2019 (2). Strokes are increasingly affecting younger individuals due to factors such as irregular work schedules, stress, unhealthy eating habits and other lifestyle related factors. Around 10% of all strokes now happen in individuals who are less than 50 years old (3). A recent study mentioned that the most common clinical presentation in stroke patients was motor symptoms such as hemiplegia or hemiparesis (4).

Hemiplegia (HP) is a common stroke-related symptom involving paralysis on one side of the body which significantly impairs the individual's ability to perform daily activities (5). Hemiplegia presents a myriad of challenges, including sensorimotor deficits like abnormal muscle tone, mobility challenges, numbness, tingling, and loss of strength in unilateral upper and lower extremities. HP Individuals may also contend with issues such as unilateral neglect, cognitive issues impacting attention and learning, mental health concerns like dementia and depression, cardiopulmonary dysfunction, vision problems, and coordination difficulties like ataxia, gait and balance issues are common. These obstacles hamper the upper extremity function to carry out daily tasks, lose their independence, and reduced social engagement further complicates the situation (6).

Rehabilitation for hemiplegic stroke typically involves a well-organized treatment plan that commences within 48 hours after onset of stroke in stable patients (7). The primary goals are to elevate the functional abilities of the patient, promote self-sufficiency, and improve their overall quality of life (8). Stroke rehabilitation necessitates a strong emphasis on improving upper limb function to achieve optimal patient outcomes and minimize disability (9). Physical therapy is one of the most prevalent professions to achieve the goal of

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helping stroke survivors to regain their ability to perform everyday activities (10).

Brain plasticity peaks in the acute and subacute stages of stroke due to the various treatment interventions experimented to enhance motor recovery (11). The evidence supports the use of constraint induced movement therapy, mirror therapy, and virtual reality interventions on improving upper limb functions in HP individuals (12) (13). A systematic review showed that no single exercise can be effective in enhancing motor recovery among HP individuals (13). Thereafter, physiotherapy treatment plan consists of a combination of interventions to improve motor control in individuals with HP.

The integration of virtual reality into physical therapy treatment plans is becoming increasingly popular in the field of neurorehabilitation. In a study by Brunner et al., it was found that VR training was equally as effective as conventional therapy in improving upper extremity function during the subacute phase after a stroke. In addition, it was observed that VR served as an encouraging complement to conventional rehabilitation methods (14).

Virtual reality can be either immersive or non-immersive. Immersive VR typically involves the use of VR headsets with head-mounted displays, which engages the user in a 360-degree virtual environment creating a panoramic environment, enhancing the sense of presence. On the other hand, non-immersive VR can be experienced on standard displays. In this setup, the user manually controls their viewing direction using input devices (15).

Recent systematic reviews suggest that immersive VR is superior to non-immersive VR. However, there is a scarcity of empirical studies conducted with actual patients to substantiate this claim (16). Thus, this study aims to explore the effectiveness of immersive and non-immersive VR in stroke rehabilitation, bridging the gap in current knowledge.

II. METHODOLOGY

This is a single blinded, preliminary, randomized controlled trial study design. The study protocol was approved by the ethical committee of Gulf Medical university (IRB-COHS-STD-75-FEB-2024) and registered in https://clinicaltrials.gov/ database (ClinicalTrials.gov ID – NCT06615141). Study participants in this study were individuals aged 25–40 years, diagnosed with hemiplegia due to stroke. And other inclusion criteria are participants < Grade 2 on the Modified Ashworth scale (indicating mild spasticity), > Stage 2 on the Brunnstrom stages of motor recovery, >35 score in cognitive Assessment Scale for Stroke Patients (CASP). This study excluded the participants who are with contraindications for VR therapy, such as severe motion sickness, photosensitive epilepsy, or impaired spatial awareness or pre-existing neurological conditions (e.g., spinal cord injury, multiple sclerosis) affecting upper limb function. 8 participants were recruited through convenient sampling methods and the informed consent was obtained prior to the intervention.

All participants were divided into two groups randomly by using sealed envelope method that contains random numbers generated by a random number generator. The outcome assessor was blinded to the group allocation to minimize the potential for assessment bias. The baseline assessment was performed by using the Fugl-Meyer Assessment, Wolf Motor Function Test and Stroke Specific Quality of Life Questionnaire.

The participants initially underwent 20 mins of regular conventional physiotherapy (stretching, strengthening, voluntary control training) treatment for upper limb functional training. Later, Group 1 participants underwent immersive virtual reality and Group 2 underwent non-immersive virtual reality therapy. The games in both immersive and non-immersive modalities were selected based on the MDA framework to ensure the meaningful participation to achieve the ultimate outcome of motor improvement (17)(18).

