Effect of Balance Exercises with Smart Phone Based Virtual Reality Programme on Balance in Stroke Patients

Nihitha Siriguppa* and B. N. Prem Kumar

Department of Physiotherapy, Rajiv Gandhi University of Health Sciences, Bangalore, India

Abstract

Background and objectives: Stroke is a neurological deficit, caused due to vascular changes. Impaired postural control and balance impairments in post stroke patients associated with high risk of fall among the stroke patients. The perturbation-based balance training is mainly used in older adults and balance impairment. Virtual Reality (VR) as a novel technology is rapidly becoming a popular intervention for improving balance. VR can visualize the computer- generated environments with full field of view by Head Mounted Displays (HMD-VR). This study was conducted to assess and investigate the effect of balance exercises with smart phone based virtual reality programme on balance in stroke patients.

Method: This was a randomized single-group pre and post-test study design. 30 subjects met the inclusion criteria and were enrolled, assigned and received intervention. Subjects were given perturbation based balance exercise and smart phone based virtual reality along with conventional physiotherapy. Intervention protocol was for 6 days/week for 4 weeks period.

Results: Following 4 weeks of intervention showed improvement in postural control and balance which was assessed using BBS, TUG, VR BESS, BESTest and SIS 3.0. Paired t test was used to differentiate the mean significance. The mean pre to post intervention difference is 12.6 with P value<0.05. TUG score improved from pre to post intervention difference is 1.443 with P value <0.05. VR BESS score improved from pre to post intervention difference is 10.266 with P value <0.05. The mean BESTest pre to post intervention difference is 11.467 with P value <0.05. SIS 3.0 score improved from pre to post intervention difference is 20.33 with P value<0.05. The result of this study showed highly significant difference in pre and post treatment.

Conclusion: The study concludes that perturbation based balance exercises with smart phone based virtual reality programme is a useful adjunct on improving balance in stroke patients along with conventional physiotherapy.

Keywords: Postural control • Balance • Stroke • Perturbation based balance training • Smart phone based virtual reality • Virtual reality balance evaluation system test

Abbreviations: ADL: Activities of Daily Living; BBS: Berg Balance Scale; BESTest: Balance Evaluation System Test; H_O: Null Hypothesis; HMD: Head Mounted Device; H_a: Alternative Hypothesis; HRQoL: Health Related Quality of Life; MOCA: Montreal Cognitive Assessment; PBBT: Perturbation Based Balance Exercise; SPSS: Statistical Package of Social Sciences; SIS: Stroke Impact Scale; TUG: Timed Up and Go test; VR: Virtual Reality; VR BESS: Virtual Reality Balance Error Scoring System

Introduction

Stroke is classically characterized as a neurological deficit and also neurological emergency attributed to an acute focal injury of the Central Nervous System (CNS) by a vascular cause [1,2], including cerebral infarction, Intracerebral Haemorrhage (ICH) and Subarachnoid Haemorrhage (SAH) and is a major cause of disability and death worldwide [3,4].

WHO definition of stroke (introduced in 1970 and still used) is "rapidly developing clinical signs of focal (or global) disturbance of cerebral function, lasting more than 24 hours or leading to death [5,6], with no apparent cause other than that of vascular origin [7]. The recommended standard WHO Stroke definition is "a focal or global neurological impairment of sudden onset and lasting more than 24 hours or leading to death and of presumed vascular origin" [8,9].

Clinical features as per vascular territory are as follows: In anterior cerebral artery infarct paresis or weakness of legs more than arm with sparing of hands, urinary incontinence, gait apraxia, akinetic mutism are seen [10]. In middle cerebral artery infarct homonymous hemianopia, aphasia (Broca's and Wernicke's), inattention, gaze paralysis, pareses of face-arm-leg are seen [11,12]. In vertebrobasilar artery infarct if occipital lobe is involved then symptoms like homonymous hemianopia, cortical blindness and other cortical visual deficits are seen [13]. If cerebellum is involved then ataxia, nystagmus is seen. If brainstem is involved then cranial nerve palsies with diplopia, vertigo, dysphagia, dysphonia is seen [14,15].

If spinal tract is involved hemiparesis and hemisensory loss are seen. In lacunar stroke syndromes (due to occlusion of deep perforating small arteries) symptoms like pure motor hemiparesis, pure sensory stroke, sensorimotor stroke, ataxic hemiparesis is seen [16,17].

