Effectiveness of Virtual Reality-Based Gait training protocol on Hemiplegic gait

Dr Swati Kajbaje, Dr.Suraj B. Kanase*

Department Of Neuro Physiotherapy , Krishna College Of Physiotherapy, Krishna Vishwa Vidyapeeth, Karad

Corresponding author:
Dr.Suraj B. Kanase
Professor/HOD
Department Of Neurophysiotherapy, KVV, Karad
Email: drsurajkanase7@gmail.com

KEYWORDS
Virtual reality, Gait, Hemiplegia, Stroke, Rehabilitation, Conventional training.

ABSTRACT

Purpose of Study: Gait impairment is one of the devastating sequel of stroke. Hence, gait recovery forms the crux of improving patients' quality of life. Traditional methods lack the nuances associated with stroke rehabilitation; however, innovative VR technology is now a widely accepted training regimen in post-stroke rehabilitation. Currently, no literature addresses VR's effectiveness on stroke-related gait rehabilitation. This study evaluated the efficacy of VR-based gait training protocol on hemiplegic gait.

Methodology:60patientswereselectedaccordingtostudycriteriaandrandomizedintoGroup A(n=30), receiving conventionalgait training, and Group B (n=30), receiving virtualreality- based and conventional training 5 days/week for 4 weeks. Patients were evaluated pre- and post-treatment for gait mobility by Time Up and Go test (TUG), Lower extremity functions by Fugl Meyer Assessment-lower extremity (FMA-LL), and Gait variables: step length, stride length, and Cadence.

Result: Data was statistically analyzed using Paired and unpaired t-tests. Group A: post- intervention TUG was 16.033±4.072, FMA-LL was 22.967±2.710 (p<0.0001). Gait variables like the step length difference (5.567±1.194),the stride length(79.333±4.475),and the cadence (80.867±3.998) (p<0.0002) show significance. However, the group B Post-intervention TUG was (12.933±1.982), FMA-LL was (25.033±3.388), and Gait variables Step length difference was (3.733±1.081),Stridelength(82.133±7.682)AndCadence(84.633±3.945)(p<0.0001)
which was extremely significant.

Between groups, TUG for group A(16.033±4.072) and group B (12.933±1.982) (p=0.0024), FMA-LL for group A (22.967±2710) & group B (25.033±3.388) (p=0.0124), and in Gait variables Step length difference for group A (5.733±1.081) and group B (3.733±1.081) with p<0.0001,Stridelength-groupA(79.333±4.358)&groupB(82.133±7.682)(p=0.0436),
Cadence for group A (80.687±3.998) & group B(85.767±5.029) (p=0.0006) which shows extremely significant.

Conclusion: Virtual reality-based gait training protocol was effective in improving Hemiplegic gait. These findings provide strong evidence supporting the use of Virtual Reality as an effective tool for gait training in individuals with hemiplegic gait.

Introduction:

