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Original Article

Physiotherapy Section

Virtual Reality for Hemiplegic Patients in Transforming Gait Recovery: An Experimental Study

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ABSTRACT

Introduction: Stroke-induced gait disability is the most common neurological condition that leads to long-term disability. Therefore, it is essential to address the factors contributing to this disability factors to improve overall quality of life of stroke survivors. Despite extensive literature, hemiplegic gait rehabilitation remains a significant challenge for practicing physiotherapists. A comprehensive treatment plan customised for various deviations in temporal and spatial variables is crucial.

Aim: To examine the add-on effect of Virtual Reality Training (VRT) combined with weight-bearing exercises on spatial parameters of gait, such as step width and step length, and temporal variables, including Center of Gravity (COG) sway velocity, reaction time, movement velocity and Limits of Stability (LOS).

Materials and Methods: This experimental study was conducted at Dr. D. Y. Patil College of Physiotherapy, Pimpri, Pune, Maharashtra, India. A six-week, pre-post experimental study was carried out on 30 ambulatory hemiplegic patients aged 25 to 60 years, with an episodes of a stroke at least 12 weeks, with spasticity of Modified Ashworth Scale (MAS) <2, Postural Assessment Scale for Stroke (PASS) score less than 30, and normal cognition were included in the study. Patients with any contractures, peripheral artery diseases, history of cardiac failures or epilepsy, or any neurological surgeries were excluded. The study duration was from June 2024 to August 2024. Spatial and temporal variables of gait assessed by the Neurocom Balance Master, were primary outcome measures. Statistical analysis was done using IBM Statistical Package for the Social Sciences (SPSS) software version 27.0, with paired and unpaired t-tests used to test the statistically significant difference.

Results: After a six-week intervention, a reduction in movement velocity during a heel strike from 1.2°/sec to 0.9°/second (p-value=0.02) was found, suggesting improved reciprocal control of agonist-antagonist muscle coordination. Other parameters for COG sway velocity, step width, and step length improved from 0.15 sec to 0.8 sec (p-value=0.04), from 25.8 cm to 15.2 cm (p-value=0.04), and from 29.7 cm to 32.5 cm (p-value=0.03), respectively. Measures of LOS in anteroposterior sway were reduced from 5°/second to 3.3°/second (p-value=0.02).

Conclusion: The findings suggest that VRT combined with weight-bearing exercises can effectively adjunct traditional rehabilitation methods, aiding spatial and temporal variable gait issues in hemiplegic patients. Authors recommend adding VRT combined with weight-bearing exercises to manage post-stroke circumduction gait problems first-line.

Keywords: Brain injury, Exercise prescription, Weakness

INTRODUCTION

Altered gait is a hallmark of stroke, often characterised by slower, circumduction and asymmetrical movements. Poststroke patients typically exhibit a decreased stance phase time and increased step length on the affected side. Observational analysis reveals increased pelvic girdle movement bilaterally, decreased extension in the spastic limb during the stance phase [1], and increased flexion in the non affected limb throughout the gait cycle. At the knee, a flexed position during a foot strike is common, while the ankle shows slight plantarflexion on the spastic limb. Patients suffering from stroke have numerous sensorimotor problems, like reduced power, spasticity, circumduction gait, impairment of sensation and reduction of ability to balance. Alteration of gait is one of the main features of stroke [2]. Post physiotherapy, around 11% of patients need assistance, whereas 50% can walk independently; however, their reduced walking speed and gait patterns are characterised by asymmetries in spatial and temporal parameters. It can be described as a decrease in the time of the stance phase and increased step length on the side which is affected side [3]. Treadmill training has proven effective for chronic stroke patients capable of independent ambulation, enhancing walking speed and endurance. Ankle-foot Orthoses (AFOs) benefit gait stability and ambulation, particularly in cases of foot drop, but their positive effects are generally limited to the ankle [4].

