Effect of Virtual Reality for Balance Training in Stroke Patients

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Abstract

BACKGROUND/OBJECTIVE: Stroke is the condition which drastically affects the livelihood of an individual. Virtual reality (VR) can be of assistance in integrating multisensory stimulation of the visual and auditory system to create a realistic environment for motivational training and goal-oriented activities. VR offers patients with enhanced goal-oriented workouts and motivational training that improves patient program adherence since it includes multimodal stimulation of the visual, auditory, tactile, and somatosensory senses to create a realistic world. This study objective is to find the effectiveness of Virtual Reality Therapy and conventional exercise on balance in patients with stroke mainly affecting lower limb.

MATERIALS AND METHODS: In this study 20 Stroke patients aged 60-80 years, selected using convenient sampling were randomly assigned to two groups: Experimental group and conventional group (each n =10). Evaluations included the Functional balance grades and Timed up and go test. The Experimental group performed Virtual Reality balance games, while the conventional group engaged in conventional exercises. Both groups took therapy for 40 minutes, four days a week for 3 weeks.

RESULT: Statistical analysis revealed a significant difference within the groups with significance of $p<0.001$. The experimental group showed greater improvement in both the outcomes than the conventional group with p-value less than 0.001.

CONCLUSION: From the results obtained we conclude that both groups showed a significant improvement, but the experimental group showed greater improvement than the conventional group hence VR therapy is more effective for balance training in Stroke patients.

Keywords: Virtual Reality Therapy, conventional therapy, sub-acute stroke, Balance Training.

Introduction

Stroke is among the most serious medical concerns of the public. In 1999, there were 5.54 million stroke deaths worldwide, 2.33 million of which happened in less developed nations, based on the World Health Organization (WHO). The most frequent neurological disorder that results in long-term disability and has a huge emotional and socioeconomic impact on patients, their families, and medical personnel is stroke. According to the most recent statistics from the Indian Council of Medical Research (ICMR), there were 930,985 stroke cases in India in 2004. As a result, 639,455 people died and 6.4 million DALYs (disability adjusted life years) were lost. Age and the risk of stroke are strongly correlated. For example, those over 80 have a 30 times higher risk of having an ischemic stroke than people under 80. [1]

It is the most common neurological disorder and is to blame for over a third of all mortality worldwide. Chronic impairment affects up to 50% of stroke survivors, which has a significant negative influence on patients' quality of life

and day-to-day functioning. Cognitive and motor impairment, loss of balance, and gait loss are the main problems impacting stroke patients' independence and participation in activities. [2]

About seven million cases of chronic stroke and about 795,000 cases of new or recurrent stroke are reported each year in the United States. The cost of the care it requires is one of Medicare's fastest-growing costs, and it is the main cause of adult long-term disability in the US.[3]

It is the main contributor to mortality and disability worldwide. In 2010, 33 million people were thought to be affected globally. There are still about 795000 incidents of stroke per year in the United States, despite a reduction in stroke mortality of 35.8% during the previous ten years. China has the highest prevalence in the entire world. Stroke survivors usually suffer problems with motor control, which affects their ability to move, balance, and use proprioception. The effects of having had a stroke on daily activities and social interactions are widely known. Significant fall risk factors that limit one's ability to do daily chores include decreased dynamic and static balance. [4]

One of the major causes of disability in the world is stroke, and a significant proportion of stroke survivors' everyday activities and quality of life are impacted by the long-lasting residual impairments and dysfunctions. [5]

Using computer-based virtual reality technology, users can engage with a multimodal simulated world and get "real-time" performance feedback. Applications for virtual reality exercise can make use of pertinent neuroplasticity ideas. [6]

Virtual reality (VR)-based rehabilitation techniques have been developed to help stroke victims regain their independence. Through a scoping review, the efficacy of virtual reality-based therapies for balance and mobility disorders after a stroke was examined. Among the findings were virtual reality game-based therapies for problems with balance and mobility. Many commercial and custom virtual reality devices were used as therapeutic tools. Among the outcome measures were assessments of balance and gait obtained from laboratories and clinics. Outcome measures of dynamic balance showed significant improvements following VR-based interventions compared to other interventions. Additionally, it was proposed that a VR-based intervention could help with two areas that could support autonomous community ambulation: managing environmental stress and increasing walking speed. Thus, VR-based therapy may prove to be a helpful tool for stroke rehabilitation when it comes to balance and gait training. The application of motor learning principles in task-related training is probably responsible for a good portion of the successful results. It might be necessary to conduct additional research to support the conclusions. Feedback, repetition, and related concepts are other ideas that were used in studies but weren't particularly looked at. In the end, thorough research designs that take into account the intensity and dose-response aspects of virtual reality training, in addition to well-defined study objectives and appropriate results, will make it easier to conduct future evidence-based analyses to assess the efficacy of VR game-based interventions.