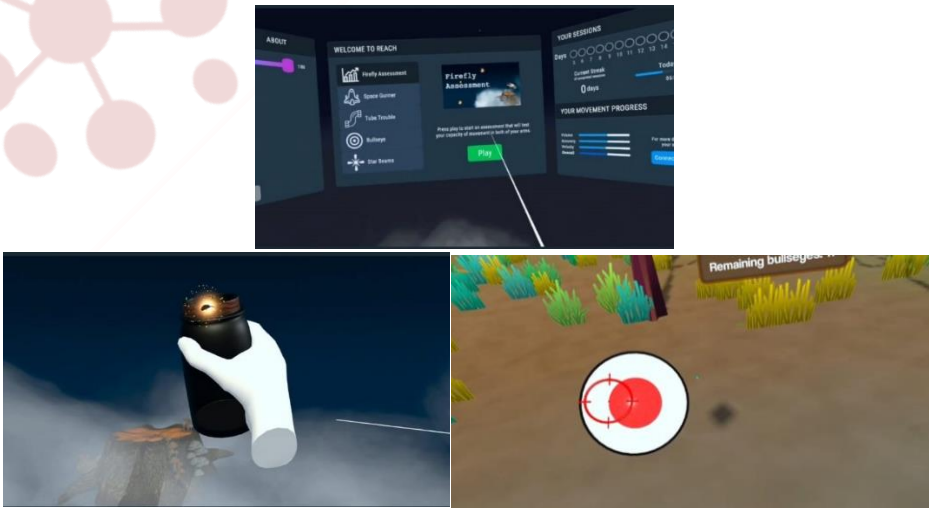

Fig 1. Top- Reach shoulder health; Left – Firefly assessment; Right – Bull's eye shooting

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Immersive VR sessions for group 1 were delivered using Oculus Quest 3. The therapy utilized the Reach Shoulder Health app, and two games were selected i.e. Firefly Assessment and Bull's Eye Shooting *(Fig 1)*. Each game played for 20 minutes with 5 minutes of rest period.

Fig 2. Left – Feed the puppies; Right - Tennis

Non-immersive VR sessions for group 2 were delivered via the Neofect Smart Board and Tyromotion device (MYRO). Feed the puppies and Tennis game from Neofect Smart Board and Star assessment and catch the falling items game form Tyromotion device (MYRO) *(Fig 2)*. Each game was played for 10 minutes with adequate rest period between the games.

Each VR therapy session lasted for up to 45 minutes per session. At end of the first session, equipment efficacy and user friendliness were assessed by using System Usability Scale (SUS) and User Experience Questionnaire (UEQ) scores for both groups. The same VR session for each group were followed 3 sessions per week for 6 weeks. At the end of the 6 weeks, the post-test score was obtained by using same baseline outcome measures.

Study Outcome Measures

Fugl-Meyer Assessment for Upper Extremities (FMA-UE)- The FMA-UE has high inter-rater reliability (ICC 0.98) and intra-rater reliability (ICC 0.96). Scores range from 0 to 66 points, with higher scores indicating better function. FMA-UE has three domains: motor, sensory and passive joint motion/pain. The motor section has 33 items divided into 4 subsets (Shoulder and Elbow Coordination, Wrist Coordination, Hand Coordination, Coordination and speed) and the scores range from 0-66 points *(19)*.

Wolf Motor Function Test (WMFT) - The WMFT is designed to assess motor function, strength, and coordination in individuals with upper extremity impairments. It consists of 17 individual tasks. The first six involve time-based assessments of functional activities, while tasks 7 and 14 assess muscle strength. The remaining nine tasks focus on evaluating the quality of movement during the execution of diverse activities. It is task oriented; time based and involves specific functional activities *(20)*. It is a reliable measure with inter-rater reliability of 0.97 and intra-rater reliability of 0.90 *(21)*.

Stroke Specific Quality of Life (SS-QOL)- The stroke specific quality of life (SS-QOL) is a self-reported scale containing 49 items in 12 domains. The SS-QOL shows excellent inter -rater reliability (ICC:0.83-0.99). The SS-QOL shows good content validity, construct validity, and criterion validity which shows that it effectively measures the aspects of life most affected by stroke and correlates well with other measures of health and functional status.

