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Virtual Reality and Functional Gait Training on Lower Limb Motor Recovery and Gait in Subjects with Stroke - A Comparative Study

Dr. Mopuru Pranathi, *Postgraduate MPT Neurology, Swatantra Institute of Physiotherapy and Rehabilitation, Rajamahendravaram- 533296.*
Dr. Pappala Kiran Prakash, *Professor, Swatantra Institute of Physiotherapy and Rehabilitation, Rajamahendravaram- 533296.*
Dr. Patchava Apparao, *Principal, Swatantra Institute of Physiotherapy and Rehabilitation, Rajamahendravaram- 533296.*
Dr. D. Sai Sushmitha, *Assistant Professor, GSL College of Physiotherapy, Rajamahendravaram - 533296.*
Dr. Ganapathi Swamy Chintada, *Professor, GSL Medical College, Rajamahendravaram - 533296.*

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Abstract: This study aimed to compare the effectiveness of virtual reality (VR) combined with conventional physiotherapy versus functional gait training with conventional physiotherapy in improving lower limb motor recovery and gait in post-stroke individuals. A quasi-experimental design was used with 66 participants (average age 58.5 years) diagnosed with stroke-related gait impairments, randomly assigned to two groups. Group A received VR-based training plus conventional physiotherapy, while Group B received functional gait training plus conventional physiotherapy, each for 30 minutes, twice weekly for six weeks. Outcome measures included the Dynamic Gait Index (DGI) and Fugl-Meyer Assessment for Lower Extremity (FMA-LE). Both groups showed significant improvements within groups; however, Group A demonstrated significantly greater improvements than Group B in both DGI and FMA-LE scores. The findings suggest that VR combined with conventional physiotherapy is more effective than functional gait training for enhancing gait and motor recovery in stroke rehabilitation.

1. Extended Abstract

Background and Objective

Gait impairment is a common complication after stroke that can affect motor recovery during rehabilitation and reduce quality of life. Virtual reality is one of the most commonly used recent treatment techniques with potential benefits for motor enhancement. The objective of this study was to compare the effects of virtual reality combined with conventional physiotherapy versus functional gait training with conventional physiotherapy on improving lower limb motor recovery and gait in post-stroke subjects.

Methods

A quasi-experimental study design was used. Sixty-six subjects with an average age of over 58.5 years, all clinically diagnosed with stroke and gait impairment, were randomly divided into two groups. Group A (n = 33) received virtual reality plus conventional physiotherapy, while Group B (n = 33) received functional gait training plus conventional physiotherapy. The intervention was administered for 30 minutes, two days a week, over a period of six weeks. The Dynamic Gait Index (DGI) and Fugl-Meyer Assessment for Lower Extremity (FMA-LE) were used to assess the effectiveness of the interventions.

Results

An independent *t*-test was used to compare the mean differences between continuous variables, and a paired *t*-test was used to assess the statistical differences between pre- and post-test scores of the DGI and FMA-LE. Statistical analysis revealed that both groups showed significant improvements within groups on both measures. However, when compared between groups, the virtual reality plus conventional physiotherapy group showed greater improvement than the functional gait training plus conventional physiotherapy group.

Conclusion

The present study concludes that both the virtual reality plus conventional physiotherapy group and the functional gait training plus conventional physiotherapy group showed significant improvements in gait and motor recovery in post-stroke subjects. However, virtual reality combined with conventional physiotherapy was found to be more effective. Therefore, it is recommended that virtual reality be used as an adjunct to conventional physiotherapy for improving gait and motor recovery in rehabilitation clinics.

Keywords: Stroke, Gait, Motor Recovery, Virtual Reality, Functional Gait Training, DGI, FMA- LE.

2. Introduction

Cerebrovascular accidents (CVA), commonly referred to as strokes, are among the leading causes of physical impairment in adults [1]. Stroke is the most frequent neurological event that results in physical disability. The World Health Organization (WHO) defines a stroke as "a focal (or global) disturbance of cerebral function with rapidly developing clinical signs, with no apparent cause other than of vascular origin, with symptoms lasting 24 hours or longer or leading to death" [2]. It is a neurological condition marked by an abrupt vascular (venous or arterial) event that causes dysfunction in various parts of the brain [1]. Strokes can be classified as either ischemic or hemorrhagic [1]. Ischemic strokes result from inadequate delivery of blood and oxygen to the brain. Ischemic occlusion can cause thrombotic or embolic events in the brain [3], [4]. In thrombotic stroke, vessel narrowing due to atherosclerosis reduces blood flow. Plaque buildup progressively narrows the vascular lumen and may lead to clot formation. In embolic stroke, reduced cerebral blood flow leads to embolism formation, significantly reducing oxygen delivery and causing cellular stress and premature cell death (necrosis) [3]. Hemorrhagic strokes, though associated with a higher initial mortality rate, generally offer better long-term recovery prospects. They are caused by the rupture of a cerebral blood vessel, resulting in bleeding and extravasation into the brain tissue. Several risk factors are associated with stroke, including hypertension, diabetes mellitus, cardiac conditions, smoking, hyperlipidemia, alcohol consumption, substance abuse, obesity, sedentary lifestyle, and inflammation [5]. Stroke remains the second most common cause of disability and death worldwide. Over the past decade, the incidence of stroke has ranged from 105 to 152 cases per 100,000 people annually, with crude prevalence rates ranging from 44.29 to 559 cases per 100,000 across different regions of the country [6].

Individuals who have had a stroke experience a wide range of impairments that impact their sensory, motor, cognitive, emotional, and behavioral abilities. These impairments typically include increased spasticity, sudden muscle weakness, loss of balance and trunk postural control, and visual function issues, particularly affecting leg motor function and resulting in the commonly observed gait abnormalities after stroke [7]. Approximately 50% of individuals who regain the ability to walk after a stroke still experience difficulty walking in their communities on a daily basis. Furthermore, the capacity to perform additional cognitive or motor tasks while walking is generally impaired following a stroke [8]. Motor impairment—defined as the loss or limitation of muscle control, movement, or mobility—is the most prevalent and recognizable consequence of stroke [9]. Injury to the motor tracts, premotor cortex, motor cortex, or related pathways in the cerebrum or cerebellum can lead to hemorrhagic or ischemic motor dysfunction. Such impairments significantly affect an individual's participation in daily life and their ability to perform everyday tasks [10]. This spectrum of deficits affects activities of daily living (ADLs) and the patient's independence, thereby severely impacting quality of life [11], [12]. Rehabilitation training can reduce disability rates and significantly improve limb function in stroke patients [13]. Early initiation of stroke rehabilitation is especially important for mitigating symptoms. The primary goal is to improve quality of life by preventing further physical decline, maximizing remaining functional abilities, and promoting social engagement [11]. The use of virtual reality (VR) and functional gait training to enhance gait-related activities and prevent physical inactivity in the chronic post-stroke phase has gained increasing attention in recent years. Virtual reality, though offering modest improvements in motor function, has emerged as a promising technique for stroke rehabilitation [14]. VR uses various sensory cues to create a simulated environment that allows for interaction, navigation, and immersion in a three-dimensional space [13].