Pooled evidence suggests that various weight-bearing exercises are effective in reducing spatial and temporal impairments of gait. However, when checked on functional movement, there was no improvement seen in gait parameters and balance [5]. Therefore, it is essential to incorporate sensory proprioceptive training with weight-bearing exercises to give a maximum effect by simultaneously reducing the spasticity and improving the pattern of gait. Hence, the current study utilised VRT with five weight-bearing exercises, including static semi-squat for vastus medialis, vastus lateralis, and gastrocnemius; static semi-squat with elastic band loading for gluteus medius; and lunges to target rectus femoris and biceps femoris [6-9]. Tandem and narrow standing further improve postural control in both medial-lateral and anterior-posterior directions by targeting postural muscles and improving proprioception [10-13].

Despite these methods, poststroke patients often continue to exhibit reduced walking speed and asymmetrical gait patterns, indicating the need for additional treatment methods to ensure complete recovery. This study explores the efficacy of combining VRT with weight bearing exercises to address these persistent impairments.

Therefore, this study aimed to see the effect of VRT on temporal and spatial variables of gait, which include COG sway velocity, reaction time, movement velocity, LOS, walk-across speed, mean step width, and mean step length. The objective of the study was to see the effect of VRT on spatial parameters, namely step width and step length, and temporal variables namely, COG sway velocity, reaction time, sway velocity, movement velocity, and LOS.

Null hypothesis: There is no significant difference in gait parameters after six weeks of VRT.

Alternate hypothesis: There is a significant difference in gait parameters after six-week VRT.

MATERIALS AND METHODS

This pre-post experimental study assessed patients on the first day of intervention and the last day of a six-week intervention. It was conducted at a tertiary care hospital, Dr. D. Y. Patil College of Physiotherapy, outpatient department, the study involved patients diagnosed with poststroke hemiplegia by a physician from the Department of Medicine. The study spanned from June 2024 to August 2024, with recruitment and screening of 100 patients according to inclusion criteria. The intervention commenced in July and concluded in August 2024. The study was initiated after receiving Institutional Ethics Committee (IEC) approval, DYPCPT/ISEC/70/20222. Written informed consent for voluntary participation was obtained from all the participants.

Inclusion criteria: Ambulatory hemiplegic patients with age from 25 to 65 years were selected. An episode of stroke at least 12 weeks ago with a MAS score of all lower limb muscles being less than two (MAS score <2) [6], a PASS score of less than 30 (PASS score <30) [5], and normal cognition assessed by the Mini-Mental State Examination (MMSE) score less than 26 (MMSE score >26) were included in the study.

Exclusion criteria: Patients with any contractures, peripheral artery diseases, history of cardiac failures or epilepsy, or any neurological surgeries were excluded from the study.

Sample size: Sample size estimation based on effect size of previously published evidence by Sade I et al., was calculated. The calculated sample size was 30, using Winpepe software version 11.38 [7]. The sample size estimation was done using mean difference and Standard Deviation (SD) obtained from the results of a previous study. Utilising proportion-based sampling, the mean difference was 2.8804 with a p-value of 0.0098.

The formula for sample size estimation was:

$$n=p*q\ (Za/2/E)^2$$

Where, p=0.95, q=0.05, Za=3.92, E=0.05

Where, $n=0.95*0.05\ (1.96/0.05)^2$

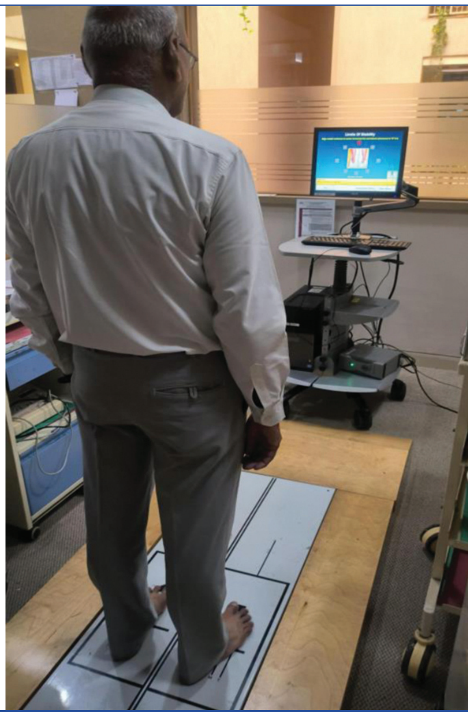
The final sample size was obtained to be 23 participants. Considering the 10% attrition rate among the study participants, the final total sample size was rounded off to 30.