An interactive virtual environment (VE) that mimics the real world can be created synthetically using a variety of technological tools, which are collectively referred to as virtual reality (VR). When it comes to the rehabilitation of balance and gait dysfunctions after a stroke, virtual reality-based therapy can be a useful addition to or replacement for traditional therapy. To find out how VR-based interventions can help this population regain their ability to walk independently in the community and retrain their gait and balance, it is imperative to conduct a review of the literature.[7]

Virtual reality(VR) is a ground- breaking technology erected on a state- of- the- art stoner- computer interface that permits real- time simulation and commerce through visual and audio sensitive channels. The sensitive information handed by 3- dimensional(3D) computer- grounded surroundings is original to that which is learned from real effects and gests . In virtual reality, people may interact with surroundings and explore them while getting better feedback. The conception of" presence" is the foundation of the description of virtual reality and describes the experience of feeling girdled by an terrain. Since it was first applied in remedial surrounds, VR technology's worth and utility have significantly increased. Due to the use of VR, there's interest in studying how it affects motor recuperation. [8]

Interest in virtual reality technology as a slice- edge recuperation fashion has grown. While engaging in particular motor conditioning, VR can give cases lesser sensitive input, a further immersive terrain, and real- time feedback that reflects

motor literacy and neuroplasticity. thus, this approach could be seen as a supplement to conventional recuperation remedy. Visual information can make up for a functional gait deficiency. [9]

By creating an fortified terrain, enabling task-specific training, and offering multimodal feedback, virtual reality(VR), a computer- generated simulation technology, has the implicit to ameliorate functional recuperation. The three primary generalities of VR are absorption, creativity, and commerce. Cases can interact with and immerse themselves in the virtual terrain by using images. Virtual reality(VR) can force cases to perform with lesser focus and increase their conduct towards that ideal in addition to conventional recuperation remedy courses. Clinicians are using VR- grounded recuperation more constantly, and fresh studies are steadily demonstrating its advantages. As a cover intervention, VR-grounded recuperation has shown encouraging earnings in upper branch function, balance, and quality of life in stroke survivors. [5]

Despite the significance of balance, postural control hasn't been the subject of as important exploration as branch or gait balance remedy. Several curatives that affect balance and box control have been studied, including weight- shift training on an unstable face, balance control training, and gait training with metrical audible stimulation. still, typical recuperation ways are constantly time- and resource- consuming and bear special coffers or instruments. The maturity of published study had encouraging results. Since the prevalence of stroke is rising annually, it's vital to find remedial approaches that are both provident and secure. Conventional physical remedy has been discovered to have positive goods over time. still, after time, cases constantly grow wearied and lose interest with these movements. [4]

People who suppose traditional balance exercises, like wobbleboard, are boring and uninteresting, may have low compliance. Experimenters and medical professionals have been looking for different kinds of balance training for the once ten times. One similar kind of instruction is virtual reality(VR) balance training, which is defined as balance training using any kind of VR technology. By manipulating a repaired interpretation of yourself, virtual reality(VR) allows you to carry out colorful tasks in a computer-simulated terrain that simulates being physically present in real or imagined worlds. Consumer- position virtual reality(VR) was first created for gaming and entertainment, but it's presently being used in other fields, like exercise related to health.

Balance training is a pivotal part of the forestallment and recuperation of lower branch musculoskeletal injuries. Virtual reality(VR) has a lot of implicit to condense or replace traditional training. This review aims to give a comprehensive overview of virtual reality games and technology used for balance recuperation and forestallment, as well as balance outgrowth measures and goods for these two processes following musculoskeletal impairments of the lower branches. [10]

Virtual reality- grounded technologies hold implicit as successful strategies for neurotrauma recovery. In particular, the rudiments system, which uses palpable interfaces and customized face computing, has demonstrated promising results in the treatment of upper branch and cognitive function after traumatic brain injury. The effectiveness of rudiments as a virtual recuperation system for stroke survivors was assessed in the current study.

Stroke is one of the most common forms of acquired brain injury(ABI), with roughly 60,000 new and intermittent cases reported annually in Australia alone. Stroke can have a variety of clinical issues, but it frequently leaves victims with patient upper- branch motor poverties, including weakness, disabled speed and mobility, and dyscoordination, as well as cognitive impairments related to information processing and superintendent function. Given its goods on participation, exertion, and body structures function at every position of the International Bracket of performing(ICF), stroke is a major cause of disability worldwide, which is n't surprising. This emphasizes how important it's to apply interventions that have an impact on several functional disciplines.