Virtual reality technology has evolved from basic desktop applications to mobile devices with headsets, enabling immersive experiences. Based on the level of immersion, VR can be categorized into three types: non-immersive, semi-immersive, and fully immersive [11], [19]. VR is often described using the "I3" concept—Interaction, Immersion, and Imagination [21]. Earlier exergame systems used TV screens, but newer systems incorporate portable head-mounted displays (HMDs) with large fields of view and stereoscopic vision that respond to head position and movement. These displays provide depth perception and block external visual stimuli, producing feasible and ecologically valid outcomes [22]. Since dedicated VR rehabilitation equipment is not widely available in clinical settings, affordable alternatives—such as motion-controlled consoles, mobile devices, and personal computers—are used for VR rehabilitation programs. These systems support various gaming software and provide real-time visual, tactile, auditory, and motion feedback in realistic scenarios [15]. The principles of motor learning are well supported in VR training, offering goal-oriented, repetitive, and varied practice tailored to the patient's abilities [16]. The use of multisensory stimuli and challenge-based levels enhances patient motivation—an essential factor for treatment adherence and improved rehabilitation outcomes [17]. VR creates a fully immersive 3D environment through HMDs (e.g., VR glasses), with separate screens for each eye, allowing users to experience full immersion without external distractions [13]. In functional gait training, the specificity and intensity of training—particularly in terms of hours of therapy—are key factors influencing recovery after stroke. Task-oriented training, in which gait and related tasks are practiced functionally, has shown greater effectiveness in improving walking ability compared to conventional practices [18], [20]. Task-oriented circuit class training (CCT)

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meets at least three essential criteria for an effective rehabilitation program [11], [18]. First, it uses multiple workstations, allowing patients to practice extensively in a meaningful and progressively structured format. Second, compared to individual sessions, task-oriented CCT is more time-efficient, as patients are actively involved in their training. This model can reduce healthcare costs by lowering staff-to-patient ratios. Third, it incorporates group dynamics, such as peer support and social interaction, enhancing the rehabilitation experience [18]. While numerous studies have explored the role of VR in stroke rehabilitation, there is limited research comparing the effectiveness of VR and functional gait training on lower limb motor recovery in stroke patients. Therefore, the objective of this study is to evaluate and compare the effectiveness of virtual reality and functional gait training on lower limb motor recovery and gait performance in individuals who have experienced a stroke.

Need for the Study

Stroke is the third leading cause of mortality in India, following heart disease and cancer. The prevalence of stroke varies across different studies, but there has been a noticeable increase in both the prevalence and incidence of stroke over the past 30 years. Gait rehabilitation is a primary focus in the recovery process for stroke patients. Motor deficits in the lower limbs are common among stroke survivors, and recovery in this area tends to be poorer than in other movement-related impairments. As a result, gait dysfunction is one of the most frequently reported issues by stroke patients.

Virtual reality (VR)-based gait training has emerged in recent years as an advanced and promising treatment for improving gait. VR training systems are feasible, lightweight, user-friendly, and cost-effective. More importantly, VR has been shown to engage users in a safe and immersive environment, which facilitates rehabilitation—particularly in areas such as cognition and gait. Given these benefits, this study aims to assess the effectiveness of a relatively new and low-budget VR approach for enhancing motor recovery and gait performance in stroke patients.

Aim of the Study

To compare the effectiveness of virtual reality and functional gait training on lower limb motor recovery and gait in individuals with stroke.

Study Objectives

- To evaluate the effect of virtual reality training combined with conventional physiotherapy on lower limb motor recovery and gait in stroke patients.
- To evaluate the effect of functional gait training combined with conventional physiotherapy on lower limb motor recovery and gait in stroke patients.
- To compare the effectiveness of virtual reality and functional gait training, both combined with conventional physiotherapy, on lower limb motor recovery and gait in stroke patients.

Hypothesis

Research Hypothesis (Hr): Virtual reality gait training is more effective than functional gait training in improving lower limb motor recovery and gait in stroke patients.

Null Hypothesis (H_0): There is no significant difference between virtual reality and functional gait training in terms of lower limb motor recovery and gait improvement in stroke patients.

3. Literature Review

Peláez-Vélez, F.J., Eckert, M., et al. (2023)[1]

This study evaluated the effectiveness of combining traditional neurological physiotherapy with a virtual reality (VR)-based program in post-stroke rehabilitation. A total of 24 patients diagnosed with stroke within the previous six months were randomly divided into control (n = 12) and experimental (n = 12) groups. Both groups received one-hour physiotherapy sessions over six weeks, while the experimental group also underwent VR training. Assessments included the Daniels and Worthingham Scale, Modified Ashworth Scale, Motricity Index, Trunk Control Test, Tinetti Balance Scale, Berg Balance Scale, and Functional Ambulation Classification.

[1] Source: Int. J. Environ. Res. Public Health, 2023, 20, 4747.

Statistically significant improvements were observed in the experimental group across multiple measures, highlighting the potential of VR as an effective supplement to traditional physiotherapy.

Coupland, A.P., Thapar, A., Qureshi, M.I., et al. (2017)[2]

This article discusses the evolution of stroke definitions and emphasizes the inclusion of "silent" brain, retinal, and spinal infarcts in modern diagnostic criteria. The current understanding no longer limits diagnosis to clinically apparent symptoms, aligning with advances in imaging and pathology.

Kuriakose, D., Xiao, Z., et al. (2020)[3]

The authors reviewed the global burden of stroke, with ischemic stroke being the most prevalent. They highlighted recent developments in understanding stroke pathophysiology and identified a shift towards more sophisticated clinical trials and animal models. The review stresses that despite medical advancements, post-stroke rehabilitation remains a significant burden on patients, families, and healthcare systems.

Dąbrowski, J., Czajka, A., et al. (2019)[4]

This study focused on the pathophysiological and neuroplastic mechanisms following ischemic stroke. The authors emphasized the importance of early motor and speech rehabilitation and examined biomarkers related to neuroplasticity. They concluded that functional recovery is closely tied to the brain's ability to reorganize itself (neuroplasticity), influenced by genetic and epigenetic factors.

Murphy, S.J.X., Werring, D.J., et al. (2020)[5]

This comprehensive overview defines stroke as a syndrome of acute focal neurological deficits due to vascular injury. It highlights the major types of stroke (ischemic and hemorrhagic), their respective causes, and the most common risk factors. The review underlines the importance of anatomical knowledge for diagnosis and management and stresses personalized treatment strategies based on stroke etiology.

Kamalakannan, S., Gudlavalleti, A.S.V., et al. (2017)[6]

In a systematic review, the authors examined the increasing burden of stroke in India. Incidence rates more than doubled in low- and middle-income countries, including India, between 1970 and 2008. The review emphasized the lack of reliable epidemiological data due to heterogeneous methodologies and small sample sizes. It called for comprehensive, state- and nationwide studies to better inform preventive and rehabilitative strategies.

de Rooij, I.J.M., van de Port, I.G.L., et al. (2019)[7]

This randomized controlled trial (ViRTAS study) aimed to evaluate the effect of virtual reality gait training (VRT) on participation in daily life among community-living individuals after stroke. Fifty stroke patients (2 weeks to 6 months post-stroke) were randomly assigned to either a VRT group or a non-VRT group. Both received 12 sessions of 30-minute gait training over six weeks. The primary outcome was participation, measured via the Utrecht Scale for Evaluation of Rehabilitation-Participation (USER-P). Secondary outcomes included walking ability, mobility, fatigue, anxiety, depression, falls efficacy, and quality of life. The study provides valuable insight into how VR-based interventions may enhance community participation after stroke.

Langhorne, P., Coupar, F., Pollock, A. (2009)[8]

This comprehensive review synthesized data from systematic reviews and randomized controlled trials to assess the efficacy of various interventions for motor recovery after stroke. Promising approaches included constraint-induced movement therapy, electromyographic biofeedback, mental imagery, and robotic assistance. Gait-related improvements were noted with repetitive task training, balance training, and high-intensity physical

[2] Source: Journal of the Royal Society of Medicine, 2017.
[3] Source: International Journal of Molecular Sciences, 2020, 21, 7609.
[4] Source: Hindawi, Neural Plasticity, 2019, Article ID 9708905.
[5] Source: Medicine, 48(9), 561. Published by Elsevier Ltd.
[6] Source: Indian Journal of Medical Research, 146, August 2017.
[7] Source: Trials (2019), 20:89.
[8] Source: Lancet Neurology, 2009; 8:741–754

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therapy. The review emphasized the importance of task-specific and repetitive interventions, despite some methodological limitations in the studies reviewed.

