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Virtual Reality Training Versus Selected Physical Therapy Program on Hand Function of Hemiparetic Patients

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ABSTRACT

Background: Hand function loss after a stroke is a major rehabilitation issue that affects millions of individuals each worldwide. To repair these people's hands, more potent rehabilitation treatments are required. Training in virtual reality (VR) offers a novel and possibly successful way to administer physical therapy therapies.

Purpose: This study aims to compare the effect of virtual reality training versus selected physical therapy program on hand function in chronic stroke patients.

Methodology: Forty-five adult subjects of both sexes with hemiparesis due to cerebrovascular stroke (CVS) were enrolled in this study. Participants were assigned randomly into three matched groups. The Group I (GI) included fifteen patients received virtual reality training, Group II (GII) included fifteen patients received a selected physical therapy program which included sustained stretching exercises for wrist flexors and wrist extensors, passive and active assisted mobilization of the upper limb, strengthening exercise, and PNF techniques. Group III (GIII) included fifteen patients received the same virtual reality training and the selected physical therapy program. The hand-held dynamometer and goniometer were used to assess the strength and wrist range of motion (ROM). The Purdue Pegboard test was used to test fingertip hand function. All measures were collected pre and post treatment.

Results: There were no statistically significant differences between the three groups in all measured variables pre-treatment ($P\text{-value} \geq 0.05$). After four weeks of intervention, there were statistically significant improvement in all outcome measures in the three groups ($p\text{-value} < 0.05$). Moreover, there were statistically significant differences between the three groups in all measured variables post treatment in favor of Group III ($p\text{-value} < 0.05$). Also, there was a statistically significant difference in all outcome measures post-intervention between groups I and II in favor of group I ($p\text{-value} < 0.05$).

Conclusion: VR training is a promising adjunct in stroke rehabilitation, demonstrating significant benefits on hand strength, wrist ROM and functional performance.

Keywords: *Stroke, Virtual Reality Training, Hand-held dynamometer, Purdue Pegboard Test.*

1. INTRODUCTION

A stroke causes many people to lose their ability and independence, making it one of the main causes of long-term impairment. Twenty percent of patients need institutional care three months after a stroke, and up to thirty percent of patients are permanently incapacitated, according to earlier reports. Disability following a stroke has a substantial impact on patients' family relationships and sense of self. The average cost of a stroke over the first 30 days following an acute incident is $13,000 USD (1).

Many hemiparetic patients suffer from hand impairments after resolving stage four (decreasing spasticity) according to Brunnstrom classification, and even after resolving all the seven stages there will be some remnants of motor hand impairments (2). Loss of hand functions following stroke is a major rehabilitation problem affecting millions of people per year globally. More effective rehabilitation therapies are needed to restore hand in these individuals (2). Persistent impairment in upper limb function may cause limitations in the execution of daily activities, as well as participation in social life (3).

Virtual reality (VR)-based virtual rehabilitation is a new and promising approach to stroke motor recovery that can complement existing rehabilitation techniques. Task-oriented, intensive (i.e., more dosages and motions), and repetitive training is crucial for fostering neuroplasticity and, consequently, motor recovery, according to motor learning theory (4).Considering motor learning theory, task-oriented, intensive (that is, more doses and movements), and repetitive training is essential for promoting neuroplasticity and thereby, motor recovery (5)

Regarding the intensity and motivation of recovery, a number of benefits of virtual rehabilitation can be proposed. Through gamification and increased enjoyment, virtual reality can encourage patient participation (6). Games that use virtual reality offer a productive, safe, and demanding learning environment for the development of motor control and neural plasticity in rehabilitation. When it comes to hand rehabilitation following a stroke, virtual reality (VR) is crucial (7).

The goal of the study is investigate the effect of virtual reality training versus selected physical therapy program on hand function in chronic stroke patients.