A stroke is an acute neurological event resulting from abnormalities in the cerebral circulation, leading to focal brain dysfunction. It is characterized by clinical signs of focal (or global) disturbances incerebral function lasting more than 24 hours or causing death, with a vascular origin being the primary cause.[1]
Stroke is the second leading cause of death and the primary cause ofdisabilityworldwide.[2] In India, the estimated prevalence rate of stroke ranges from 84-262 per 100,000 in rural areas and334-424per 100,000 in urban areas. Recent population studies report an incidence rate of 119-145 per 100,000.[3] Approximately 65% of strokes caused by vascular occlusion occur in the territory of the middle cerebral artery, with smaller percentages affecting the anterior(2%) and posterior cerebral artery territories (9%) or the brainstem and cerebellum.[4]
Strokes are classified into two main types: ischemic strokes, accounting for 85% of cases of acute stroke cases, and hemorrhagic strokes, which affect 15% of patients.[4] Hemorrhagic strokes can be further categorized into intracerebral hemorrhage (ICH) and subarachnoid hemorrhage. Additionally, the TOAST classification identifies four primary types of ischemic strokes: large vessel atherosclerosis, small vessel diseases (lacunar infarcts), cardioembolic, and cryptogenic strokes.[4,5]
The major risk factors for stroke include hypertension, cerebral embolism, diabetes, hypercholesterolemia,obesity,physicalinactivity,smoking,andgeneticpredisposition.Stroke leads to both structural and functional impairments, significantly affecting physical performance.[5] Motor and cognitive impairments, including gait, balance, limb function, and psychologicalhealthdeficits,oftenreducethequalityoflife.Theamostcommonsymptomafter a stroke is motor impairment, particularly affecting one side of the body, causing hemiplegia or hemiparesis.[6] Even though many stroke patients regain the ability to walk independently, they often do so inefficiently. Gait disturbances such as uneven stride length, shorter step length, longer double support time, and reduced walking velocity are common. This leads to increased energy expenditure, reduced flexibility, and difficulty performing tasks in varied environments, such as walking on uneven surfaces, slopes, or busy streets. These challenges can also contribute to depression.[7]
Human gait is a critical component of independent living often disrupted in stroke patients. Gait disturbances can impede individuals' return to productive roles in society. Improving gait ability can enhance independence, societal participation, and quality of life while reducing the burdenoncaregivers.Hemiplegicgaitdeviationsaretypicallycharacterizedbybiomechanical and kinesiological abnormalities and a loss of centrally programmed motor control mechanisms.[7,8,9] Approximately 50% of individuals who regain ambulation after a stroke continue to experience difficulties walking in the community, such as navigating changes in terrain, avoiding obstacles, walking long distances, and performing secondary tasks simultaneously. This makes the ability to perform dual tasks essential for adapting to environmental changes during walking, such as stepping over obstacles or crossing streets.[9,10]
Thus, the restoration of gait function is a primary goal of rehabilitation. Traditional treatment strategies for hemiplegic gait include conventional gait training, robotic-assisted training, and treadmill training. However, virtual reality(VR)-based gait training is an emerging technique withlimitedresearch,andnostandardizedprotocolscurrentlyexist.[11]VRisaninnovativetool that enables users to interact with computer-simulated environments that mimic real-world scenarios.[12]Itallowspatientstoperformphysicaltasksinvirtualenvironments,whichmaynot be possible or safe in the real world. VR offers a unique advantage as it allows patients to engage inimmersiveandcontrolledenvironmentsfromthecomfortandsafetyoftheirhomes, facilitating learning and rehabilitation without physical risk.[12]
VR training enhances neural plasticity by providing a safe and enriched environment for functional task-specific activities with increased repetitions, intensity, and motivation.[13]

Feedback through the virtual environment, including visual and auditory cues, helps enhance motorlearningbyprovidingreal-timeresults.VRtechnologyhasbeenappliedtorehabilitation toprovidestrokepatientswithopportunitiestoengagewithsimulatedenvironmentssimilarto real-world settings. When combined with treadmill training, VR allows users to interact with virtual environments while receiving real-time feedback, enhancing the motivation and effectiveness of rehabilitation.[14]

One of the major challenges in stroke rehabilitation is the limited exposure to various environmental conditions, such as walking on uneven surfaces, avoiding obstacles, or navigatingstairswithinaclinicalsetting.VRaddressesthislimitationbysimulatingreal-world conditions while minimizing risks. It allows patients to experience various environments and practice functional tasks repetitively, making rehabilitation more engaging and safer.[15,16]

In recent years, immersive VR technology has gained traction in education, tourism, and healthcare. However, its effectiveness in rehabilitation, particularly for stroke patients, still requires further exploration. Research in this area is growing, with studies showing the potential of VR to improve physical and cognitive functions in rehabilitation settings.[17,18,19]

This study evaluated the effectiveness of a Virtual Reality-based gait training protocol for hemiplegic gait rehabilitation. This research introduces an innovative approach to gait rehabilitation, leveraging VR technology to simulate environments and tasks that promote recovery and improve gait function in stroke patients.

Methodology:

Study design and participants:

The study was a pre-test and post-test experimental assessment study on 60 patients at Krishna College of Physiotherapy, KIMSDU, Karad. The study was carried out for1year after ethical approval from the Institutional Ethics Committee of KIMSDU, Karad, Maharashtra. Written informed consent was obtained from the patients for participation after the study parameters, and the benefits and risks were thoroughly explained.