Balance is the capability of maintaining the body's centre of gravity within the base of support. Balance activity is mediated by three systems: biomechanical, neurological and sensory systems [18,19]. Motor, sensory and higher brain cognitive faculties to various degree, which leads to diminished balance, more postural sway, asymmetric weight distribution [20,21].

The novelty of perturbation training is in the focus on speed of processing and execution of limb movements [22,23], as well as rapid restabilization; this differs from 'traditional' balance training programs using voluntary movements that allow participants to control speed [24,25].

Virtual reality as a novel technology is rapidly becoming a popular intervention for improving balance and proliferated in the field of

neurorehabilitation [26,27]. Interactive multimedia technologies offer certain advantages over traditional rehabilitation treatments either due to accessibility issues, geography or treatment availability, providing motivational activities, therapeutic adherence and treatment compliance [28,29]. Immersive VR we can visualize the computer - generated environments with full field of view by Head Mounted Displays (HMD-VR). This immersive virtual environment which represents as real environment can be used in balance training in which it continues visual feedback [30,31].

Virtual reality can be described in I^3 terms:- INTERACTION+IMMERSION +IMAGINATION [32].

Conventional physical therapy based on activities of daily living skills include active assistive exercises for lower limb and upper limb, active exercises, functional retraining exercises, stretching, strengthening exercises, weight bearing exercises, weight shifting exercises, reaching exercises in sitting and standing, gait training [33,34].

Aim of the study

Aim of the study is to investigate the effect of balance exercises with smart phone based virtual reality programme on balance in stroke patients.

Research gap

There is no gap in knowledge or understanding of a subject. There is no lack of understanding of mechanisms behind disease and technology works.

Hypothesis

Null hypothesis: There may be no significant effects of balance exercises with smart phone based virtual reality programme on balance in stroke.

Alternate hypothesis: There may be significant effects of balance exercises with smart phone based virtual reality programme on balance in stroke.

Hence we accept alternative hypothesis and reject null hypothesis

Methodology

The purpose of the study is to investigate the effect of balance exercises with smart phone based virtual reality programme on balance in stroke patients.

Method of collection of data

Study design: Randomized single- group pre and post - test study design.

Sample size: 30

Sample design: Purposive sampling

Study duration: 12 months

Source of data

- Out-patient department and in-patient department of General Medicine in Kempegowda Institute of medical sciences hospital and research centre, Bengaluru.

- Out-patient department of physiotherapy in Kempegowda Institute of medical sciences hospital and research centre, Bengaluru.

- Out-patient department and inpatient department of neurology, neurosurgery in Kempegowda institute of medical science hospital and research centre, Bengaluru.

Sample size estimation

- Sample size of unknown population-SS_{ukp}

$$SS_{ukp} = \frac{z^2 \times p\,(1-p)}{e2}$$

- z value - cumulative normal frequency, z= 1.96

- p - power of confidence

- e - margin of error= 0.05 (type I error)

- Here, p = 95% i.e., 0.05

So

$$SS_{ukp} = \frac{(1.96^2) \times (0.05) \times (1-0.05)}{(0.05^2)}$$

$= 1.96 \times 1.96 \times 0.05 \times 380 = 72.990$

- SS_{ukp} = 245.6

- Sample size of known population - SS_{kp}

$$SS_{kp} = \frac{SS_{ukp}}{1 + (SS_{ukp}/N)}$$

- Here, N = Total number of patients per month= 2.5

$SSkp = 72.990 = 1+(72.990/2.5) = 2.417$

- SS_{kp} which is approximately equal to 5 Therefore, SS_{kp}=2.5 for one month

- Here, the study duration is 1 year (12 months) so, sample size=12 × 2.417=29.004 ≈ 30

- Therefore, total sample size = 30

Selection criteria

Inclusion criteria:

- Patients with Ischemic stroke diagnosed with a CT scan.

- Stroke within 45 days.

- A score of 26 points or higher of the Montreal cognitive assessment

- Both genders included.

- Subjects who are willing to participate, who have been explained and signed the written informed consent.

Exclusion criteria:

- Subjects with Perceptual cognitive deficits like hemi spatial neglect, attention and memory deficit.