Jones, H.A., et al. (2018)[9]

The study highlighted the post-stroke brain's capacity for neural remodeling and plasticity, emphasizing that compensatory behavioral strategies—though often necessary—can shape neurological outcomes. These strategies may either aid or hinder optimal recovery, depending on how they influence neuroplastic processes. The authors advocated for deeper exploration into how therapeutic behaviors might deliberately guide neural reorganization to maximize functional gains.

Demeco, A., Zola, L., Frizziero, A., et al. (2023)[10]

This systematic review analyzed the impact of fully immersive virtual reality (FIVR) in post-stroke rehabilitation. Twelve randomized controlled trials involving 350 patients were assessed. FIVR demonstrated significant benefits over standard therapy, particularly in enhancing upper limb dexterity, gait performance, and dynamic balance. The findings support FIVR as a multi-dimensional, immersive approach that increases patient engagement and functional outcomes in stroke rehabilitation.

de Sirea, A., Moggioa, L., et al. (2021)[11]

This systematic review and meta-analysis examined the impact of rehabilitative interventions on hemiplegic shoulder pain (HSP), a common complication in stroke survivors. Results showed that combining conventional rehabilitation with other therapeutic modalities significantly reduced pain and improved clinical outcomes compared to conventional therapy alone. These findings underscore the value of a multifaceted approach in managing post-stroke musculoskeletal complications.

Ilona J. M. de Rooij, Ingrid G. L. van de Port et al. (2019)[12]

In this study, the authors state that stroke often results in gait impairments, activity limitations, and restricted participation in daily life. Virtual reality (VR) has been shown to be beneficial for improving gait ability after stroke. Previous studies on VR have mainly focused on improvements in functional outcomes. Since participation in daily life is an important goal of post-stroke rehabilitation, it is crucial to investigate whether VR gait training can enhance participation. The primary aim of this study is to examine the effect of VR gait training on participation in community-living individuals after stroke. The ViRTAS study is a single-blinded, randomized controlled trial with two parallel groups. Fifty individuals between 2 weeks and 6 months post-stroke, who experience difficulties with walking in daily life, are randomly assigned to either a virtual reality gait training (VRT) group or a non-virtual reality gait training (non-VRT) group. Both training interventions consist of 12 sessions of 30 minutes each, over 6 weeks, conducted in an outpatient rehabilitation clinic. Assessments are conducted at baseline, post-intervention, and 3 months after the intervention. The primary outcome is participation, measured using the Utrecht Scale for Evaluation of Rehabilitation-Participation (USER-P). Secondary outcomes include subjective physical functioning, functional mobility, walking ability, walking activity, fatigue, anxiety and depression, falls efficacy, and quality of life. The study provides insights into the effect of VR gait training on participation after stroke.

Peter Langhorne, Fiona Coupar, Alex Pollock et al. (2009)[13]

This review highlights that loss of functional movement is a common consequence of stroke, and various interventions have been developed to address it. The authors aim to provide an overview of the available evidence on interventions for motor recovery after stroke by evaluating systematic reviews and recent randomized controlled trials. Most trials were small and had design limitations. Improvements in arm function were observed with constraint-induced movement therapy, electromyography biofeedback, mental practice with motor imagery, and robotics. Enhancements in transfer ability or balance were seen with repetitive task training, biofeedback, and moving platform training. Walking speed improved with physical fitness training, high-intensity therapy (usually

[9] Source: Nature Reviews Neuroscience (2018), Author manuscript available in PMC.
[10] Source: Sensors, 2023, 23(1712).
[11] Source: [Exact journal details not provided, presumed from clinical rehabilitation literature, 2021].
[12] Rooij, I. J. M. de, van de Port, I. G. L., et al. Trials (2019) 20:89.
[13] Langhorne, P., Coupar, F., Pollock, A., et al. Lancet Neurol (2009); 8: 741–54.

physiotherapy), and repetitive task training. Despite limitations in study design, several treatments show promise, especially those emphasizing high-intensity and task-specific repetitive practice.

Heresa A. Jones et al. (2018)[14]

The study notes that stroke initiates a dynamic process of repair and remodeling of the remaining neural circuits, shaped by behavioral experiences. The onset of motor disability creates a strong incentive for patients to develop compensatory strategies for daily activities. These strategies significantly influence post-stroke neural remodeling and can have mixed effects on functional outcomes. Harnessing the potential of compensatory behavior to positively impact neural reorganization remains an underexplored approach for optimizing functional recovery after stroke.

Andrea Demeco, Laura Zola, Antonio Frizziero et al. (2023)[15]

In recent years, alongside conventional rehabilitation techniques, new technologies have been applied to stroke rehabilitation. Fully immersive virtual reality (FIVR) has shown promising results due to its ability to immerse subjects in realistic virtual environments. This study investigates the efficacy of FIVR in stroke rehabilitation by screening databases up to November 2022, ultimately including 12 randomized controlled trials (RCTs) with 350 post-acute and chronic stroke survivors (234 men and 115 women; mean age: 58.36 years). Despite high heterogeneity among outcomes, the results demonstrate that FIVR provides additional benefits compared to standard rehabilitation. Improvements were noted in upper limb dexterity, gait performance, and dynamic balance, which positively influenced patient independence. FIVR thus appears to be a flexible and engaging tool in post-stroke rehabilitation, enhancing patient compliance and improving function and quality of life.

Alessandro de Sirea, Lucrezia Moggioa et al. (2021)[16]

The study concludes that hemiplegic shoulder pain (HSP) is a disabling complication affecting stroke survivors. Rehabilitation may play a crucial role in managing HSP. Despite a lack of recent systematic reviews on rehabilitative approaches for HSP pain reduction, this meta-analysis of randomized controlled trials demonstrates that adding supplementary rehabilitative techniques to conventional therapy is significantly more effective than conventional therapy alone in the comprehensive management of HSP.

Bohan Zhang, Ka-Po Wong et al. (2023)[17]

This systematic review aimed to evaluate the effectiveness of virtual reality rehabilitation on physical outcomes in stroke patients. Databases such as PubMed, EMBASE, Cochrane Library, PEDro, CINAHL, Web of Science, and ProQuest Dissertations were searched through April 30, 2022. Review quality was assessed using the AMSTAR 2 tool, and evidence strength was evaluated with the GRADE system. Twenty-six studies were included, focusing on limb motor function, balance, gait, and daily function. Findings suggest beneficial effects of VR, with "very low" to "moderate" quality evidence for improvements in motor function, balance, and daily activities, as well as gait. Despite growing interest, high-quality evidence for routine clinical use of VR in stroke rehabilitation is still lacking. More research is needed to clarify the most effective treatment modalities, durations, and long-term effects.

Huihui Cai, Tao Lin, Lina Chen et al. (2021)[18]

This study emphasizes that the high incidence of cerebral apoplexy (stroke) makes it one of the leading causes of adult disability, with gait disorders being a prominent consequence. Restoring walking ability is vital to improving quality of life. Although virtual reality is increasingly used in post-stroke rehabilitation and has proven to be effective and safe, few studies have specifically examined the impact of immersive VR on gait recovery. This prospective, randomized controlled clinical trial will enroll 36 stroke patients within one month of stroke onset. Participants will be randomly assigned to a VRT group (30-minute VR-assisted sessions, 5 days/week for 3 weeks) or a non-VRT group receiving conventional gait training. Primary outcomes include the Time "Up & Go" Test (TUGT), while secondary outcomes include MMT muscle strength grading, Fugl-Meyer Assessment (FMA),

[14] Jones, H. A., et al. Nat Rev Neurosci. (2018); PMC author manuscript.
[15] Demeco, A., Zola, L., Frizziero, A., et al. Sensors (2023), 23, 1712.
[16] de Sirea, A., Moggioa, L., et al. Annals of Physical and Rehabilitation Medicine (2022), 65.
[17] Zhang, B., Wong, K.-P., et al. Medicina (2023), 59, 813.
[18] Cai, H., Lin, T., Chen, L., et al. (2021).