While there are still numerous obstacles for recuperation specialists to overcome before stroke victims can recapture their functional capacities, innovative uses of slice- edge technologies, similar as virtual reality, may prove profitable. Creating training programs that are applicable, demanding, and study- provoking is one of the most important pretensions in order to come up with new ways to involve guests in their remedy. In virtual recuperation(VR), cases interact with presented virtual or stoked surroundings through the use of technology.

High situations of patient engagement during physical remedy for stroke victims have been demonstrated to be enhanced by virtual reality(VR), and indeed minimum training can ameliorate function at the exertion/ skill position. [11]

Deficits in balance and gait pose a serious health risk to people's quality of life and independence in everyday activities. Clinical therapies used to restore balance and gait typically rely on motor learning and neuroplasticity concepts, sometimes known as motor learning techniques. Through intensive, repetitive training that is task-oriented and tailored to each individual's limitations, these therapies hope to improve sensory, motor, and cognitive abilities. Particularly, it seems that improved motor-cognitive dual-tasking improves gait and balance.

Traditional rehabilitation program sometimes suffers from shortcomings like low participant interest and training amounts and intensities that are less demanding than recommended. Through interactive simulation, virtual reality (VR) technology provides users with access to environments that are very similar to the real thing. Virtual reality (VR) technology is being used more frequently for repetitive intervention tasks, limb function recovery after stroke, and stroke rehabilitation. It is beneficial for diagnosing, instructing, and training in rehabilitation. [12]

Virtual reality helps significantly with functional recovery following a stroke. It could be able to deliver the helpful intervention at a fair fee. VR provides patients with improved goal-oriented workouts and motivational training that improves patient program adherence. It can include multimodal stimulation of the visual, auditory, tactile, and somatosensory senses to produce a realistic world. According to earlier studies, it may be more effective than normal therapy for those who have had subacute or chronic strokes in terms of improving dynamic balance control and lowering the chance of falling. Though it might not always be superior than conventional therapy. Reviewing the research on virtual reality's effects on balance control in stroke patients is essential because, in the past two decades, VR software have advanced quickly, making it possible. [13]

The sensory, motor, cognitive, and visual deficits that are prevalent in stroke patients have an impact on their ability to do daily tasks. About 80% of stroke victims experience motor impairment, which is defined as a loss and restriction in muscle strength and coordination. Motor dysfunction in the legs has a substantial impact on balance and walking abilities. This relearning is achieved in traditional therapy through physical therapy, which places a significant emphasis on high-intensity, repetitive practice for specific tasks. High-intensity, repetitive, task-oriented, and task-specific training is the key to successful rehabilitation in all phases following a stroke. However, traditional rehabilitation methods often only have a limited and delayed positive impact on stroke survivors. In recent years, the use of virtual reality has expanded. [14]

Materials and method

Subjects: Patients diagnosed with sub-acute stroke, subjects were selected according the inclusion and exclusion criteria

Sampling technique: Convenient Sampling

Sample size: 20

Selection criteria:

Inclusion criteria:

Patients diagnosed with sub-acute stroke based on CT and MRI findings , both male and female, age – 60 to 80 years, Functional Balance Grades- Fair and Timed Up and Go test score more than or equal to 14 seconds.

Exclusion criteria:

The exclusion criteria will be the patient is on DVT protocol, Individuals with hearing disability and visual impairment, unable to understand and answer a simple verbal command, lower extremity deformity and bedridden patients.

Study procedure:

• This study will be conducted in Saveetha Medical College and Hospital, a total of 20 subjects will be recruited for study through the convenient sampling method

• All participants will be recruited based on the inclusion and exclusion criteria. Before commencing the study, an information sheet will be provided to all the participants regarding the study procedure and informed consent will be obtained. The recruited participants will be assigned to two groups (Experimental group: 10participants) and (Conventional group: 10participants) will undergo pre-test to analyse balance by using Functional Balance Grades and Timed Up and Go test for the stroke patients.

• Experimental group: The participants in the group will receive virtual reality balance game for a time period of about 40 mins a day. The VR headgear and the motion sensor provide subjects 360 degree of virtual world.

i.Keep balance VR game is used the balance training of the participants, in which the participants were asked to walk in a straight path.