- Subjects with Spinal and lower extremity deformity

- Subjects with Terminal illness or medically unstable

Materials used

- Smart phone

- Virtual reality- IRUSU MINI

- IN CELL (game app)

- Firm mattress

- Foam mattress

- Stop watch

- Measuring tape

- Arm rest Chair

- Cones / markers

The subject included will be explained about the intervention in the language understood by the subject / family members. A signed informed consent will be obtained in subjects/family own understandable language (Figure 1).
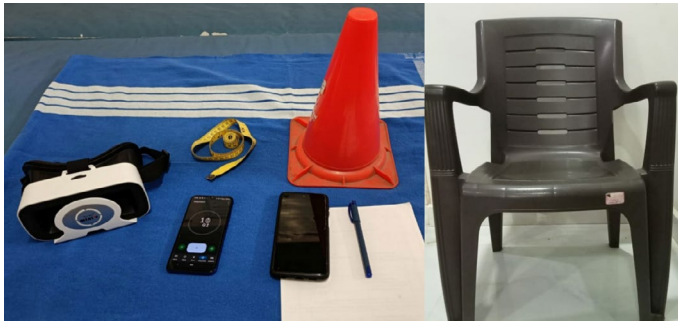
Figure 1. Materials used.

Data analysis

Descriptive and inferential statistical analysis has been carried out in the present study. Results on continuous measurements are presented on Mean ± SD (Min-Max) and results on categorical measurements are presented in Number (%). Significance is assessed at 5% level of significance (Table 1).

The following are the assumptions of the data;

- Dependent variables should be normally distributed,
- Samples drawn from the population should be random; Cases of the samples should be independent.

Statistical software: The Statistical software namely SPSS is used for the analysis of the data and Microsoft word and Excel have been used to generate graphs, tables etc.

Outcome measures

The Montreal Cognitive Assessment (MoCA) is a tool that can be used to systematically and thoroughly assess cognitive and mental status. It is a 1-page, 30-point test, administrable in ≈10minutes, which evaluates different domains: visuospatial abilities, executive functions, short-term memory recall, attention, concentration, working memory, language and orientation to time and space. The total possible score is 30, a score of 26 or above is considered as normal.

The Berg Balance Scale (BBS) was originally designed to quantitatively assess balance. The BBS is a 14 items scale that quantitatively assesses balance and risk for falls [35,36]. The scale requires 10 to 20 minutes to complete and measures the patient's ability to maintain balance either statically or while performing various functional movements- for a specified duration of time. The BBS measures both static and dynamic aspects of balance [37,38].

The Timed up and Go test (TUG) is an objective clinical measure for assessing functional mobility and balance and thus the risk of falling [39,40]. The TUG measures the time taken for an individual to rise from chair, walk 3 meters, turn walk back and sit down using regular footwear and a walking aid if required [41,42]. Subjects are asked to stand up from a standard chair with a height of between 40 and 50 cm, walk a 3m distance at a normal pace, turn, walk back to the chair and sit down [43,44].

The Virtual Reality Balance Error Scoring System (VR-BESS) has improved the capability to detect lingering neurological and balance deficits [45,46]. This involved 3 minutes of sitting followed by 3 minutes of standing while wearing the VR headset and experiencing the rollercoaster stimulus attempting to maintain balance in two-leg, single-leg, or tandem stance on both foam and firm surface for 20 seconds in each stance (Figure 2).

The Balance Evaluation System Test (BESTest) is a new tool that assesses different balance systems including biomechanical constraints, stability limits/verticality, anticipatory postural adjustments, postural responses, sensory orientation and gait stability [47,48]. It is divided into 27 tasks and 6 subgroups, each item is scored on a 4-level, ordinal scale from 0 (worst performance) to 3 (best performance). The total score for the test is 108 points.

The Stroke Impact Scale (SIS) 3.0 assesses 59 items of a patient's quality of life, divided into eight dimensions where a stroke has an overall effect on health and well-being [49,50]. After SIS is administered, the respondent is asked to rate their percent recovery since their stroke on visual analogue scale of 0 to 100 with 0 meaning no recovery & 100 meaning full recovery.

Intervention

Perturbation based balance training:

- Perturbations were given in the sitting position on a couch and standing positions, with 10 sec hold, 10 perturbations in each position, 5 minutes.

Table 1. Data.