Motor Assessment Scale (MAS), the Barthel Index, knee angle, support time, step frequency, step length, pace, and stride length. Immersive VR, through engaging virtual games, is expected to enhance patient motivation and active participation.

Soltani, P., Andrade, R., et al. (2020)[19]

This systematic review evaluated the use of virtual reality (VR) head-mounted display (HMD) systems for balance training in older adults. Nineteen studies involving 637 participants were analyzed. Despite heterogeneity in age ranges and clinical conditions, VR HMD systems were found to be valid tools for assessing balance, improving postural control and gait, and helping differentiate between healthy and balance-impaired individuals. Older adults exhibited more cautious behavior during VR-based balance tests. VR HMD systems provide ecologically valid environments for balance assessment and training and can be used independently or alongside other interventions. However, further research is needed due to the high risk of bias and poor methodological quality in existing studies.

Sana, V., Ghous, M., et al. (2023)[20]

This randomized clinical trial compared the effects of vestibular rehabilitation therapy (VRT) and virtual reality (VR) on balance, gait, and dizziness in sub-acute stroke patients. Thirty-four patients were assigned to either the VRT or VR group. Each received 24 sessions over 8 weeks. The Time Up and Go test, Dynamic Gait Index, and Dizziness Handicap Inventory were used for assessment. VR showed significant improvements in balance and gait ($p = .01$), while VRT was more effective for reducing dizziness ($p < .001$). Both groups showed significant within-group improvements in all outcomes ($p < .001$). VR was found to be more effective for enhancing balance and gait.

Kiper, P., Luque-Moreno, C., et al. (2020)[21]

This study investigated the effects of virtual reality (VR) therapy on balance, gait, and motor recovery in stroke patients. Participants were divided into sub-acute and chronic groups. VR therapy, enriched with artificially reinforced feedback, facilitated activation of brain areas related to motor learning. Improvements were observed in lower limb function across both stroke phases. The study concluded that VR is a promising tool for enhancing motor outcomes during rehabilitation.

Iqbal, M., Arsh, A., et al. (2020)[22]

This randomized controlled trial compared dual-task training with conventional physical therapy in patients with chronic stroke. Sixty-four participants were divided into two groups. Group A received dual-task training, including walking with a sandbag, while Group B received conventional therapy. Pre- and post-treatment assessments included the Time Up and Go test and 10-meter walk test. Group A showed significantly better improvements in gait parameters such as step length, stride length, cycle time, and cadence ($p < .05$). The study concluded that both interventions improved gait, but dual-task training was more effective in enhancing spatial and temporal gait variables.

Dettmers, C., Teske, U., et al. (2005)[23]

This study assessed the impact of distributed constraint-induced movement therapy (CIMT) on motor function in 11 individuals with chronic stroke. The intervention consisted of 3 hours of daily motor training and 9.3 hours of constraint therapy over 20 days. Assessments included the Motor Activity Log, Wolf Motor Function Test, and Stroke Impact Scale. Participants demonstrated significant improvements in motor activity, strength, spasticity, and quality of life, with sustained benefits up to 6 months post-treatment. Distributed CIMT was found to be an effective rehabilitation strategy for enhancing upper limb function.

Liepert, J., Bauder, H., et al. (2000)[24]

[19] Source: Front. Sports Act. Living, 09 February 2021.
[20] Source: Medicine (2023), 102:24.
[21] Source: J Rehabil Med, 52, 2020.
[22] Source: J Pak Med Assoc, 70(1), January 2020.
[23] Source: Arch Phys Med Rehabil, 86, February 2005.

[24] Source: Stroke, 31, 1210–1216 (2000).

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This study explored treatment-induced cortical reorganization in stroke patients. After an intensive rehabilitation protocol, the affected hand's cortical representation increased significantly, correlating with improved motor function. Follow-up showed that motor performance remained high, and cortical excitability between hemispheres returned to a more balanced state. This was the first evidence in humans of long-term brain changes resulting from therapy-induced recovery post-stroke.

Jones, T. A., et al. (2017)[25]

This review discussed the role of compensatory behaviors in shaping neural reorganization after stroke. While such behaviors help regain functionality, they can also influence neural remodeling in ways that affect outcomes. The review emphasized the importance of understanding and guiding compensatory strategies to optimize recovery, highlighting a relatively unexplored avenue in stroke rehabilitation research.

4.Materials and Methods

Study Design:

This study employed a quasi-experimental design.

Ethical Clearance and Informed Consent:

The study protocol was approved by the Institutional Ethical Committee of GSL Medical College & General Hospital (Annexure-I). The investigator explained the purpose of the study to all participants and provided a patient information sheet. Written informed consent was obtained from each participant (Annexure-II). The rights and confidentiality of all participants were fully protected throughout the study.

Study Population:

The study included subjects who were clinically diagnosed with stroke by a neurologist.

Study Setting:

The study was conducted in the Department of Physiotherapy at a tertiary care hospital in Rajamahendravaram, Andhra Pradesh, India.

Study Duration:

The study was conducted over a period of one year, from August 1st, 2023 to July 31st, 2024.

Intervention Duration:

Each participant received intervention for a duration of six weeks, with two sessions per week.

Sampling Method:

A convenience sampling method was employed.

Sample Size:

A total of 80 subjects were initially screened. Based on the stroke prevalence rate of 559 per 100,000 population, 66 eligible participants were recruited. After obtaining informed consent and confirming eligibility, participants were randomly allocated into two equal groups ($n = 33$ each) using a convenience sampling technique.
Sample size was calculated using the formula:

$$\mathbf{n = Z^2PQ / L^2},$$

where:

[25] Source: Nature Reviews Neuroscience, 18, 267–280 (2017).

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- **P** = Prevalence = 0.559%,
- **Q** = 100 − P = 99.441%,
- **L** = Absolute error = 2%.

Group Allocation:

- **Group A (n = 33):** Received virtual reality gait training combined with conventional physiotherapy.
- **Group B (n = 33):** Received functional gait training combined with conventional physiotherapy.

Group	Number of Subjects	Treatment
A	33	Virtual reality gait training along with Conventional physiotherapy
B	33	Functional gait training along with Conventional physiotherapy

Materials Used
- Head-Mounted Display (Virtual Reality)
- Smartphone
- IN CELL (Game application)
- Stopwatch
- Wooden Staircase
- TheraBand

Criteria For Sample Selection

Inclusion Criteria
- First-ever stroke (initial episode)
- Age between 18 and 80 years
- Stroke onset within 1 month
- Functional Ambulation Category (FAC) score ≥ 3
- Adequate hearing and vision

Exclusion Criteria
- Cognitive impairments or language deficits preventing reliable response to simple questions
- Severe ataxia or uncontrolled epileptic seizures
- Presence of other orthopedic disorders
- Diagnosed cardiac conditions
- Neurodegenerative diseases such as Alzheimer’s disease

Outcome Measures

Dynamic Gait Index (DGI):

The DGI is used to assess an individual's ability to maintain walking balance under varying task demands. It uses a 4-point ordinal scale ranging from 0 to 3, where:
- **0** indicates severe impairment, and
- **3** indicates normal performance. **Total score = 24.** *(Annexure III)*

Fugl-Meyer Assessment – Lower Extremity (FMA-LE):

This scale assesses motor function, balance, sensation, and joint range of motion in post-stroke hemiplegia patients. It is commonly used to determine the severity of stroke, monitor recovery progress, and evaluate treatment outcomes.
Total score = 86. *(Annexure IV)*

Intervention

This six-week study involved two intervention groups:

- **Group A** received **Virtual Reality (VR) Gait Training** combined with **Conventional Physiotherapy**.
- **Group B** received **Functional Gait Training** combined with **Conventional Physiotherapy**.

Outcome measures were assessed using the **Dynamic Gait Index (DGI)** and the **Fugl-Meyer Assessment for Lower Extremity (FMA-LE)**, both targeting lower limb motor recovery and gait in post-stroke individuals. All eligible participants were randomly assigned to either group.