Study Procedure

All patients underwent an extensive gait examination in which initially bedside gait assessment was done. Further, spatial variables, i.e., step width and step length, as well as temporal variables, i.e., COG sway velocity, reaction time, movement velocity, and LOS were examined using Neurocom Balance Master, a force plate system utilised to objectively check ground reaction forces of locomotion.

A total of five components of the temporal variable of gait, mean COG velocity in seconds (sec), movement velocity in degrees per second (°/sec), reaction time in seconds, LOS, and walk across speed (cm/sec). Two spatial variables of gait, i.e., mean step width and step length in centimeters, were noted. An assessment proforma was used to select the study samples. Patients were instructed to stand on the Neurocom Balance Master, force plate system that objectively examines the ground reaction forces during gait [Table/Fig-1].

Patients were instructed to follow visual commands shown on the screen [8]. Patients were asked to stand on a Virtual Reality (VR) platform and perform weight-bearing exercises, including a static semi-squat [Table/Fig-2], static semi-squat with elastic band loading, lunge standing [Table/Fig-3], static semi-squat with Theraband, narrow standing, and tandem standing. Patients were instructed to perform each exercises for 15 repetitions, completing three sets of each position for three minutes, with a one-minute break between each exercise.



[Table/Fig-1]: Patient standing on Neurocom balance master.

[Table/Fig-2]: Semi squat standing.
[Table/Fig-3]: Lunge standing. (Images from left to right)

STATISTICAL ANALYSIS

Data analysis was done using IBM SPSS software version 27.0, along with the Kolmogorov Smirnov test and the Shapiro-Wilk test to assess the normality of distribution. Since the data was normally distributed, parametric tests were applied. A paired t-test was applied for numerical data for within-group comparison and Wilcoxon signed-rank test was applied for categorical data, with a confidence interval of 95% and significance set at 0.05.

RESULTS

The age group included in the study was from 25 years to 60 years. Seven patients were from the age group 25 to 34 years, seven from 35 to 44 years, seven from 45 to 54, and nine from 55 to 65 years. Out of 30 samples, 18 were male and 12 were female.

Baseline variables: The mean score of MAS was 1.5 out of 6-point score, and that of PASS was 20.6. The mean MMSE score was

26.5, implicating normal cognitive functions, and the mean duration of stroke was 4.5 years. In terms of temporal variables of gait, the mean COG sway velocity was 0.15 seconds, mean reaction time was 0.91 seconds, mean movement velocity was 1.2°/seconds, and walk across speed was 32.4 centimeters (cm)/seconds. For spatial variables, the mean step width was 25.8 cm, and the mean step length was 29.7 cm, respectively [Table/Fig-4].

S. No.	Baseline variables	
1	Mean Score of Modified Ashworth scale (MAS)	1.5
2	Mean Score of Postural Assessment Scale for Stroke (PASS)	20.6
3	Mean Score of Mini-mental State Examination (MMSE)	26.5
4	Mean duration of stroke (years)	4.5 years
	Temporal variables	
5	Mean Centre of Gravity (COG) sway velocity (sec)	0.15
6	Mean reaction time (sec)	0.91
7	Mean movement velocity (°/sec)	1.2
8	Walk across-speed (cm/sec)	32.4
	Spatial variables	
9	Mean step width (cm)	25.8
10	Mean step length (cm)	29.7

[Table/Fig-4]: Baseline variables.