Sl.no	Age	Gender	Berg Balance Scale (BBS)		Timed Up and Go Test (TUG)		Virtual Reality Balance Error Scoring System (VR-BESS)		Balance Evaluation System Test (BESTEST)		Stroke Impact Scale (SIS 3.0)	
			Day 1	Day 4th week	Day 1	Day 4th week	Day 1	Day 4th week	Day 1	Day 4th week	Day 1	Day 4th week
1	51	Male	31	48	13	10.93	31	20	80	93	30%	75%
2	55	Male	26	44	16.8	13	29	11	69	84	60%	75%
3	43	Male	36	45	12.14	17	30	19	75	83	75%	80%
4	66	Male	24	40	16	13	32	26	69	77	60%	75%
5	50	Male	33	43	17.12	13	33	29	64	76	40%	65%
6	55	Male	49	54	16.12	12	36	26	58	73	50%	75%
7	50	Female	36	45	12.14	17	30	19	75	83	75%	80%
8	66	Male	24	40	16	13	32	26	69	77	60%	75%
9	67	Male	36	45	12.14	17	30	19	75	83	75%	80%
10	74	Female	36	45	12.14	17	30	19	75	83	75%	80%
11	55	Male	26	44	16.8	13	29	11	69	84	60%	75%
12	75	Male	36	45	12.14	17	30	19	75	83	75%	80%
13	60	Female	36	45	12.14	17	30	19	75	83	75%	80%
14	66	Male	24	40	16	13	32	26	69	77	60%	75%
15	42	Male	36	45	12.14	17	30	19	75	83	75%	80%
16	51	Male	31	48	13	10.93	31	20	80	93	30%	75%
17	55	Male	26	44	16.8	13	29	11	69	84	60%	75%
18	50	Male	33	43	17.12	13	33	29	64	76	40%	65%
19	55	Male	49	54	16.12	12	36	26	58	73	50%	75%
20	51	Male	31	48	13	10.93	31	20	80	93	30%	75%
21	66	Male	24	40	16	13	32	26	69	77	60%	75%
22	50	Male	33	43	17.12	13	33	29	64	76	40%	65%
23	55	Male	49	54	16.12	12	36	26	58	73	50%	75%
24	51	Male	31	48	13	10.93	31	20	80	93	30%	75%
25	55	Male	26	44	16.8	13	29	11	69	84	60%	75%
26	50	Male	33	43	17.12	13	33	29	64	76	40%	65%
27	55	Male	49	54	16.12	12	36	26	58	73	50%	75%
28	51	Male	31	48	13	10.93	31	20	80	93	30%	75%
29	55	Male	26	44	16.8	13	29	11	69	84	60%	75%
30	66	Male	24	40	16	13	32	26	69	77	60%	75%

Figure 2. Virtual reality balance error scoring system.

• Perturbations were given in both right and left sideways forward and backward directions in sitting and standing.

• Perturbations were given at the shoulder, trunk and waist region (Figure 3).

Smartphone based virtual reality training:

• The therapist explains the neurorehabilitation program based on perturbation based balance exercise with head mounted display virtual reality (IRUSU MINI) with smart phone enclosed in it with the game "IN CEEL VR" and demonstrates the game through showing screen recording how to play (Figure 4).

• IN CELL VR game is an action racing VR game with a bit of strategy and science thrown into the mix. It will take an exciting journey inside the highly unusual micro world of human cell and stop the virus advance [51,52].

• IN CELL VR game that has specific tasks like hitting the proteins and avoiding the viruses. The subject had to hit the protein and avoiding the viruses, which is done in standing position [53].

Results and Discussion

Interpretations

Above table and graphs shows the mean and standard deviation of age. Subjects studied as mean of 56.367 and standard deviation of 8.29 (Table 2) (Figure 5).

Interpretation: Using t-statistics and a 5% level of significance. The critical value for the test with df=29 and alpha=0.05 is 2.045 and the decision rule is to reject null if the t-value is greater than are equal to 2.045. i.e., calculated value ≥ critical value.

Figure 3. Perturbation based balance training.

Figure 4. Smartphone based virtual reality training.

Table 2. Assessment of age.

Missing	0
Mean	56.367
Standard Deviation	8.2982
Range	33
Minimum	42
Maximum	75

• Calculated value = 14.586 and critical value=2.045.

• Hence, we reject null (H_0) because 14.586 ≥ 2.045 and p<0.05. We have statistically significant evidence at alpha=0.05 to show there is a difference in the mean of the Berg Balance Scale on day 1 and the day 4th week.

• The result showed a significant difference in Berg balance scale scores within the group (p=0.00). Hence, we reject the null hypothesis and accept the alternative hypothesis that smart phone based virtual reality balance training with perturbation based balance training has a significant effect on stroke (Table 3).