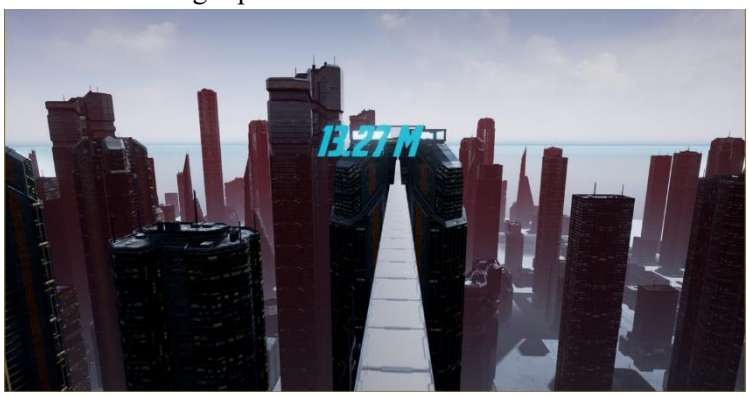


Fig.1.Keep Balance VR game

ii.Gravity tunnel VR game , in which the participants are asked to walk in a rotating tunnel of space ,where the participants see some obstacle.

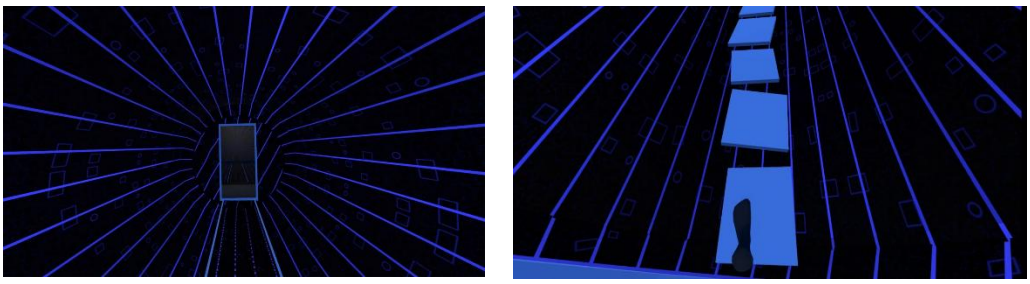


Figure.2. Gravity Tunnel VR game

iii.Slackline VR game , in which the participants are asked to walk in a straight line rope in tandem walking.

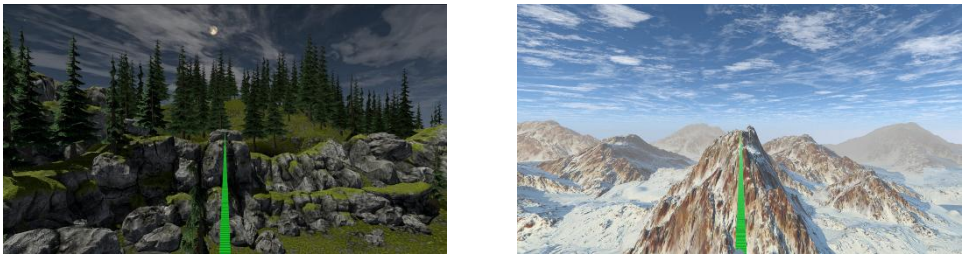


Figure.3. Slackline VR game

The VR balance game training was performed 40 minutes a day with break of 7 minutes between each 10 minutes.

• Conventional group: The participants of the conventional group will receive conventional exercise for improving balance, the exercise includes tandem stance, one leg standing, standing normal base of support, lateral weight shift.

i. Tandem stance: place one foot directly in front of the other foot, with the toes of one foot almost touching the heel of the other foot, maintain the position for about 60 seconds and then return to normal stance. Repeat the exercise for 10 times.

ii. One leg standing: Stand with your feet in which weight equally distributed on both legs. Place the hands in the hip. Lift your left leg of the floor and bend it back. Hold the position for 60 seconds. Then return to normal stance. Repeat the exercise for 10 times.

iii. Standing with normal base of support: Stand with feet apart. The feet should be 6 – 8 inches away from each other and the toes pointing forward, maintain the position for 60 seconds, then relax. Repeat the exercise for 10 times.

iv. Lateral weight shift (side to side): while standing, shift weight of the body to right and then to left for 60 seconds, then return to normal stance. Repeat the exercise for 10 times. Each exercise is done for 10 minutes, total time taken for the conventional exercise is 40 minutes per session.

The treatment duration for both groups will be 4 days a week for a total of 3 weeks. The outcome measures will be taken before and after the therapy.

Outcome measures:

Functional Balance Grades was used. The Functional Balance Grades helps in determine a person's ability to safely balance. It consists of 4 grades (Normal; Good, Fair, Poor), the participants with fair grade .Timed Up and Go test is a simple test used to assess a person’s mobility and requires both static and dynamic balance. [Normal Score= 10 seconds or less].