2. METHODS

2.1 Design

This randomized controlled trial (RCT) was carried out at the outpatient clinic of the Faculty of Physical Therapy, Cairo University, Egypt, from June 2024 to January 2025. The study was approved from the local ethical committee(….) of the Faculty of Physical Therapy at Cairo University. All participants signed written informed consent prior to their involvement, and their rights and confidentiality were upheld throughout the duration of the study.

2.2 Participants

Forty five subacute stroke patients of both sexes were included in the study. They were diagnosed based on careful clinical evaluation by the neurologists and magnetic resonance imaging (MRI) of the brain.

Patients were eligible for the study if they had: ischemic stroke; age ranged from 45 to 65; duration of illness ranged from six weeks up to six months; upper limb spasticity ranged from 1 to 1+ according to the Modified Ashworth scale; Brunstrom's stage of hand recovery ranged from 2nd to 3rd stage; patients can sit independently without assistance; mini-mental state score > 25 enables comprehension of basic spoken instructions; the paretic upper limb's degree of weakness was at least grade 2 according to the manual muscle testing scale, complete passive range of motion in the fingers and wrist and normal vision and hearing.

The patients were excluded if they had: unstable medical condition; psychiatric disorders; aphasia within three months; limited wrist joint range of motion; patients who have severe visual like homonymous hemianopsia and or auditory problems.

Randomization and blinding

Patients were randomly allocated through a sealed envelope into three equal matched groups. Group I received virtual reality training, group II received a selected physical therapy program and group III received the same intervention of virtual reality training and selected physical therapy program.

2.3 Procedures

All outcome measures were assessed for each patient individually before and after physical therapy treatment.

Assessment procedures were carried out to evaluate pre and post-intervention hand function in stroke patients. Standardized, validated tools were used to assess various domains of hand function, including hand grip strength, wrist range of motion and fingertip hand function. These measurements were conducted in a quiet clinical environment to ensure consistency and reliability across all sessions.

Hand grip strength assessment

Hand grip strength was assessed using a calibrated hand-held dynamometer (Lafayette Hand-Held Dynamometer), a reliable and valid instrument widely utilized for evaluating muscle strength in stroke rehabilitation **(8)**. Participants were seated in a standardized position with the shoulder adducted and neutrally rotated, the elbow flexed at 90 degrees, and the forearm and wrist in a neutral posture. The test was performed three times for each hand, and the mean value was recorded. Importantly, the assessment focused exclusively on the wrist joint, measuring wrist flexion and wrist extension.

Wrist range of motion assessment

The active range of motion (ROM) of the wrist joint was assessed using a standard goniometer, following contemporary protocols to ensure measurement accuracy and reliability **(9)**. Participants were instructed to actively perform wrist flexion and extension movements while the forearm was supported on a flat surface in a neutral position to minimize compensatory motions. The goniometer was carefully aligned along the radial border of the forearm and the shaft of the third metacarpal bone to capture precise angular displacement. Measurements are recorded in degrees, with multiple trials often averaged to improve reliability. These values represent the functional mobility of the wrist joint and are used

Fingertip hand function assessment

The fingertip hand function was assessed by the Baseline Purdue Pegboard Test. This test, featuring a board with 9 holes and 9 pegs, is widely used to assess fingertip hand function, particularly in neurological populations **(10)**. Participants were instructed to place as many pegs as possible into the holes using the affected hand. Two consecutive trials were performed, and the time of for each trial was recorded. The average score of the two trials was used for analysis to ensure consistency and reliability. The Baseline Purdue Pegboard Test is recognized for its sensitivity in detecting subtle impairments in fine motor control and is a valuable tool for monitoring rehabilitation progress.

2.4 Treatment procedures:

Each treatment session lasted 60 minutes at a frequency of three sessions per week for four successive weeks.