Pre-post analysis of temporal variables of gait assessed by Neurocom Balance Master [Table/Fig-5]: A paired t-test was applied to test the statistical significance.

S. No.	Outcome variables	Mean±SD Pre	Mean±SD Post	T value	p-value
1	Centre of Gravity (COG) velocity (sec)	0.15±1.2	0.8±1	0.293	0.04
2	Reaction time (sec)	0.91±2	0.80±1.1	1.25	0.02
3	Limits of Stability (LOS)				
	End-point excursion (%)	48.1±1	53.3±1.1	1.23	0.02
	Maximum excursion (%)	70.5±1	73.2±1.1	0.90	0.01
	Directional change (%)	59.3±2	59.6±1	0.89	0.01
4	Movement velocity (°/sec)	1.2±1	0.9±1	0.293	0.02
5	Walk across-speed (cm/sec)	32.4±1	39.05±1.7	1.38	0.20

[Table/Fig-5]: Pre-post analysis of temporal outcome variables.

Pre-post analysis of COG sway velocity: An improvement in the mean was observed, increasing from 0.15±1.2 seconds to 0.8±1 seconds (p-value=0.04). VR improves spatial navigation, therefore reducing the circumduction of the hemiplegic limb during locomotion, this perhaps reduced the sway velocity during heel strike.

Pre-post analysis of reaction time: Mean reaction time improved from 0.91±2 seconds to 0.80±1.1 seconds (p-value=0.02). This implies that the VR box platform has a facilitatory effect on plantar fascia receptors, thereby improving peripheral reaction time.

Pre-post analysis of movement velocity: There was a reduction in mean movement velocity from 1.2±1°/second to 0.9±1°/second (p-value=0.02). Weight-bearing exercises performed on the VR platform might have improved the weight-bearing capacity of the lower limb and, therefore less unsteadiness during locomotion and resulted in improved mean scores post-six-week intervention.

Pre-post analysis of Limits of Stability (LOS): Improvement in all three domains of LOS was observed. End-point excursion improved from 48.1±1 to 53.3±1.1% (p-value=0.02). Maximum excursion improved from 70.5±1% to 73.2±1% (p-value=0.01), and directional control improved from 59.3±2% to 59.6±1% (p-value=0.01). The VRT with weight-bearing exercises had a positive effect on antagonistic control, thereby improving the LOS.

Pre-post analysis of walk-across speed: There was improvement seen in the mean walk across speed, increasing from 32.4±1cm/sec to 39.05±1.7 cm/sec (p-value=0.20). The difference in the mean was not statistically significant; the possible reason could be that weight-bearing with VRT improves agonist antagonist control of movement; however, it does not have a modifying effect on the timing of muscle recruitment.

There was a reduction in mean step width post-6-week intervention, decreasing from 25.8±1 cm to 15.2±1.1 cm (p-value=0.04). By improving toe clearance during the swing phase, the consequent improvement in mean step width was seen. There was an improvement in mean step length, increasing from 29.7±2 cm to 32.5±1 cm (p-value=0.03) [Table/Fig-6].

S. No.	Outcome variables	Mean±SD Pre	Mean±SD Post	T-value	p-value
1	Mean step width (cm)	25.8±1	15.2±1.2	1.35	0.04
2	Mean step length (cm)	29.7±2	32.5±1	0.34	0.03

[Table/Fig-6]: Pre-post analysis of spatial outcome variables.

DISCUSSION

In this study, the effects of VRT on temporal and spatial components of gait in hemiplegic patients were studied. After six weeks of intervention, significant improvements were observed in all parameters of balance and hemiplegic gait. Notably, the COG sway velocity, assessed by the Neurocom Balance Master, improved from 0.15 seconds to 0.08 seconds (p-value=0.04). This improvement was likely due to the proprioceptive capacity of the plantar aspect of the foot, which the VR platform may have enhanced by positively affecting the somatosensory perception of the foot. Present study findings are supported by a study conducted by Kin JW and Lee JH, which suggested that two weeks of VRT improves stability by enhancing proprioceptive ability [4].