Interpretation: Using t-statistics and a 5% level of significance. The critical value for the test with degree of freedom=29 and alpha=0.05 is 2.045 and the decision rule is to Reject null if the t-value is greater than are equal to 2.045. i.e., calculated value ≥ critical value.

• Calculated value = 2.191 and critical value = 2.045.

• Hence, we reject null (H_0) because 2.191 ≥ 2.045 and p<0.05. We have statistically significant evidence at alpha=0.05 to show there is a difference in the mean of the Timed up and Go test on day 1 and the day 4th week.

• The result showed a significant difference in Timed up and go test scores within the group (p=0.037). Hence, we reject the null hypothesis and accept the alternative hypothesis smart phone based virtual reality balance training with perturbation based balance training has a significant effect on stroke (Table 4).

Interpretation: Using t-statistics and a 5% level of significance. The critical value for the test with degree of freedom=29 and alpha=0.05 is 2.045 and the decision rule is to Reject null if the t-value is greater than are equal to 2.045. i.e., calculated value ≥ critical value.

• Calculated value=12.867 and critical value=2.045.

• Hence, we reject null (H_0) because 12.867 ≥ 2.045and p<0.05. We have statistically significant evidence at alpha=0.05 to show there is a difference in the mean of the virtual reality balance error scoring system on day 1 and the day 4th week.

• The result showed a significant difference in Virtual reality balance error scoring system scores within the group (p=0.00). Hence, we reject the null hypothesis and accept the alternative hypothesis that
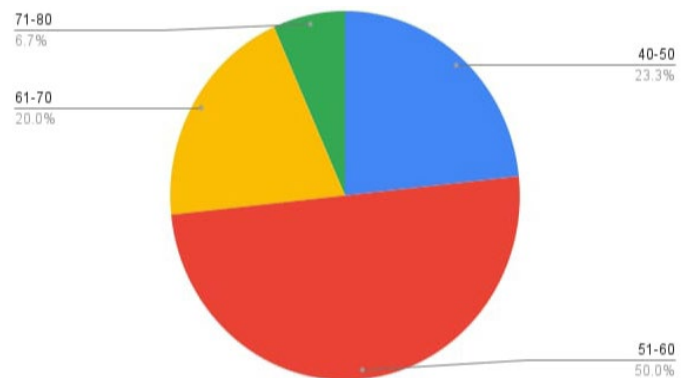

Figure 5. Count of age category.

Table 3. An assessment of Berg Balance Scale (BBS) variables at pre and post measurements of patients.

Variables		Mean	Std. Deviation
BBS	Pre-score	32.833	7.7819
	Post-score	45.433	4.191
	Difference	12.6	3.5909
P value (within the group) - paired t test	<0.05** (t= -14.586)		

smart phone based virtual reality balance training with perturbation based balance training has a significant effect on stroke (Table 5).

Interpretation: Using t-statistics and a 5% level of significance. The critical value for the test with df=29 and alpha=0.05 is 2.045 and the decision rule is to Reject null if the t-value is greater than are equal to 2.045. i.e., calculated value ≥ critical value.

- Calculated value = 20.604 and critical value=2.045.

- Hence, we reject null (H_0) because 20.604≥ 2.045and p<0.05. We have statistically significant evidence at alpha=0.05 to show there is a difference in the mean of the Balance evaluation system test on day 1 and the day 4th week.

- The result showed a significant difference in Balance evaluation system Test scores within the group (p=0.00). Hence, we reject the null hypothesis and accept the alternative hypothesis that smart phone based virtual reality training with perturbation based balance training has a significant effect on stroke (Table 6).

Interpretation: Using t-statistics and a 5% level of significance. The critical value for the test with degree of freedom=29 and alpha=0.05 is 2.045 and the decision rule is to Reject null if the t-value is greater than are equal to 2.045. i.e., calculated value ≥ critical value.

- Calculated value=8.36 and critical value=2.045.

- Hence, we reject null (H_0) because 8.36 ≥ 2.045and p<0.05. We have statistically significant evidence at alpha=0.05 to show there is a difference in the mean of the Stroke impact on day 1 and the day 4th week.

- The result showed a significant difference in SIS scores within the group (p=0.00). Hence, we reject the null hypothesis and accept the alternative hypothesis that smart phone based virtual reality balance training with perturbation based balance training has a significant effect on stroke (Table 7).

Table 4. An assessment of Timed Up and Go test variables (TUG) at pre and post measurements of patients.