Selected Physical therapy program

The conventional intervention protocol consisted of manual therapy techniques sustained stretching exercises for wrist flexors and wrist extensors , passive and active assisted mobilization of the upper limb; exercises with resistance or assistance with balls, elastic bands and dumbbells, active assisted mobility exercises of the upper limb and fingers in a sitting position, scapular mobilizations and moving objects horizontally on a table, elevation and superposition of objects in vertical plane, active and active assisted diagonal movement of the upper limb (Peripheral Nerve Facilitation techniques) and gripping activities **(11).**

Virtual Reality Training program

Virtual reality (VR) training was administered using a head-mounted VR display connected to an Xbox console. The VR program, specifically designed for upper limb rehabilitation, was projected through the headset to create an immersive training environment. Prior to initiating the training session, the therapist provided a clear explanation to the patient regarding the purpose of the intervention and the objectives of the VR-based exercises. Once the patient demonstrated understanding, they were asked to actively participate in the VR training program. Additionally, Kinect motion-sensing technology was employed via the Xbox system to track and analyze the patient’s upper limb movements in real time. The Kinect camera enabled markerless motion capture, enhancing engagement and ensuring that the system accurately reflected the patient's motor performance. Throughout the training sessions, both quantitative and qualitative observations were recorded. Patient performance, exercise progression, and motor control improvements were documented using video recordings using iphone cinematic mode video and sessional therapist notes. This dual-method approach ensured a comprehensive evaluation of patient interaction with the VR system and allowed for detailed analysis of progress over time **(12)**.

2.5 Statistical Analysis:

With an alpha threshold of 0.05, the measured variables were statistically examined and contrasted using SPSS for Windows version 23 (SPSS, Inc., Chicago, IL). Data were checked for extreme scores, homogeneity of variance, and the normalcy assumption. The results of the Shapiro-Wilks test for normality indicated that the variables under study were normally distributed (p >0.5). For every outcome, the mean and standard deviation are used to express the data. Patients' physical attributes were compared across three groups using one-way analysis of variance (ANOVA). To compare the groups on the combined effect of all outcomes, a two-way mixed design MANOVA was employed. When MANOVA shows Modified, follow-up univariate ANOVAs with Bonferroni correction were performed for every outcome measure to protect against type I error.

3. RESULTS

Demographic characteristics: The patient characteristics of three groups are displayed in Table (1). Regarding the general characteristics of the patients, there were no statistically significant differences between the three groups (p-value ≥ 0.05). To find out how the treatment affected the variables that were measured, a mixed design multivariate analysis was used. The results showed a statistically significant difference between the groups: partial eta squared (2) = 0.62, Wilk's A = 0.14, F (10,76) = 12.48, and P-value < 0.001. Additionally, Wilk's A = 0.08, F (5, 38) =89.14, p-value < 0.001, 2 = 0.92, and the interaction between groups and time (Wilk's A = 0.27, F (10, 76) = 7.02, p-value < 0.001, 2 = 0.48) showed a statistically significant effect on time (pre-post treatment).

Within-groups comparison

There were statistically significant differences in all outcome measures when comparing the pre and post-intervention results (p-value<0.05) in three groups table (2). The average percentages of change of purde pegboard score for groups I, II and III were 28%, 10.73% and 40.9% respectively. The wrist flexor strength percentages of change were 22.55%, 7.46% and 42% respectively. The wrist extensor strength percentages of change were 81%, 28.54% and 116.5% respectively. The wrist flexion ROM percentages of change were 36.64%, 18.44% and 46.41% respectively. The wrist extension ROM percentages of change were 28.43%, 15.53% and 32.73% respectively.

Between-group comparison: Baseline and after four weeks of intervention

All of the variables that were assessed after the four-week intervention showed statistically significant differences between the three groups in favor of Group III (p-value < 0.05). Also, there was a statistically significant difference in all outcome measures post-intervention between groups I and II in favor of group I (p-value < 0.05) as shown in tables (3, 4).

Table 1: Demographic Characteristics of Participants.