Statistical Methods

The descriptive Analysis done on the study participant's demographic variables such as age, gender, and affected side were analysed by using mean, median, standard deviation, frequencies, and percentages. The inferential analysis performed based on the normality test. Based on the normality of data a paired T test or Wilcoxon signed Rank Test was signed for within group comparisons and Mann Whitney U test for between group comparisons. All statistical analysis performed in SPSS package and p values set at <0.05 for considered to indicate the significance.

III. RESULTS

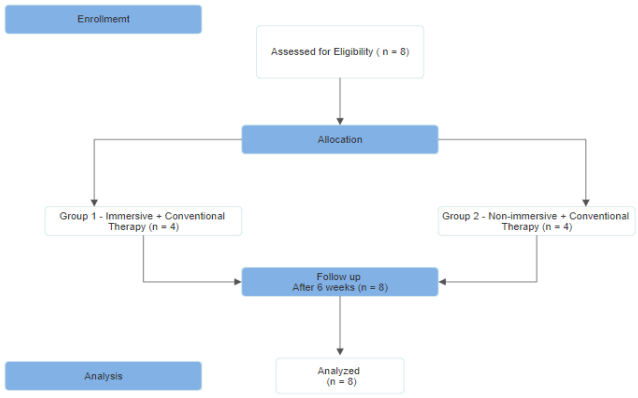

Fig 3. Consort Flow Diagram

A total of 8 patients were included in this study and the details were mentioned in study consort flow chart (Fig 3). All participants were completed the 6 weeks of treatment protocol. All participants baseline characteristics were analysed and all showed statistically no significant differences at p >0.05 level. These details are mentioned below in table 1.

Table I: Demographic Characteristics

Variables		Group 1 (n=4)	Group 2 (n=4)	p value
Age(years)	Mean±SD	36.67 ± 6.287	38.67 ± 6.812	0.366
Gender (%)	Female	46.70	60.00	0.715
	Male	53.30	40.00	
Affected Side (%)	Left	60.00	60.00	1.00
	Right	40.00	40.00	

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MAS (%)	Grade 1	33.3	46.7	0.71
	Grade 2	66.7	53.3	
BSMR (%)	Stage 2	60	66.7	1.00
	Stage 3	40	33.3	

% percentage; MAS – Modified Ashworth scale; BSMR – Brunnstorm Stages of Motor Recovery

After the first session treatment, the VR sessions satisfaction level was assessed by using System Usability Scale (SUS) and User Experience Questionnaire (UEQ) scores. Both groups showed high satisfactory level in system usability (82 & 83) and user friendliness (6.1 & 5.9) for both immersive and non-immersive VR sessions and these details are given in below table II.

Table II: System Usability and User Experience

	Group	Mean ± Std. Deviation	Minimum	Maximum	95% CI	
					Lower Bound	Upper Bound
SUS	Group 1 (n=4)	82.27 ± 4.334	75	92	79.87	84.67
	Group 2 (n=4)	83.33 ± 4.135	75	89	81.04	85.62
UEQ	Group 1 (n=4)	6.11 ± 0.26	5.62	6.5	5.97	6.26
	Group 2 (n=4)	5.90 ± 0.35	5.45	6.75	5.70	6.09

SUS - System Usability Scale; UEQ - User Experience Questionnaire.

The motor function of upper limb was assessed by Fugl-Meyer Assessment and Wolf Motor Function Test and the quality of life was assessed by Stroke Specific Quality of Life. The FMA score showed within group and between the group statistical significance difference at $p<0.001$ level. Similarly, the WMFT and SSQOP also showed statistical significance difference in within group and between group comparison at $p<0.05$ level. These test details were given in below table III.

Table III: Within group and between group comparison of all outcome measures.

Outcome Measure	Group	Pre *(M±SD)	Post *(M±SD)	Post-Pre *(M±SD)	Test	Within group	Between group
FMA	Group 1 (n=4)	34.73± 6.1	44.80± 5.6	10.06± 2.1	t = 18.103	<0.001	<0.001
	Group 2 (n=4)	34.27± 6.8	39.53± 5.6	5.27 ±2.017	z= –3.421	0.001	
WMFT	Group 1 (n=4)	130.9± 28.5	76.7± 14.8	54.2± 22.7	z= 3.409	0.001	0.004
	Group 2 (n=4)	129.7± 34.5	92± 23.04	37.73 ±13.04	z= 3.412	0.001	
SSQOL	Group 1 (n=4)	2.8± 0.4	3.5± 0.5	0.67± 0.31	z= –3.408	0.001	0.029
	Group 2 (n=4)	2.6± 0.5	3.07± 0.4	0.46 ±0.20	z= –3.352	0.001	