Variables		Mean	Std. Deviation
TUG	Pre-score	14.898	2.04383
	Post-score	13.455	2.12711
	Difference	1.443	0.08328
P value (within the group) - paired t test		<0.05** (t=2.191)	

Table 5. An assessment of Virtual Reality Balance Error Scoring System (VR BESS) variables at pre and post measurements of patients.

Variables		Mean	Std. Deviation
VR BESS	Pre-score	31.533	2.193
	Post-score	21.267	5.9069
	Difference	10.266	3.7139
P value (within the group) - paired t test		<0.05** (t=12.867)	

Table 6. An assessment of Balance Evaluation System Test (BEST TEST) variables at pre and post measurement of patients.

Variables		Mean	Std. Deviation
BEST TEST	Pre-score	70.1	6.9597
	Post-score	81.567	6.4844
	Difference	11.467	0.4753
P value (within the group) - paired t test		<0.05** (t=-20.604)	

Table 7. An assessment of Stroke Impact Scale (SIS) variable at pre and post measurements of patients.

Variables		Mean	Std. Deviation
SIS	Pre-score	54.50%	15.72%
	Post-score	74.83%	4.45%
	Difference	20.33	11.27
P value (within group) - paired t test		<0.05** (t=-8.36)	

Limitations of the study

- Sample size was small, limited the generalizability of the results.

- The age group was kept wide due to unavailability of sample size.

- Only sub-acute stroke patients were included.

- Study duration was short i.e., only for 4 weeks.

- The study analysed only the short term benefits with respect to mobility, balance and function only.

Future scope and suggestions

- Future clinical trial study can be carried out on a large sample size.

- A similar study can be conducted in patients with different neurological conditions like Parkinson's, cerebral palsy.

- In present study improvement in balance, postural control was seen in sub-acute stroke patients, so future study can also be done to see the effect of perturbation based balance training on all phases of stroke patients i.e., in acute and chronic.

- Further studies are needed to investigate the long term effects of mobile based virtual reality programme along with conventional physiotherapy treatment on balance, postural control.

Conclusion

Stroke is the leading cause of disability and frequent falling is one of the complications of post stroke. Impaired postural control and balance is associated with high incidence of falling in stroke. Incidence of fall in stroke, hence balance exercises are essential.

This study was conducted to find the effect of perturbation based balance exercise with smart phone based virtual reality along with conventional physiotherapy. After four weeks of intervention, Berg Balance Scale (BBS), Timed up and Go test (TUG), Virtual Reality Balance Error Scoring System (VR BESS), Balance Evaluation System Test (BESTest), Stroke Impact Scale 3.0 (SIS 3.0) were used to analyze the data, results of data analysis showed significant improvement in lower extremity function, balance, gait speed, functional ability, postural stability, muscular coordination, mobility and fall risk.

The findings provide a new paradigm of training guidelines for balance control and can reduce the risk of falling. This perturbation based balance training with smart phone based virtual reality program appears to be feasible and effective for improving balance after ischemic stroke. The findings from our study are clinically important, as they provide an innovative method for the treatment of stroke patients with an efficient, safe and low-cost program.

References

1. Sacco, Ralph L., Scott E. Kasner, Joseph P. Broderick and Louis R. Caplan, et al. "An updated definition of stroke for the 21st century: A statement for healthcare professionals from the American Heart Association/American Stroke Association." *Stroke* 44 (2013): 2064-2089.

2. Komlodi-Pasztor, Edina, Mark R. Gilbert and Terri S. Armstrong. "Diagnosis and management of stroke in adults with primary brain tumor." *Curr Oncol Rep* 24 (2022): 1251-1259.

3. Coupland, Alexander P., Ankur Thapar, Mahim I. Qureshi and Harri Jenkins, et al. "The definition of stroke." *J R Soc Med* 110 (2017): 9-12.

4. Truelsen, Thomas, Stephen Begg and Colin Mathers. "The global burden of cerebrovascular." WHO (2006).

5. Kamalakannan, Sureshkumar, Aashrai SV Gudlavalleti, Venkata S. Murthy Gudlavalleti and Shifalika Goenka, et al. "Incidence & prevalence of stroke in India: A systematic review." *Indian J Med Res* 146 (2017): 175.

6. Avan, Abolfazl, Hadi Digaleh, Mario Di Napoli and Saverio Stranges, et al. "Socioeconomic status and stroke incidence, prevalence, mortality and worldwide burden: An ecological analysis from the Global Burden of Disease Study 2017." *BMC Med* 17 (2019): 1-30.