Characteristics	Virtual reality group (n=15)	physical therapy program group (n=15)	Combined group (n=15)	F-value	P Value
Age (years)	56.07±7.32	53.27±5.09	52.73±5.07	1.4	0.27
Weight (kg)	82.15±11.02	80.65±9.2	78.22±6.57	0.52	0.6
Height (cm)	173.53 ±10.65	170.53 ±10.05	168.13 ±12.14	0.91	0.41
BMI (kg/m^2)	27.15±0.76	27.67±1.05	27.53±0.67	1.49	0.24
Gender, n (%)					
Female	6 (40%)	7 (46.67%)	8 (53.33%)	X^2= 0.54	0.77
Male	9 (60%)	8 (53.33%)	7 (46.67%)		

BMI, body mass index; X^2, Chi-Square; Data are mean± SD for all demographics; P-Value < 0.05 indicate statistical significance*

Table 2. Within group changes after 4 weeks of interventions.

Outcome	Virtual reality group (n=15)		physical therapy program group (n=15)		Combined group (n=15)	
	MD (95% CI)	**P-Value**	**MD (95% CI)**	**P-Value**	**MD (95% CI)**	**P-Value**
Average Purde Pegboard (score)	9.07 (5.87, 12.27)	0.001*	3.62 (0.42, 6.82)	0.03*	12.5 (9.3, 15.7)	0.001*
Wrist flexor strength (kg)	-8.13 (-10.72, -5.55)	0.001*	-2.65 (-5.24, -0.07)	0.04*	-15.57 (-18.15, -12.99)	0.001*
Wrist extensor strength (kg)	-25.51 (-30.09, -20.93)	0.001*	-8.94 (-13.52, -4.36)	0.001*	-38.04 (-42.61, -33.46)	0.001*
Wrist flexion ROM (degree)	-17.27 (-21.73, -12.8)	0.001*	-8.87 (-13.33, -4.4)	0.001*	-22.73 (-27.2, -18.27)	0.001*
Wrist extension ROM (degree)	-13.4 (-16.81, -9.99)	0.001*	-7.47 (-10.87, -4.06)	0.0001*	-16.03 (-19.44, -12.63)	0.001*

*MD, Mean Difference; CI, confidence interval; P-Value < 0.05 indicates statistical significance; ROM: range of motion; * significant*

Table 3. Comparison of outcome measures at baseline and after four weeks of interventions between the three groups.

Outcomes	Time	Virtual reality group (n=15)	physical therapy program group (n=15)	Combined group (n-15)	P-Value
Average Purdue Pegboard (score)	*Baseline*	32.35±4.48	33.71±5.61	30.56±1.21	0.39
	After 4 weeks	23.28±2.44	30.1±2.36	18.06±3.01	0.001*
Wrist flexor strength (kg)	*Baseline*	36.05±5.77	35.51±5.82	37.03±4.47	0.74
	After 4 weeks	44.18±4.76	38.16±5	52.6±8.9	0.001*
Wrist extensor strength (kg)	*Baseline*	31.49±2.23	31.32±4.78	32.64±4.31	0.79
	After 4 weeks	57±6.87	40.26±4.63	70.67±5.89	0.001*
Wrist flexion ROM (degree)	*Baseline*	45.73±8.83	47.07±5.1	46.87±4.88	0.83
	After 4 weeks	63±3.53	55.93±8.4	69.6±4.79	0.001*
Wrist extension ROM (degree)	*Baseline*	47.13±7.72	48.1±3.2	48.97±5.84	0.7
	After 4 weeks	60.53±4.47	55.57±2.9	65±3.09	0.001*