*Mean ± Standard deviation; FMA - Fugl Meyer Assessment; WMFT - Wolf Motor Function Test; SS-QOL- Stroke Specific Quality of Life

IV. DISCUSSION

This preliminary randomized controlled trial was designed to evaluate and compare the effectiveness of immersive virtual reality therapy and non-immersive virtual reality therapy in enhancing upper limb motor function in individuals with subacute stage hemiplegia. The games in both immersive and non-immersive modalities were selected based on MDA framework which helps in analyzing whether the games had the dynamics to fulfill the therapeutic rehabilitative needs of the participants. Mechanics and aesthetics were assessed to check whether they were able to engage and motivate the participants. The analysis of System Usability (SUS) and User Experience Questionnaire (UEQ) scores between Group 1 and Group 2 reveals insights into usability and user experience outcomes. Both immersive and non-immersive VR demonstrated high usability perceptions with similar consistency and no statistically significant differences. Group 1 displayed notable scores, suggesting a highly positive perception of usability among participants. When considering user experience, Group 1 showed variability and Group 2 showed uniformity. While some users in Group 1 may have had different experiences, many found the system to be engaging and effective.

Recent research shows that both immersive and non-immersive VR has shown to be effective in improving upper limb motor function in stroke patients (22) (23). In line with this, our results for both Groups across all three outcome measures confirm that both types of VR produce significant improvement in motor function and quality of life when given in combination with conventional therapy.

Participants who underwent immersive virtual reality therapy and conventional therapy showed improvements in FMA, WMFT and SS-QOL which demonstrated statistically significant differences. The mean difference showed that on average, participants improved by approximately 10 points. Similar to our study finding, previous research has highlighted the significant role of immersive VR for upper limb function in individuals with neurological conditions (24).

Participants who underwent non immersive virtual reality therapy in combination with conventional therapy also had a significant effect on enhancing upper limb motor function and quality of life. The results of the Wilcoxon signed rank test conducted to compare the FMA, WMFT and SS-QOL pre and post scores showed significant differences which indicates the efficacy of non-immersive virtual reality therapy in enhancing motor and quality of life outcomes. HS, et al. in their study found that at week 8, upon completion of the non-immersive VR training, the intervention group demonstrated significantly greater WMFT scores which aligns with the findings of this study (25).

The results of the Mann-Whitney U test conducted to compare the two Groups showed that there was significant difference between the two Groups. The results showed that Group 1 experienced significantly higher improvements in motor function, task completion time and quality of life. Specifically, FMA scores for the Immersive group demonstrated statistically significant difference from those of non-immersive group which means that immersive VR therapy led to greater gains in motor function. The percentage of improvement in Group 1 for FMA was 28%, 41% reduction in time taken to complete tasks in WMFT and 25% improvement in SS-QOL while it was 15%, 29% and 18% respectively for FMA, WMFT and SS-QOL in Group 2. Similarly, study findings also suggest that participants of the immersive group had significant reduction in time taken to complete upper limb tasks in WMFT compared to those of the non-immersive group. These significant improvements observed in motor function and reduced task completion time could have contributed to the improvement in quality of life. This supports the systematic review conducted by Hao et al. to compare immersive and non-immersive VR therapy (26). Many researchers have found a positive correlation between neural plasticity changes and VR induced functional changes (27).

The clinical implication of this study explores the potential integration of virtual reality into rehabilitation programs for individuals with upper limb impairments due to stroke. These results showed that virtual reality sessions are effective, and comparable. The treatment protocol is feasible to implement in neuro rehabilitation. This preliminary study showed a 0% dropout rate and none of the participants registered any side effects to the treatment protocols. Overall, both groups registered statistically significant improvement in both groups. This shows the 3 sessions per week are adequate and appropriate.

Although the current study findings were significant and added to the existing body of research, there are a few limitations that need to be noted.

Studies with larger sample size, longer intervention periods and long term follow up assessments would help in understanding the sustained effects of VR therapy in future. An understanding in these areas would significantly contribute to creating and optimizing personalized VR based interventions based on patient's need for improvement.

V. CONCLUSIONS

In conclusion, the study protocols of immersive and non-immersive virtual reality are feasible and applicable in stroke population. Although immersive and non-immersive VR therapies were found to be effective, the findings of this study also showed that immersive virtual reality was more effective in improving upper limb motor function than non-immersive virtual reality alongside conventional therapy. These findings must be analyzed in future research.

VI. ACKNOWLEDGEMENT

NIL.

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