7. Kuriakose, Diji and Zhicheng Xiao. "Pathophysiology and treatment of stroke: Present status and future perspectives." *Int J Mol Sci* 21 (2020): 7609.

8. Martin, Suzanne Tink and Mary Kessler. "Neurologic interventions for physical therapy-e-book." *Elsevier Sci* (2020).

9. Smajlović, Dževdet. "Strokes in young adults: Epidemiology and prevention." *Vasc Health Risk Manag* (2015): 157-164.

10. Patten, Carolynn, Jan Lexell and Heather E. Brown. "Weakness and strength training in persons with poststroke hemiplegia: Rationale, method and efficacy." *J Rehabil Res Dev* 41 (2004).

11. Choi, Hea Lim, Kyojin Yang, Kyungdo Han and Bongsung Kim, et al. "Increased risk of developing depression in disability after stroke: A Korean nationwide study." *Int J Environ Res Public Health* 20 (2023): 842.

12. https://www.deccanherald.com/india/karnataka/prevalence-of-stroke-in-ktaka-higher-than-national-average-1008770.html

13. Won, Sang Hee, Jae Cheol Kim and Duck-Won Oh. "Effects of a novel walking training program with postural correction and visual feedback on walking function in patients with post-stroke hemiparesis." *J Phys Ther Sci* 27 (2015): 2581-2583.

14. Navarro-Orozco, Daniel and Juan Carlos Sánchez-Manso. "Neuroanatomy, middle cerebral artery." (2018).

15. Bernhardt, Julie, Kathryn S. Hayward, Gert Kwakkel and Nick S. Ward, et al. "Agreed definitions and a shared vision for new standards in stroke recovery research: The stroke recovery and rehabilitation roundtable taskforce." *Int J Stroke* 12 (2017): 444-450.

16. Lennon, Sheila, Gita Ramdharry and Geert Verheyden. "Physical management for neurological conditions e-book." *Elsevier Sci* (2018).

17. Woodruff, Trent M., John Thundyil, Sung-Chun Tang and Christopher G. Sobey, et al. "Pathophysiology, treatment and animal and cellular models of human ischemic stroke." *Mol Neurodegener* 6 (2011): 1-19.

18. Murphy, Stephen JX and David J. Werring. "Stroke: Causes and clinical features." *Med* 48 (2020): 561-566.

19. Gund, B. M., P. N. Jagtap, V. B. Ingale and R. Y. Patil. "Stroke: A brain attack." *IOSR J Pharm* 3 (2013): 1-23.

20. Li, Juan, Dongling Zhong, Jing Ye and Mingxing He, et al. "Rehabilitation for balance impairment in patients after stroke: A protocol of a systematic review and network meta-analysis." *BMJ Open* 9 (2019): e026844.

21. Lee, Kyeongjin. "Speed-interactive pedaling training using smartphone virtual reality application for stroke patients: Single-blinded, randomized clinical trial." *Brain Sci* 9 (2019): 295.

22. Liu, Chang, Jill L. McNitt-Gray and James M. Finley. "Impairments in the mechanical effectiveness of reactive balance control strategies during walking in people post-stroke." *Front Neurol* 13 (2022): 1032417.

23. Mansfield, Avril, Anthony Aqui, Andrew Centen and Cynthia J. Danells, et al. "Perturbation training to promote safe independent mobility post-stroke: Study protocol for a randomized controlled trial." *BMC Neurol* 15 (2015): 1-10.

24. Kumar, Chandan and N. Pathan. "Effectiveness of manual perturbation exercises in improving balance, function and mobility in stroke patients: A randomized controlled trial." *J Nov Physiother* 6 (2016): 2.

25. Inness, Elizabeth L., Avril Mansfield, Bimal Lakhani and Mark Bayley, et al. "Impaired reactive stepping among patients ready for discharge from inpatient stroke rehabilitation." *Phys Ther* 94 (2014): 1755-1764.

26. Handelzalts, Shirley, Michal Kenner-Furman, Ganit Gray and Nachum Soroker, et al. "Effects of perturbation-based balance training in subacute persons with stroke: A randomized controlled trial." *Neurorehabil Neural Repair* 33 (2019): 213-224.

27. Kancherlapalli, Ooha, P. Thulasi, Patchava Apparao and P. Prakash, et al. "Effectiveness of mobile based virtual reality training on improving balance in elderly population." *Eur J Pharm Med Res* 8 (2021): 369-378.