Statistical procedures:

The gathered information was analyzed and examined. For each parameter, the mean and standard deviation were utilized. The statistically significant differences between pre - test and post-test measures were examined using the Paired T-tests will be employed. The difference between the post-test values was determined by Unpaired T-test.

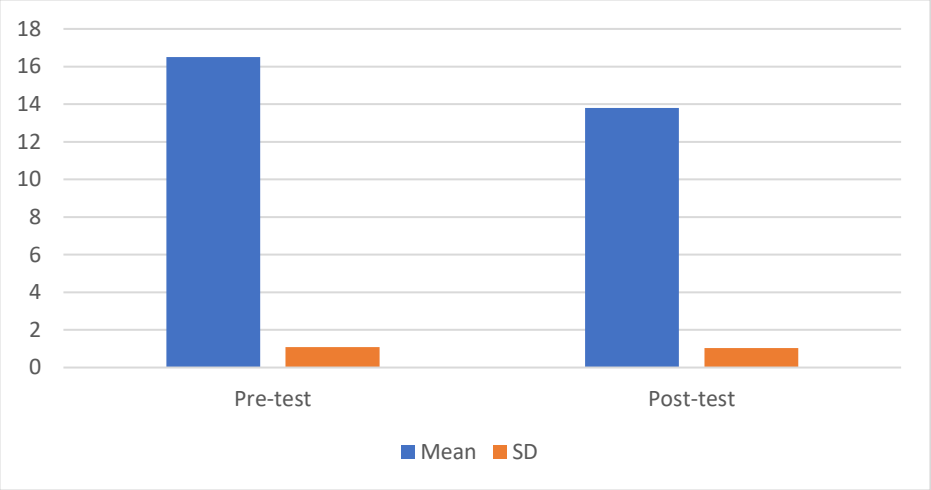
Results

When compared the pre and post-test assessment of Experimental group for TUG test, there shows a significant improvement in the balance by performing the TUG test. The statistical mean value for the pre-test of the Experimental group is 16.50 and the statistical mean value for the post-test of the experimental group is 13.80 and the standard deviation for pre-test value of the experimental group is 1.08, the standard deviation for post-test of the experimental group is 1.08.

The t-value comparison of the pre-test and post-test values of the experimental group was 17.6756 and with the P-value of 0.0001.

Table 1: Pre and post-test values of Experimental Group for TUG Test

Experimental Group	Mean	SD	T-value	P-value
Pre-test	16.50	1.08	17.6756	0.0001
Post-test	13.80	1.03		

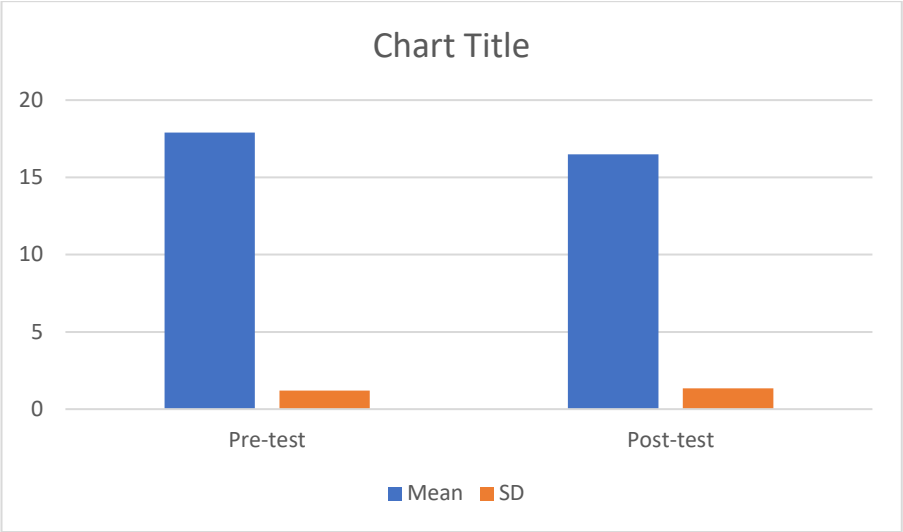


Graph 1: Pre and Post-test values of Experimental Group for TUG Test

The comparison of the pre and post-test assessment of the Conventional group for TUG test, there shows a significant improvement in the balance by performing the TUG test. The statistical mean value for the pre-test of the conventional group is 17.90 and the statistical mean value of the post-test of the Conventional group is 16.50. The standard deviation for the pre-test of the conventional group is 1.20 and the standard deviation of the post-test is 1.35. The t-value of the pre and post-test of the Conventional group is 8.5732 and with the P-value of 0.0001.