Group A: Virtual Reality Gait Training [26, 27, 28, 30]

Participants in Group A underwent VR-based gait training in addition to conventional physiotherapy. The intervention was delivered for **60 minutes per session**, **twice per week**, for **6 weeks**.

Virtual Reality Training (30 minutes per session)

The VR training was administered using an **immersive head-mounted display (IRUSU MINI)**, with a **smartphone** running the game **IN CELL VR**. A demonstration via screen recording was shown before the session. The VR environment instructed the participants to walk while engaging in tasks such as:

- Hitting proteins
- Avoiding viruses

These tasks required the subject to perform coordinated lower limb movements, including:

- Hip flexion and extension
- Knee flexion and extension
- Ankle plantarflexion and dorsiflexion

This game-based VR approach provided cognitive and physical challenges, encouraging synchronized motion execution and activating relevant neural pathways for motor recovery.

Conventional Physiotherapy (30 minutes per session)

Conventional physiotherapy included:

- **Strengthening exercises** using **TheraBand**
- **Stretching exercises** targeting:
    - Hamstrings
    - Quadriceps
    - Gastrocnemius

These were performed in varied positions: **standing**, **sitting**, **supine**, and **prone**.

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Figures:

Fig. 1: Walking with head-mounted virtual reality

Fig. 2: Head-mounted virtual reality setup

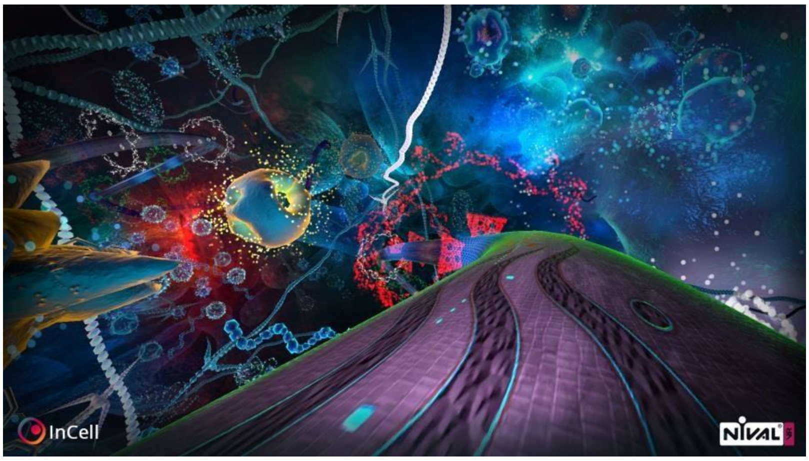

Fig. 3: Smartphone-based virtual reality

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Group B: Functional Gait Training [8, 29, 30]

Participants in Group B received **functional gait training** alongside conventional physiotherapy. The intervention followed the same duration and frequency as Group A: **60 minutes per session**, **twice weekly**, for **6 weeks**.

Functional Gait Training (30 minutes per session)

Exercises were based on the FIT Stroke Trial and included six task-specific activities:

1. Tapping or stepping up and down a step
2. Walking and picking up various objects from the ground
3. Walking on a non-level surface
4. Walking a slalom pattern
5. Stepping in hoops (to increase step length)
6. Stepping over a stick suspended between two pylons

Exercises were tailored by the physiotherapist based on each participant's abilities. Task difficulty was progressively increased across sessions, and all progressions were documented.

Conventional Physiotherapy (30 minutes per session)

As in Group A, physiotherapy included:

- **TheraBand-based strengthening**
- **Stretching exercises** (hamstrings, quadriceps, gastrocnemius)
- Exercises performed in multiple postures: **standing**, **sitting**, **supine**, and **prone**

Figures:

Fig. 4: Stepping up and down a step

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Fig. 5: Walking and picking up objects from the ground

Fig. 6: Walking on non-level surface

Fig. 7: Stepping in hoops

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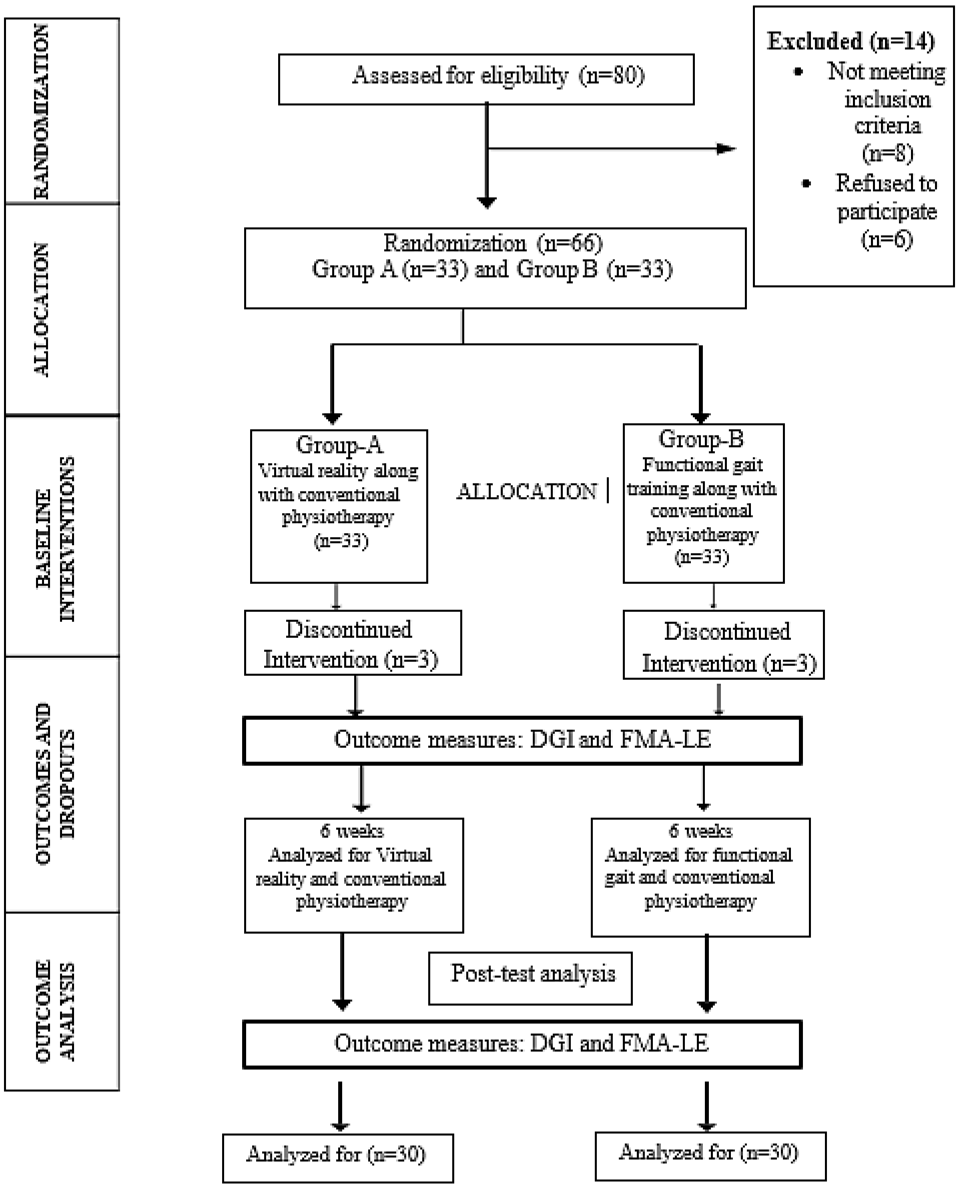
Flow Chart



5. Statistical Analysis

All statistical analyses were performed using **SPSS version 20.0** and **Microsoft Excel 2010**. Descriptive statistics are presented as **mean ± standard deviation (SD)**.