The VRT platform generates vertical and horizontal oscillation movements, with the contact surface transmitting vibrations from the feet to the entire body [11]. Present study observed a reduction in peripheral reaction time and a consequent reduction in movement time during gait in hemiplegic patients. This may be attributed to improved step-toe clearance with pelvic rotation in the forward direction at the terminal swing, observed post-six-week application of VRT with five weight-bearing positions. Pelvic rotation was better controlled during heel strike, and foot-dragging with circumduction was less pronounced, with toes clearing off during the entire swing phase. However, no change was observed in the pattern or appearance of hemiplegic gait. A reduction in ankle plantar flexor spasticity post six-week intervention may contribute to this improvement [6], although the quality of movement was not affected despite reduced movement time.

Conversely, a study by Lau RWK et al., suggested that VRT has no additive effect on the neuromuscular components of gait [12]. Other studies indicate that VRT has no impact on tone, balance, strength, and mobility [13]. Authors hypothesise that this variability in results could be due to factors such as age, functional capacity, duration of stroke, and the involvement of dominant and non-dominant sides of hemiplegia. Nonetheless, present study results suggest that a six-week VRT regimen improves peripheral reaction time and movement time.

The current study observed statistically significant changes in three domains of LOS: endpoint excursion, maximum excursion, and directional control. The VRT platform activates muscle spindles, inducing muscular contraction via stretch reflex, thereby improving agonist-antagonist movement control. Enhanced co-contraction of lower limb muscles likely contributed to correcting hip-ankle stepping strategies of postural control, thus improving the LOS in all directions [8]. However, plantar flexor spasticity might be a confounding factor in these results.

These improvements were likely due to reduced COG sway, enhancing the ability to shift COG according to changes in posture. However, no improvement in walking speed was observed in present study. Extending the duration of the study might yield different results. A meta-analysis by Fischer M et al., supports the long-term effects of VRT on human gait biomechanics [14].

Despite the varied reports on the positive effects of VRT on hemiplegic gait, present study suggests that VRT is effective in addressing the spatial and temporal impairments of hemiplegic gait. No side-effects were observed from VRT, such as headache, tremors, or fatigue, indicating that it can be used as an alternative or adjunct to conventional physiotherapy, especially in patients for whom exercise therapy is challenging [10].

Limitation(s)

This study does have limitations. First, no functional outcome measure was used to assess functional walking status. It is recommended that future studies explore the impact of VRT on gait components related to functional or community ambulation. Second, authors did not consider the long-term carryover effect of VRT. Third, authors only included ambulatory stroke patients, so the results may not be generalisable to different functional stages of rehabilitation. Lastly, no control group was included; hence, future studies should conduct randomised controlled trials to generate empirical evidence. It is also recommended that kinesiological Electromyography (EMG) be used to assess physiological changes in muscular contraction, which will aid in further objective findings. However, research is needed to address these limitations and establish a standardised rehabilitation plan targeting gait capacities across diverse populations. The confounding factors, such as the degree of paralysis, involvement of artery, and years of hypertension, were not considered in this study, which might have affected the results.

CONCLUSION(S)

The study's findings suggest that VRT combined with weight-bearing exercises can significantly improve spatial and temporal gait variables in hemiplegic patients. These improvements highlight the potential of VRT as an adjunct to traditional rehabilitation methods, offering a promising approach to addressing the complex biomechanical impairments associated with hemiplegia.

The compounding problems of such biomechanical impairment present a clinical challenge for physiotherapists, includes inability to provide adequate feedback to patients, which emphasises to prepare a customised training plan. The findings reflect the ability of VRT combined with weight-bearing exercises to be conceptualised in future movement-based approaches of such magnitude and severity during the chronic stages of rehabilitation.

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