Table 2 : Pre and Post-test values of Conventional Group for TUG Test

Conventional Group	Mean	SD	T-value	P-value
Pre-test	17.90	1.20	8.5732	0.0001
Post-test	16.50	1.35		

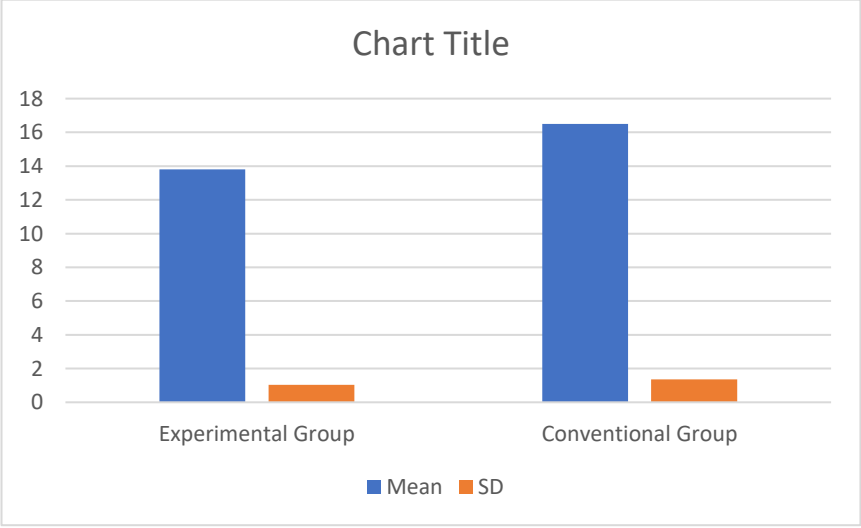


Graph 2: Pre and Post-test values of Conventional Group for TUG Test

In the comparison of the post-test of both experimental group and the conventional group, the experimental group shows slight improvement in balance. The statistical mean value of the experimental group is 13.80 and the conventional group is 16.50. The standard deviation of the post-test of experimental group is 1.03 and the post-test of conventional group is 1.35. The post-test comparison of both groups gives t-value of 5.0138 with p-value of 0.0001.

Table 3: Post test values of Experimental Group and Conventional Group for TUG Test

Post-test	Mean	SD	T-value	P-value
Experimental Group	13.80	1.03	5.0138	0.0001
Conventional Group	16.50	1.35		



Graph 3: Comparison of Post tests of Experimental Group and Conventional

Group of TUG Test

Discussion

The purpose of the study is to find the effect of the Virtual reality in balance training for the patients with the sub-acute stroke. The study consisted of 2 groups, the experimental group, which received Virtual reality therapy and the conventional group, which received conventional exercise for balance training. Result showed that the experimental group showed significant improvement than conventional group in TUG TEST measures. The study method includes the experimental study design, recruiting 20 subjects diagnosed with sub-acute stroke, by convenient sampling method, the participants were randomly assigned to experimental group and the conventional group, with 10 subjects in each group. The duration of exposure of treatment for both the group was 4 days a week, a total of 3 weeks. The result was assessed using the functional balance scale and the TUG Test. Statistical analysis including paired t-test and unpaired t-test was used to assess the significance of differences between the two groups. The statistical analysis of the post test of both the group revealed the significant different between the two groups. The post-test of both experimental group and the conventional group, the experimental group shows slight improvement in balance.

Myung Mo Lee et al. (2018) – correlated that a randomized controlled clinical trial is the first to evaluate the effects of game-based virtual reality (VR) rowing training on postural balance and upper extremity function in subacute stroke patients. The results of this study suggest that adding game-based VR training to standard post-stroke rehabilitation programs may be more effective than traditional rehabilitation alone in improving postural balance and upper extremity function. Game-based VR training in a more realistic clinical setting can lead to significant therapeutic effects on stroke patients.[28]

Lohse KR et al. (2014) – correlated that Virtual reality therapy has a significant moderate advantage over CT in body function and activity outcomes. Research on participant outcomes is limited, but preliminary data show a positive benefit of Virtual Reality therapy compared to CT.[25]

Kim JH et al. (2009) – correlated that the randomized controlled trial showed that virtual reality combined with conventional physical therapy has an additive effect on balance and walking function in patients with chronic hemiparetic stroke.[26]

Conclusion

Stroke is among the most serious medical concerns of the public. In 1999, there were 5.54 million stroke deaths worldwide, 2.33 million of which happened in less developed nations, based on the World Health Organization (WHO). The most frequent neurological disorder that results in long-term disability and has a huge emotional and socioeconomic impact on patients. The study effect of Virtual reality for balance training in stroke patients, the pre-test and post-test of the experimental group shows a significant improvement of balance and in the conventional group, the comparison of the pre-test and the post-test shows a significant improvement in balance. Both the experimental group and the conventional group shows good improvement in the balance. While comparing the post-test values of both the experimental group and the conventional group, the experimental group shows a slight improvement in the balance than the conventional group and there is good improvement in the balance in the experimental group.