- **Within-group comparisons:** Paired Student's *t*-test was used to assess pre-test and post-test differences in gait and lower limb motor recovery for each group.
- **Between-group comparisons:** Independent *t*-test was applied to evaluate statistically significant differences in mean values of the Dynamic Gait Index (DGI) and Fugl-Meyer Assessment Lower Extremity (FMA-LE) between the two groups.

Data were tabulated and graphically represented for clarity. A **p-value < 0.05** was considered statistically significant.

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6. Results

The study outcomes were analyzed using the DGI and FMA-LE to evaluate improvements in lower limb motor recovery and gait.

The CONSORT flow chart illustrates participant screening, random allocation, and analysis following intervention. Out of 80 individuals screened, **66 subjects met the inclusion criteria** and were enrolled. Baseline assessments were completed for all participants.

Subjects were randomized into two equal groups:

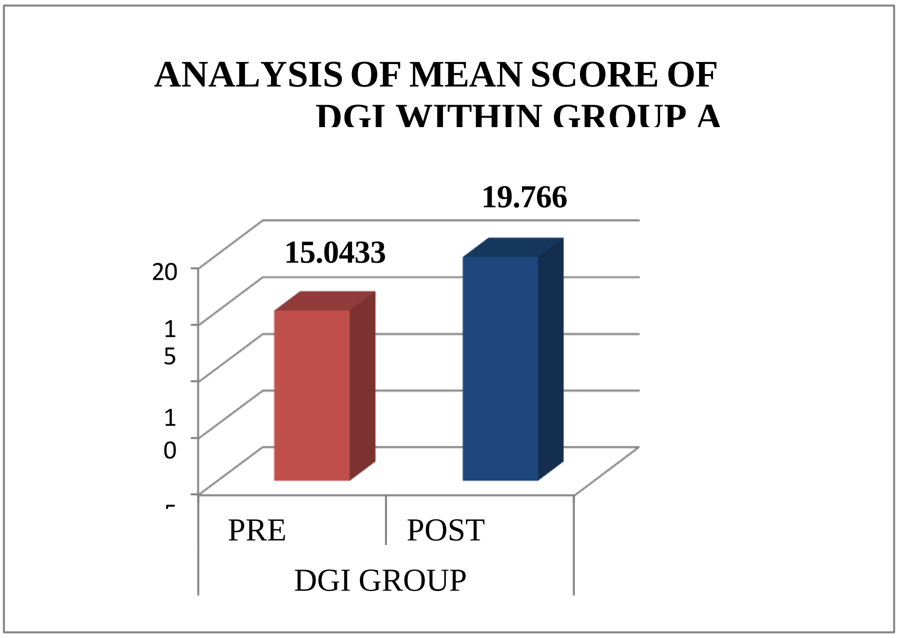
- **Group A:** 33 allocated, 30 completed
- **Group B:** 33 allocated, 30 completed

There were **3 dropouts in each group** during the intervention.

Statistical analysis demonstrated significant improvements both **within groups** and **between groups**. These results indicate that both virtual reality gait training and functional gait training combined with conventional physiotherapy were effective in improving lower limb motor recovery and gait in post-stroke patients.

Table-1 Analysis of Mean Scores of DGI within the Group – A

Groups		Mean	Standard Deviation	P-value	Inference
Group – A	DGI Pre test	15.04333	1.325697	0.0001	Highly significant
	DGI Post test	19.7667	1.612095		



Graph – 1 Results: The graph and corresponding table illustrate the mean Dynamic Gait Index (DGI) scores for Group A at pre-test and post-test. A statistically significant improvement was observed in DGI scores following the intervention in Group A ($p < 0.005$), indicating enhanced gait balance and stability after the virtual reality gait training combined with conventional physiotherapy.

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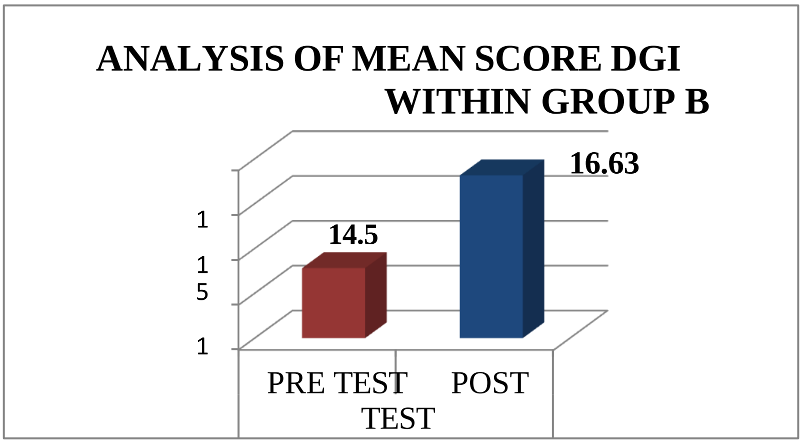
Table-2 Analysis of Mean Scores of DGI within the Group – B

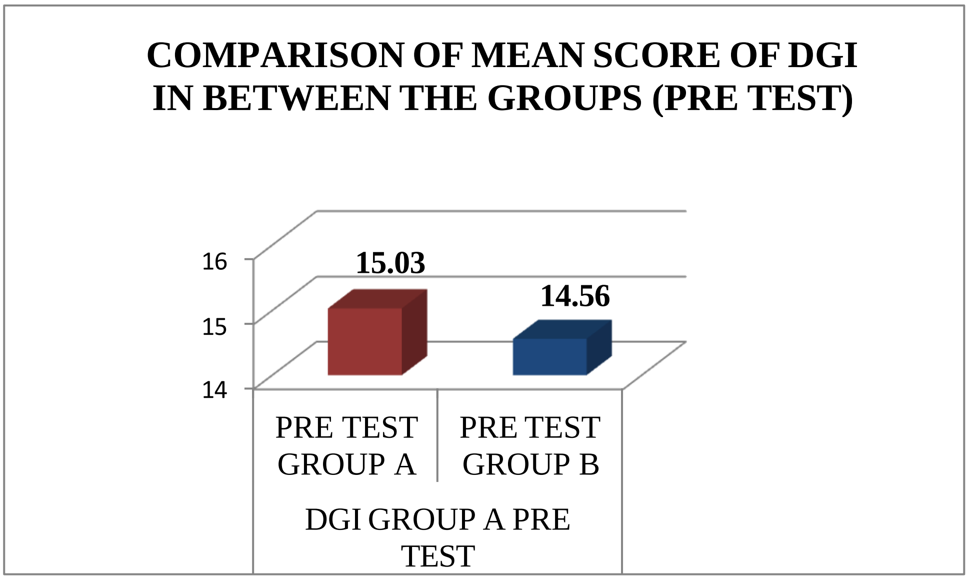
Groups		Mean	Standard Deviation	P-Value	Inference
Group –B	DGI Pre-test	14.56	1.250747	0.0001	Highly significant
	DGI Post-test	16.63	1.033352		



Graph – 2 Results: The table and graph above show the mean Dynamic Gait Index (DGI) scores for Group B at pre-test and post-test. The results indicate a statistically significant improvement in DGI scores within Group B following the intervention ($p < 0.005$), demonstrating enhanced gait performance after functional gait training combined with conventional physiotherapy.