Patients diagnosed with stroke in the age bracket of 30-65 years were included in the study. Additionally,theywereassessedfortheabilitytowalkwithoutphysicalassistanceforbalance and coordination (Functional Ambulation Category ≥3), along with residual gait defects or partial anti-gravity dorsiflexion.[7] The participants were excluded if they were suffering from severe behavioral or mental disorders or cognitive impairment (MMSE ≤24 Points), had a recent episode of lower extremity deep vein thrombosis, quadriplegia, or any other orthopedic conditions.Theoneswhohadahistoryofcerebrovascularaccidentbeforethestroke,incidence of vital organ failure, malignant tumor, or other unstable conditions were also excluded.[20]

Data Collection:

The study subjects were randomized in a1:1 ratio in Groups A(Control) and B(Experimental). Patients had 20 treatment sessions (5 days/week for 35-40 minutes on average with proper rest).

The study data were collected based on these three major parameters

A. Functional Mobility by **Time up &go test**

B. Lower Extremity functions by **Fugl-Meyer test for lower limbs**

C. Gait parameters by **step length, stride length & cadence**

TrainingProgram:

Training Parameter	**Conventional Group**	**Virtual Reality(VR)Group**
Duration	30min/day for 4 weeks	30min/day for 3 weeks
Days/week	5	5
Type	Conventional Gait Rehabilitation training	VR-assisted Gait + Conventional training
Training Types	Indoor (parallel bar training): Standing on one leg, heel raises, toe raises, obstacle walking, backward walking, and side walking. Cycling and Treadmill training for 10 min Outdoor gait training (stair climbing, walking on uneven surfaces).	Indoor (parallel bar training): Standing on one leg, heel raises, toe raises, obstacle walking, backward walking, and side walking. Plank bridge training with VR. Cycling and Treadmill training withVR (walking on a street and forest) Outdoor gait training (stair climbing, walking on uneven surfaces).

Statistical Analysis:

DataanalysiswascarriedoutusingSPSSVersion23.0software.Thewithin-groupand between-group comparisons were made using paired and unpaired T-tests, respectively.

Results:

The study assessed 60 subjects with stroke, 62% female and 32% male. The distribution in terms of age was varied, with the maximum number of patients in the 56-65 age category (55%), followed by 46-55 (40%) and 35-45 (5%).The mean age ofthe patients was 57.330 ± 6.171.

Regarding outcome measures, the improvements after FuglMeyer's assessment for lower limbs were extremely significant in Group B after pre- and post-intervention (20.533 vs 25.033, p<0.0001). In contrast, the improvements were slightly lesser in Group A(21.533 vs. 22.967, p<0.0001).

Meanwhile, there were significant mean differences in the two study groups, pre- and post-intervention, for the time up and go test (Group A: 20.133 to 16.033 p<0,0003 vs Group B: 19.233 to 12.933, p<0.0001). The improvements were quite substantial for step length (gait parameters), wherein the mean scores reduced from 10.167 to 3.733 (p<0.0003) in the VR-assisted group as opposed to 5.567 from8.033 (p<0.0014) in the conventional training group.