Reference

1. Prasad K, Singhal KK. Stroke in young: An Indian perspective. Neurology India. 2010 May 1;58(3):343-350.

2. Zhang B, Li D, Liu Y, Wang J, Xiao Q. Virtual reality for limb motor function, balance, gait, cognition and daily function of stroke patients: A systematic review and meta-analysis. Journal of advanced nursing. 2021 Aug;77(8):3255-3273.

3. Patel J, Fluet G, Qiu Q, Yarossi M, Merians A, Tunik E, Adamovich S. Intensive virtual reality and robotic based upper limb training compared to usual care, and associated cortical reorganization, in the acute and early sub-acute periods post-stroke: a feasibility study. Journal of neuro engineering and rehabilitation. 2019 Dec;16:1-2.

4. Chen L, Lo WL, Mao YR, Ding MH, Lin Q, Li H, Zhao JL, Xu ZQ, Bian RH, Huang DF. Effect of virtual reality on postural and balance control in patients with stroke: a systematic literature review. BioMed Research International. 2016 Dec 7;2016.

5. Hao J, Xie H, Harp K, Chen Z, Siu KC. Effects of virtual reality intervention on neural plasticity in stroke rehabilitation: a systematic review. Archives of Physical Medicine and Rehabilitation. 2022 Mar 1;103(3):523-541.

6. Laver KE, Lange B, George S, Deutsch JE, Saposnik G, Crotty M. Virtual reality for stroke rehabilitation. Cochrane database of systematic reviews. 2017(11).

7. Darekar A, McFadyen BJ, Lamontagne A, Fung J. Efficacy of virtual reality-based intervention on balance and mobility disorders post-stroke: a scoping review. Journal of neuro engineering and rehabilitation. 2015 Dec;12(1):1-4.

8. Rutkowski S, Kiper P, Cacciante L, Mazurek J, Turolla A. Use of virtual reality-based training in different fields of rehabilitation: A systematic review and meta-analysis. Journal of Rehabilitation Medicine. 2020 Nov 19;52(11):1-6.

9. Rutkowski S, Kiper P, Cacciante L, Mazurek J, Turolla A. Use of virtual reality-based training in different fields of rehabilitation: A systematic review and meta-analysis. Journal of Rehabilitation Medicine. 2020 Nov 19;52(11):1-6.

10. Vogt, S., Skjæret-Maroni, N., Neuhaus, D. and Baumeister, J., 2019. Virtual reality interventions for balance prevention and rehabilitation after musculoskeletal lower limb impairments in young up to middle-aged adults: A comprehensive review on used technology, balance outcome measures and observed effects. *International journal of medical informatics*, *126*, pp.46-58.

11. Rogers JM, Duckworth J, Middleton S, Steenbergen B, Wilson PH. Elements virtual rehabilitation improves motor, cognitive, and functional outcomes in adult stroke: evidence from a randomized controlled pilot study. Journal of neuro engineering and rehabilitation. 2019 Dec;16(1):1-3.

12. Cano Porras D, Sharon H, Inzelberg R, Ziv-Ner Y, Zeilig G, Plotnik M. Advanced virtual reality-based rehabilitation of balance and gait in clinical practice. Therapeutic advances in chronic disease. 2019 Aug;10:2040622319868379.

13. Chen L, Lo WL, Mao YR, Ding MH, Lin Q, Li H, Zhao JL, Xu ZQ, Bian RH, Huang DF. Effect of virtual reality on postural and balance control in patients with stroke: a systematic literature review. BioMed Research International. 2016 Dec 7;2016.

14. De Rooij IJ, Van De Port IG, Meijer JW. Effect of virtual reality training on balance and gait ability in patients with stroke: systematic review and meta-analysis. Physical therapy. 2016 Dec 1;96(12):1905-1918.

15. Laver K, George S, Thomas S, Deutsch JE, Crotty M. Cochrane review: virtual reality for stroke rehabilitation. European journal of physical and rehabilitation medicine. 2012 Jun 20;48(3):523-530.

16. Langhorne P, Coupar F, Pollock A. Motor recovery after stroke: a systematic review. The Lancet Neurology. 2009 Aug 1;8(8):741-754.

17. Pollock C, Eng J, Garland S. Clinical measurement of walking balance in people post stroke: a systematic review. Clinical rehabilitation. 2011 Aug;25(8):693-708.