Table-3 Comparison of Mean Scores of DGI between the Groups - Group A & B (Pre- Test)

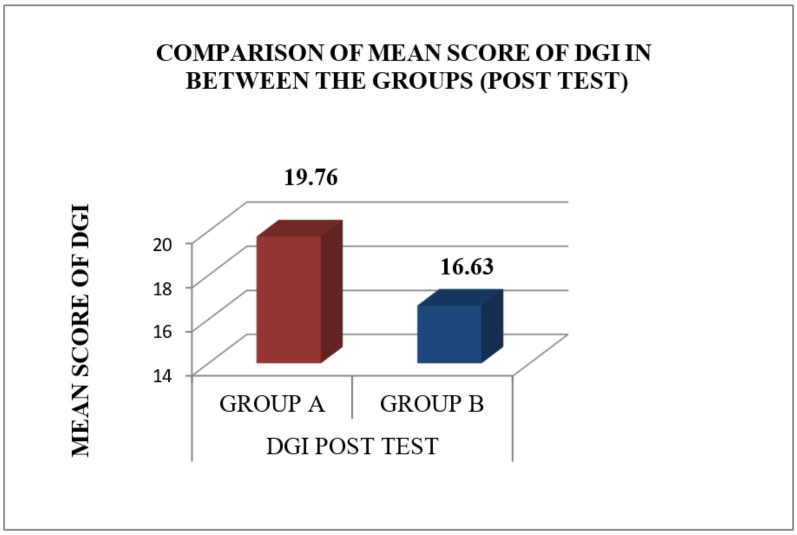
Groups		Mean	Standard Deviation	P-Value	Inference
DGI Pre-test	Group – A	15.03	1.325697	0.1661	Insignificant
	Group – B	14.56	1.256747		



Graph – 3 - Results: The table and graph above show the baseline Dynamic Gait Index (DGI) scores for Group A and Group B. There was no statistically significant difference between the two groups at baseline, indicating that both groups started with comparable gait function before the interventions.

Table-4 Comparison of Mean Scores of DGI between the Groups - Group A & B (Post- Test)

Groups		Mean	Standard Deviation	P-Value	Inference
DGI Post-test	Group – A	19.76	1.612095	0.0001	Highly significant
	Group – B	16.63	1.033352		



Graph – 4 - Results: The table and graph above show the post-test mean DGI scores for Group A and Group B. A statistically significant difference ($P < 0.005$) was observed between the two groups, indicating that Group A (Virtual Reality Gait Training) demonstrated greater improvement in gait performance compared to Group B (Functional Gait Training).

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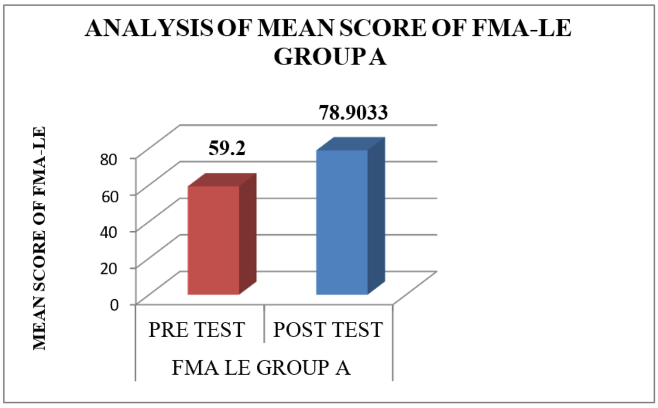
Table-5 Analysis of Mean Scores of FMA-LE within the Group – A

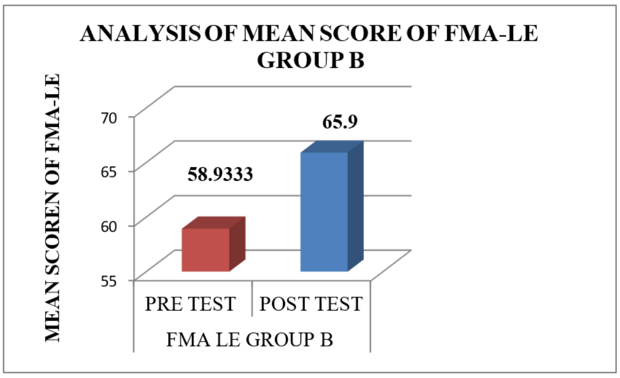
Groups		Mean	Standard Deviation	P-value	
Group – A	FMA-LE Pre test	59.2	2.734202	0.0001	
	FMA-LE Post test	78.0033	2.403302		



Graph – 5 - Results: The table and graph above illustrate the mean FMA-LE scores in Group A (Virtual Reality Gait Training) from pre-test to post-test. A statistically significant improvement (P < 0.005) was observed, indicating that the intervention effectively enhanced lower limb motor recovery in post-stroke individuals.

Table-6 Analysis of Mean Scores of FMA-LE within the Group – B

Groups		Mean	Standard Deviation	P-Value	Inference
Group -B	FMA-LE Pre-test	58.9333	2.72831	0.0001	Highly significant
	FMA-LE Post-test	65.9	1.953776		



Graph – 6 - Results: The table and graph above demonstrate the mean FMA-LE scores in Group B (Functional Gait Training) from pre-test to post-test. A statistically significant improvement (P < 0.005) was noted, indicating that functional gait training was effective in enhancing lower limb motor recovery in post-stroke individuals.

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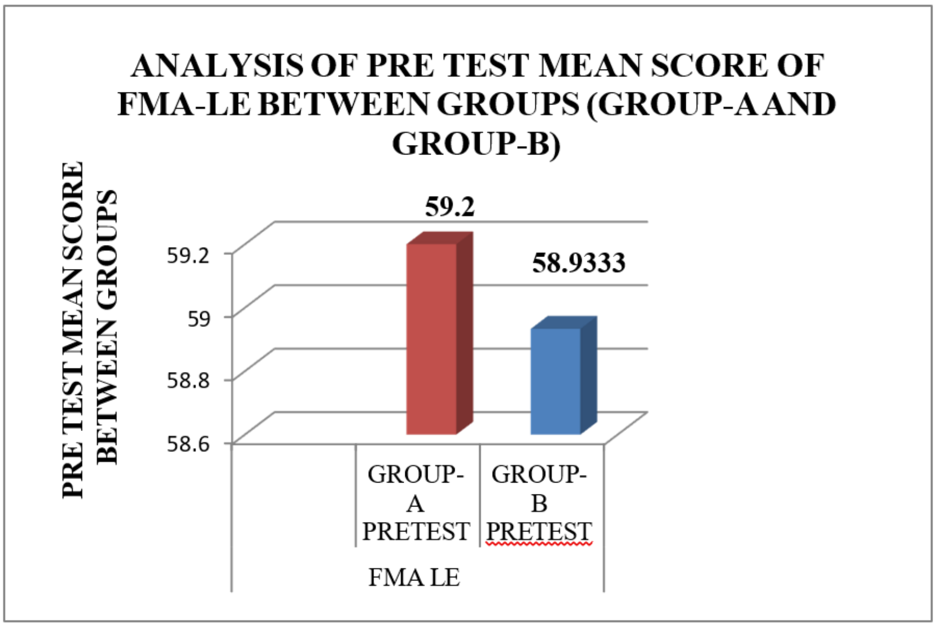
Table-7 Comparison of Mean Scores of FMA-LE between the groups - Group A & B (Pre- Test)

Groups		Mean	Standard Deviation	P-Value	Inference
FMA-LE Pre-test	Group - A	59.2	2.734202	0.7067	Insignificant
	Group - B	58.9333	2.72831		



Graph – 7 - Results: The table and graph above show the baseline Fugl-Meyer Assessment for Lower Extremity (FMA-LE) scores for both Group A (Virtual Reality Gait Training) and Group B (Functional Gait Training). The comparison revealed no statistically significant difference between the two groups at baseline, indicating both groups were comparable prior to the intervention.