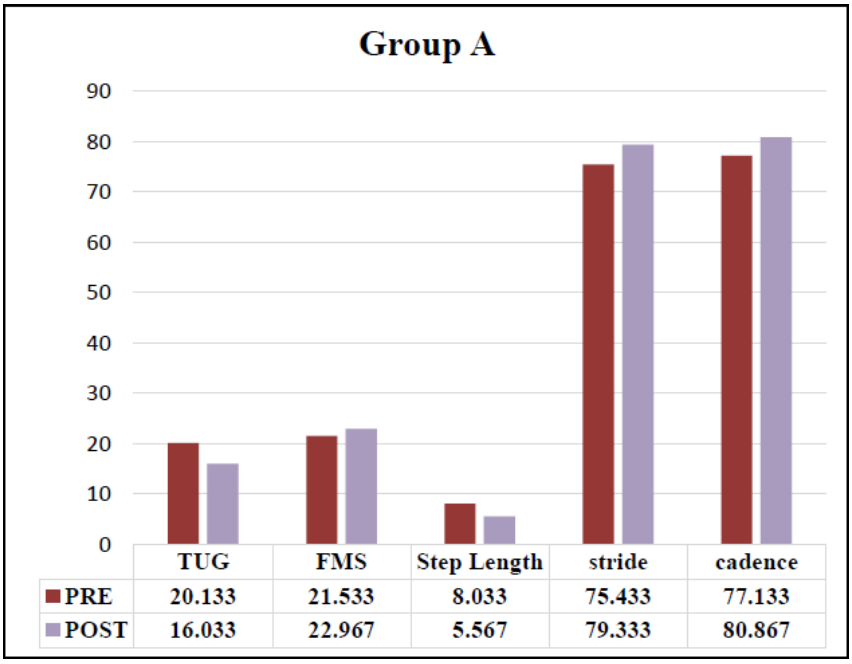

Fig:Pre-andpost-interventiondataforalloutcomesinGroupA(conventionaltraining)

Stride length was also assessed, and the mean difference between pre-and post-training with VR programs was extremely significant (82.133 from 68.067, p<0.0003). In contrast, the conventional training participants depicted a mean difference of only 79.333 from 75.433 (p<0.00014).

Finally, the mean difference in Cadence for bothVR-assisted and conventional training groups was quite significant, with the former scoring 84.633from76.333post-training (p<0.0003) and the latter scoring 80.867 from 77.133 post-training (p<0.0001).

Figure 1 depicts the pre-and post-intervention outcome measures for Group A(Conventional training), while Figure 2 illustrates the same in Group B (VR-assisted training).

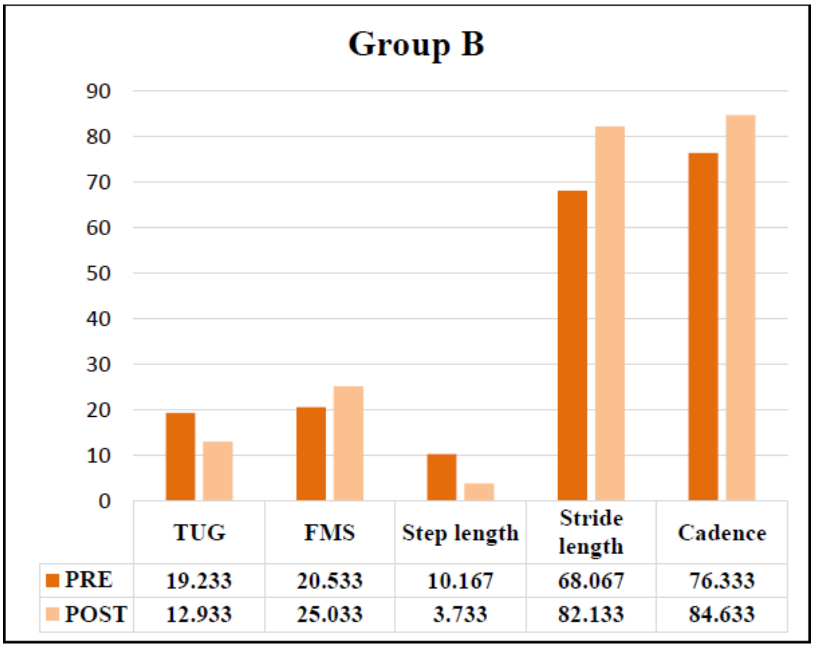

Fig: Pre-and post-intervention data for all outcomes in Group B (VR-assisted training)

Discussion:

ThestudypurportedtostudytheeffectivenessofVR-basedgaittrainingprotocolon hemiplegicgaitcomparedtoconventionalgaittrainingprograms.Afterfourweeksoftraining, both groups experienced significant improvements in hemiplegic gait for all outcomes measured in the study. In terms of mean difference in control (Group A) and experimental groups(GroupB),thelatterexperiencedextremelysignificantoutcomesforallvariablestested in the study. A similar conclusion was drawn by Emmade Keersmaekeret al. (2019), wherein VR-enhanced gait training was more effective for post-stroke patients.[11]Similarly, Walker et al. reported the significance of adding VR to treadmill walking, which resulted in profound improvements in concentration when carrying out the tasks.