18. Moreira MC, de Amorim Lima AM, Ferraz KM, Benedetti Rodrigues MA. Use of virtual reality in gait recovery among post stroke patients–a systematic literature review. Disability and Rehabilitation: Assistive Technology. 2013 Sep 1;8(5):357-362.

19. Michael KM, Allen JK, Macko RF. Reduced ambulatory activity after stroke: the role of balance, gait, and cardiovascular fitness. Archives of physical medicine and rehabilitation. 2005 Aug 1;86(8):1552-1556.

20. Imam B, Jarus T. Virtual reality rehabilitation from social cognitive and motor learning theoretical perspectives in stroke population. Rehabilitation research and practice. 2014 Jan 9;2014.

21. Saposnik G. Virtual reality in stroke rehabilitation. Ischemic Stroke Therapeutics: A Comprehensive Guide. 2016:225-233.

22. Yang S, Hwang WH, Tsai YC, Liu FK, Hsieh LF, Chern JS. Improving balance skills in patients who had stroke through virtual reality treadmill training. American journal of physical medicine & rehabilitation. 2011 Dec 1;90(12):969-978.

23. Pollock AS, Durward BR, Rowe PJ, Paul JP. What is balance ?. Clinical rehabilitation. 2000 Aug;14(4):402-406.

24. Tsang WW, Fu AS. Virtual reality exercise to improve balance control in older adults at risk of falling. Hong Kong Med J. 2016 Feb;22(22):S19-22.

25. Lohse KR, Hilderman CG, Cheung KL, Tatla S, Van der Loos HM. Virtual reality therapy for adults post-stroke: a systematic review and meta-analysis exploring virtual environments and commercial games in therapy. PloS one. 2014 Mar 28;9(3):e93318.

26. Kim JH, Jang SH, Kim CS, Jung JH, You JH. Use of virtual reality to enhance balance and ambulation in chronic stroke: a double-blind, randomized controlled study. American Journal of physical medicine & rehabilitation. 2009 Sep 1;88(9):693-701.

27. Kiper P, Szczudlik A, Mirek E, Nowobilski R, Opara J, Agostini M, Tonin P, Turolla A. The application of virtual reality in neurorehabilitation: motor re-learning supported by innovative technologies. Rehabilitation Medyczna. 2013;17(4):29-36.

28. Lee MM, Lee KJ, Song CH. Game-based virtual reality canoe paddling training to improve postural balance and upper extremity function: a preliminary randomized controlled study of 30 patients with subacute stroke. Medical science monitor: international medical journal of experimental and clinical research. 2018;24:2590-2598.

29. Kalron A, Fonkatz I, Frid L, Baransi H, Achiron A. The effect of balance training on postural control in people with multiple sclerosis using the CAREN virtual reality system: a pilot randomized controlled trial. Journal of neuro engineering and rehabilitation. 2016 Dec;13:1-10.

30. Chen, J., Or, C. K., Li, Z., Yeung, E. H. K., & Chen, T. (2025). Perceptions of Patients With Stroke Regarding an Immersive Virtual Reality–Based Exercise System for Upper Limb Rehabilitation: Questionnaire and Interview Study. JMIR Serious Games, 13(1), e49847.

31. Shannon, M. M., Lipson-Smith, R., Elf, M., White, M., Olver, J., Yang, T., & Bernhardt, J. (2025). Exploration of hospital room design on emotions, activity, and social connections after stroke: a qualitative study of patient experiences using virtual reality. Disability and Rehabilitation, 1-10.

32. Sauvage, C., Chaulet, P., Lopez, L. R., Garbusinski, J., Cabaraux, P., Duvigneaud, Z., & Baudry, S. (2025). Immersive virtual reality to assess unilateral spatial neglect in stroke patients: a preliminary study. Journal of Rehabilitation Medicine, 57, 41195.

33. Soleimani, M., Ghazisaeedi, M., & Heydari, S. (2024). The efficacy of virtual reality for upper limb rehabilitation in stroke patients: a systematic review and meta-analysis. BMC Medical Informatics and Decision Making, 24(1), 135.

34. Khan, A., Imam, Y. Z., Muneer, M., Al Jerdi, S., & Gill, S. K. (2024). Virtual reality in stroke recovery: a meta-review of systematic reviews. Bioelectronic Medicine, 10(1), 23.

35. Patsaki, I., Dimitriadi, N., Despoti, A., Tzoumi, D., Leventakis, N., Roussou, G., ... & Karatzanos, E. (2022). The effectiveness of immersive virtual reality in physical recovery of stroke patients: A systematic review. Frontiers in Systems Neuroscience, 16, 880447.