Table-8 Comparison of Mean Scores of FMA-LE between the groups - Group A & B (Post- Test)

Groups		Mean	Standard Deviation	P-Value	Inference
FMA-LE Post-test	Group - A	78.9033	2.403302	0.0001	Highly significant
	Group – B	65.9	1.953776		

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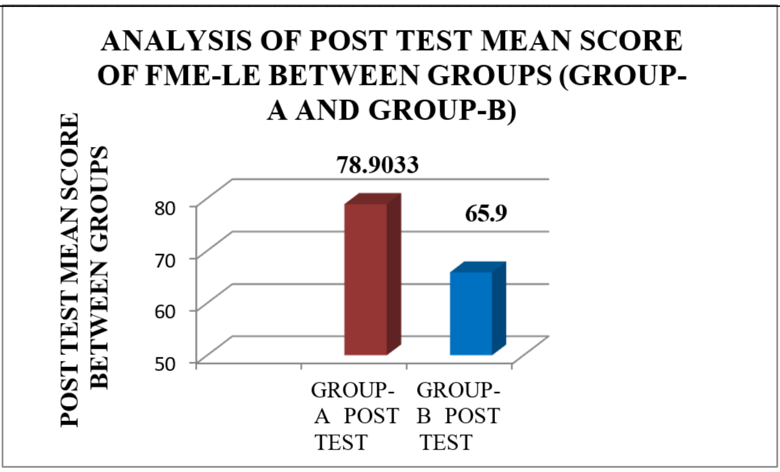

Graph – 8 - Results: The table and graph above illustrate the post-test Fugl-Meyer Assessment for Lower Extremity (FMA-LE) mean scores between Group A (Virtual Reality Gait Training) and Group B (Functional Gait Training). The comparison revealed a statistically significant difference between the two groups ($P < 0.005$), indicating that Virtual Reality Gait Training was more effective in improving lower limb motor recovery in stroke patients.

7. Discussions

The aim of the study was to assess the effects of virtual reality and functional gait training on lower limb motor recovery and gait in subjects with stroke. Virtual reality is one of the most widely used recent treatment techniques and is considered a potentially beneficial option for motor enhancement. The main objective of the study was to implement a low-cost, easily accessible treatment program using a mobile device. Due to their small size and light weight, these devices are portable and can be used without any issues related to the person's surroundings.

Virtual reality is widely used in the recovery of patients who have sustained neurological injuries such as stroke, spinal cord injuries, or other neurological disorders. Numerous studies have confirmed that virtual reality has a significant effect on limb rehabilitation in stroke patients. However, there are limited studies exploring the combined effect of virtual reality and functional gait training on lower limb motor recovery and gait in subjects with stroke.

Subjects were assessed for lower limb motor recovery and gait at baseline and at the end of the intervention using the Dynamic Gait Index (DGI) and Fugl-Meyer Assessment of the Lower Extremity (FMA-LE). There were three dropouts in Group A (Virtual reality gait training and conventional physiotherapy) and three dropouts in Group B (Functional gait training and conventional physiotherapy).
In Group A, there was a statistically significant improvement in DGI ($P = 0.001$), with improvements also seen in FMA-LE ($P = 0.001$). According to Francisco-Javier Peláez-Vélez et al., the use of neurological physiotherapy in combination with VR and video games is more effective for treating patients following a stroke than neurological physiotherapy alone. Therefore, the experimental therapeutic approach used in stroke rehabilitation is an effective and efficient tool for improving balance, gait, trunk control, and reducing motor deficits.

According to Bohan Zhang et al., VR provides real-time multisensory feedback—such as visual, auditory, and haptic input—and tracks patient performance and training variables such as type and intensity of exercise. This study found that VR can successfully enhance treatment for upper and lower limb function, balance, gait, and daily functioning in stroke patients. VR positively influenced functional recovery processes, including pain reduction, muscle strengthening, and sensory recovery. However, high-quality evidence is still limited.

According to Lee et al., who used VR to improve balance in stroke patients, VR games had a positive impact on balance, and patients experienced greater enjoyment during the intervention compared to standard treatment. Furthermore, VR promotes neural plasticity by allowing patients to perform functional, task-specific activities in an enriched environment.

In Group B, there was also statistically significant improvement in DGI ($P = 0.001$), with improvements seen in FMA-LE ($P = 0.001$). According to Ingrid G.L. van de Port et al., the main characteristics of the task-oriented Circuit Class Training (CCT) program are its progressive intensity and task specificity. The primary aim of the FIT-Stroke trial was to evaluate the effects and cost-effectiveness of a structured, progressive task-oriented CCT program compared to usual physiotherapeutic care during outpatient rehabilitation in a rehabilitation center.

According to Ilona J.M. de Rooij et al., VR gait training also impacts secondary outcome measures, including subjective physical functioning, functional mobility, walking ability, walking activity, fatigue, anxiety and depression, fall efficacy, and quality of life. VR is believed to enhance neuroplasticity and motor learning after stroke by facilitating brain reorganization and activating areas involved in motor planning, learning, and execution. VR gait training for sub-acute stroke survivors is considered a valuable addition to conventional physiotherapy (e.g., treadmill training or functional gait exercises) as it offers intensive, variable, and enjoyable therapy that can be adjusted to the patient's ability level. Multiple motor learning principles can be effectively applied during a VR gait training session. VR allows for multiple repetitions of various movements within meaningful tasks by modifying the type and settings of gait exercises within each session. Such variability is important for the retention and transfer of learned skills.

The study findings indicate that after six weeks of intervention, virtual reality combined with conventional physical therapy was more effective than functional gait training combined with conventional physiotherapy in improving lower limb motor recovery and gait in stroke patients. According to Jan Dąbrowski et al., neuroplasticity is a widespread phenomenon in the nervous system. Representations of sensory and motor cortical areas can be modified through environmental stimulation during motor learning and memory processes. Daily activity, motor learning, and training greatly influence brain function and adaptability, especially following ischemic injury. Forming correct connections through axons, projections, synapses, and chemical transmitters is a complex, ongoing process that continues throughout life. Physiotherapy strategies used during recovery influence spontaneous neuroplasticity. Thus, this study concludes that virtual reality is a valuable adjunctive treatment for improving lower limb motor recovery and gait in stroke patients.

8. Limitations

There was no follow-up in this study to evaluate the sustained effectiveness of the intervention over time. The evaluators of outcomes were not blinded.

9. Recommendations for Further Research

Long-term follow-up assessments could provide valuable insights into the sustained effectiveness of the intervention. Future studies could strengthen their findings by employing more rigorous randomization methods and incorporating larger sample sizes.

10. Conclusion

The present study concludes that after six weeks of intervention, both groups showed statistically significant improvement in post-test values. However, virtual reality combined with conventional physiotherapy was more effective compared to functional gait training combined with conventional physiotherapy. Thus, the study concludes that virtual reality is a useful adjunct to physiotherapy in improving motor recovery and gait in post-stroke subjects.

11. Summary

Title:

Virtual Reality and Functional Gait Training on Lower Limb Motor Recovery and Gait in Subjects with Stroke – A Comparative Study

Purpose:

The purpose of the study was to evaluate the effectiveness of virtual reality and functional gait training on lower limb motor recovery and gait in subjects with stroke.

Methods:

This quasi-experimental study included 66 subjects with a mean age of 58.5 years, all clinically diagnosed with stroke. They were randomly divided into two groups. Group A (n = 33) received virtual reality training along with conventional physiotherapy, while Group B (n = 33) received functional gait training along with conventional physiotherapy. The intervention was administered for 6 weeks, with two sessions per week. The Dynamic Gait Index (DGI) and Fugl-Meyer Assessment for Lower Extremity (FMA-LE) were used to assess the effectiveness of the interventions.

Results:

An independent t-test was used to compare the mean differences between continuous variables, and a paired t-test was used to assess statistical differences between pre- and post-test scores for DGI and FMA-LE. Statistical analysis revealed that both groups showed significant improvements in both parameters when compared within groups. However, when compared between groups, the group receiving virtual reality training along with conventional physiotherapy showed greater improvement than the group receiving functional gait training with conventional physiotherapy alone.

Conclusion:

The present study concludes that virtual reality training combined with conventional physiotherapy leads to significant improvements in lower limb motor recovery and gait in subjects with stroke. Moreover, it is more effective than functional gait training combined with conventional physiotherapy. Therefore, it may be recommended that virtual reality be used as an adjunct treatment for lower limb motor recovery and gait rehabilitation in clinical settings.

Keywords: Post-Stroke, Gait, Lower Limb Motor Recovery, Virtual Reality, Functional Gait Training, DGI, FMA-LE.

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