There were significant differences in lower extremity functioning, gait mobility, and gait parameters in the interventional group (Group B) as opposed to control (Group A). These findings were consistent with the results of the study by Illlona JM et al., which highlighted that VRtraining is a more effective option than normal gait training through improvements in gait ability in stroke patients.[21]

Relearning the walk after a stroke requires frequent practice with more repetition sets and exercise variations to adapt to changing environments and increasing physical demands. VR allows a simpler, engaging, and motivating approach than traditional interventions, enabling individuals to move, interact, and dynamically manipulate objects.[22]

The literature has demonstrated the effectiveness of treadmill training in improving gait for stroke patients, explaining the significant improvements observed over time in both study

groups.However,theinteractionbetweenthegroupandtimerevealedthattheimprovementin gait was more pronounced in group B (VR-based gait training) compared to group A (conventionaltraining).Inthestudy,theuseofVRresultsinthefunctionalrecoveryofpatients via increased input to multisensory feedback, such as visual and auditory, and also alleviated motor learning abilities.[24]
VR creates a sense of highly repetitive and variable patient-specific motor training, forming a physiological basis for learning. The visual and auditory senses are the major systems interacting with VR and play a major role in improving walking. Through this sensory information, the central nervous system(CNS) determines the position and orientation of body segments and adjusts to complex external environments.
The study showed that patients who interacted with VR-based training improved their motor skills more than those who had not experienced conventional training. The head-mounted display (HMD) in the VR gear enables patients to navigate through spatial and temporal experiences close to the real world. This, in turn, increases their motivation and purpose through community engagement and real-time feedback via treadmill walking.
We observed improvements in functional mobility, lower extremity function, and gait parameters, including increased stride length, cadence, and reduced step length asymmetry. Thesegaitimprovementsarethoughttobedrivenbythemultisensoryfeedbackprovided during treadmill training, which simulates various community environments. Feedback enhances learning, and VR, a 3D training platform, offers multisensory feedback while promoting active patient participation and repetitive practice, which is vital for motor learning.[12]
Several studies have shown that walking on a treadmill or cycling on a stationary bike while viewingnaturevideosthroughahead-mounteddevicecanyieldpsychophysiologicalbenefits, such as improving mood and alleviating mental fatigue. These findings support that virtual nature environments can benefit physical and psychological recovery supported by Pretty et al., 2005; Plante et al., 2006;Akers et al., 2012;White et al., 2015; andYeh et al., 2017.
The improvements in gait observed in our study included increased velocity, cadence, and overallgaitability.VRtechnologyfocusesongaitmovementbyeliminatinginterferencefrom other visual stimuli, which enhances the interaction between vision and proprioception. In contrast, traditional treadmill training typically involves walking in a fixed visual environment, which can disrupt the integration of visual and proprioceptive feedback.
Previous studies have demonstrated significant improvements in gait speed, cadence, and functional ambulation through treadmill training, and our study also showed significant improvements in gait variables for both groups. Visual feedback in the VR environment motivates participants to engage more actively in their training. This, combined with better concentration and postural stability, supports the development of a more natural gait pattern. Therefore, our study supports the hypotheses is that virtual reality-based gait training significantly improves hemiplegic gait.
During the study, no participants experienced exaggerated symptoms such as pain, motion sickness, or discomfort before or after performing the exercises, and no harmoccurredto any patient.

Conclusion:

Based on the statistical analysis, presentation, and interpretation of the data, this study concluded that the Virtual Reality-based gait training protocol led to significant improvements and clinically beneficial effects on hemiplegic gait compared to conventional gait training. The findings provide strong evidence supporting the use of Virtual Reality as an effective tool for gait training in individuals with hemiplegic gait.

Limitations:

The study has limitations, including a short evaluation period and a limited geographical scope. Future research involving larger population with a longer follow-up period is needed to assess the long-term benefits of this treatment. The study was conducted only on stroke patients who could walk independently. Finally, it was also limited to one geographical location.

Suggestions and recommendations

A follow-up study using advanced virtual reality techniques can be done. A similar analysis can be done in different neurological conditions to evaluate which virtual reality technique proves effective. This study can be done on a larger population.

Conflict of Interest: None

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