** Data are mean± SD, P-Value < 0.05 indicates statistical significance; ROM: range of motion; * significant*

Table 4. Between Groups Effects after 4 weeks of intervention

Outcome	Virtual reality vs physical therapy		Virtual reality vs combined		Physical therapy vs combined	
	MD (95% CI)	P-Value	MD (95% CI)	P-Value	MD (95% CI)	P-Value
Average Purde Pegboard (score)	-6.82(-11.4, -2.23)	0.002*	5.22(0.64, 9.8)	0.02*	12.04 (7.46, 16.62)	0.001*
Wrist flexor strength (kg)	6.02(0.1, 11.93)	0.04*	-8.43(-14.35, -2.51)	0.003*	-14.44(-20.36,-8.53)	0.001*
Wrist extensor strength (kg)	16.74(11.39,22.08)	0.001*	-13.67(-19.02,-8.33)	0.001*	-30.41(-35.76,-25.07)	0.001*
Wrist flexion ROM (degree)	7.07(1.66, 12.48)	0.007*	-6.6(-12.01, -1.19)	0.01*	-13.67 (-19.08, -8.26)	0.001*
Wrist extension ROM (degree)	4.97(1.73, 8.21).	0.001*	-4.47(-7.71, -1.23)	0.004*	-9.43(-12.67, -6.2)	0.001*

MD, Mean Difference; CI, confidence interval; P-Value < 0.05 indicates statistical significance; ROM: range of motion; * significant

4. DISCUSSION

The current study was conducted to compare the virtual reality exercises and different facilitation techniques on the hand function of hemiparetic patients. The findings of this study revealed significant improvements in multiple measures of hand grip strength, wrist range of motion and hand function in stroke patient in all groups.

Patients who received conventional physical therapy treatment only showed improvement in muscle strength and overall function are also enhanced through the use of active and active-assisted mobility exercises, especially when resistance is introduced. Incorporating PNF techniques, which involve diagonal and functional movement patterns, had been shown to further improve upper limb function, particularly in patients recovering from stroke or neuromuscular impairments (**13).**

Patients who received VR training alone or in combination with the selected therapy program, exhibited more significant improvements in all measured parameters indicating that adding VRT 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. **Iosa et al. (2015)** observed similar outcomes in stroke patients, VR-based rehabilitation showed higher engagement and more significant improvements compared to traditional therapy methods **(14)**. VR allows patients to perform task- oriented exercises while receiving real-time visual and auditory feedback. Therefore, VRT not only promotes neuroplasticity through repetitive task-specific training but also enhances patient motivation, leading to more consistent and effective rehabilitation **(15).**

Virtual reality has been shown to support the activation of brain regions involved in sensorimotor function. According to **Wang et al. (2017),** VR-based training significantly improved motor functional recovery in subacute stroke patients, demonstrating a shift in sensorimotor cortical activity as observed through functional MRI (fMRI) **(16)**. The VR environment's ability to simulate real-life tasks and provide visual and proprioceptive feedback further supports the process of motor learning.

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 range of motion **(17)**. VR-based interventions provide a richer, more engaging, enjoyable environment for patients. The VRT platform allows for individualized, repetitive practice with continuous feedback, making it more conducive to neuroplastic changes and motor learning **(18)**.

Virtual reality training is an effective adjunct to traditional stroke rehabilitation, particularly for improving wrist ROM. Its interactive nature and adaptability make it a valuable tool for enhancing motor recovery. However, further research should optimize VR protocols for individualized patient needs. **Saposnik et al. (2016)** conducted a randomized controlled trial (RCT) and found that VR training significantly improved upper limb function, including wrist movement, compared to conventional therapy **(19)**.

Despite its promising applications, VR-based rehabilitation has several limitations. Accessibility and cost remain significant barriers, also as side effects of virtual reality are c**ybersickness** that can characterized by symptoms such as nausea, dizziness, and disorientation. This is particularly prevalent in applications that create a high sense of presence in the virtual environment **(20)**. **Fatigue is also a side effect as** VR sessions can lead to physical and mental fatigue, especially in patients who are not accustomed to prolonged exercise routines **(21).** Prolonged use of VR **may also cause eye strain** and discomfort, necessitating breaks and proper adjustment of the equipment **(22).**

5. CONCLUSION

Virtual reality training assists in the rehabilitation of the motor impairments of the hand after a stroke. This way of treatment provides a fruitful, secure, and challenging learning environment for motor control and neural plasticity development in the rehabilitation of hand function of stroke patients.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Conflict of interest

There are no conflicts of interest.

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