28. Marques-Sule, Elena, Anna Arnal-Gómez, Gloria Buitrago-Jiménez and Luis Suso-Martí, et al. "Effectiveness of Nintendo Wii and physical therapy in functionality, balance and daily activities in chronic stroke patients." *J Am Med Dir Assoc* 22 (2021): 1073-1080.

29. Huygelier, Hanne, Brenda Schraepen, Raymond Van Ee and Vero Vanden Abeele, et al. "Acceptance of immersive head-mounted virtual reality in older adults." *Sci Rep* 9 (2019): 4519.

30. Hao, Jie, Haoyu Xie, Kimberly Harp and Zhen Chen, et al. "Effects of virtual reality intervention on neural plasticity in stroke rehabilitation: A systematic review." *Arch Phys Med Rehabil* 103 (2022): 523-541.

31. Li, Zhen, Xiu-Guo Han, Jing Sheng and Shao-Jun Ma. "Virtual reality for improving balance in patients after stroke: A systematic review and meta-analysis." *Clin Rehabil* 30 (2016): 432-440.

32. Kamińska, Magdalena Sylwia, Agnieszka Miller, Iwona Rotter and Aleksandra Szylińska, et al. "The effectiveness of virtual reality training in reducing the risk of falls among elderly people." *Clin Interv Aging* (2018): 2329-2338.

33. Truijen, Steven, Auwal Abdullahi, Danique Bijsterbosch and Eline Van Zoest, et al. "Effect of home-based virtual reality training and telerehabilitation on balance in individuals with Parkinson disease, multiple sclerosis and stroke: A systematic review and meta-analysis." *Neurol Sci* 43 (2022): 2995-3006.

34. Ortiz Gutierrez, Rosa, Fernando Galan del Rio, Roberto Cano de la Cuerda and Isabel M. Alguacil-Diego, et al. "A telerehabilitation program by virtual reality-video games improves balance and postural control in multiple sclerosis patients." *NeuroRehabil* 33 (2013): 545-554.

35. Pintado-Izquierdo, Silvia, Roberto Cano-de-la-Cuerda and Rosa María Ortiz-Gutiérrez. "Video game-based therapy on balance and gait of patients with stroke: A systematic review." *Appl Sci* 10 (2020): 6426.

36. Shin, Doo Chul and Chang Ho Song. "Smartphone-based visual feedback trunk control training using a gyroscope and mirroring technology for stroke patients: Single-blinded, randomized clinical trial of efficacy and feasibility." *Am J Phys Med Rehabil* 95 (2016): 319-329.

37. Lee, Myung Mo, Kyeong Jin Lee and Chang Ho Song. "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." *Med Sci Monit* 24 (2018): 2590.

38. Lin, Ruei-Ching, Shang-Lin Chiang, Margaret McLean Heitkemper and Shu-Min Weng, et al. "Effectiveness of early rehabilitation combined with virtual reality training on muscle strength, mood state, and functional status in patients with acute stroke: A randomized controlled trial." *Worldviews Evid Based Nurs* 17 (2020): 158-167.

39. Iqbal, Muhammad, Aatik Arsh, Syed Muhammad Hammad and Ijaz Ul Haq, et al. "Comparison of dual task specific training and conventional physical therapy in ambulation of hemiplegic stroke patients: A randomized controlled trial." JPMA 2019 (2020).

40. Suda, Satoshi, Kanako Muraga, Akiko Ishiwata and Takuya Nishimura, et al. "Early cognitive assessment following acute stroke: Feasibility and comparison between mini-mental state examination and montreal cognitive assessment." *J Stroke Cerebrovasc Dis* 29 (2020): 104688.

41. Dautzenberg, Géraud, Jeroen Lijmer and Aartjan Beekman. "Clinical value of the Montreal Cognitive Assessment (MoCA) in patients suspected of cognitive impairment in old age psychiatry. Using the MoCA for triaging to a memory clinic." *Cogn Neuropsychiatry* 26 (2021): 1-17.

42. Blum, Lisa and Nicol Korner-Bitensky. "Usefulness of the berg balance scale in stroke rehabilitation: A systematic review." *Phys Ther* 88 (2008): 559-566.

43. Miranda-Cantellops, Natalia and Timothy K. Tiu. "Berg balance testing." (2021).

44. Hafsteinsdottir, Thora B., Marijke Rensink and Marieke Schuurmans. "Clinimetric properties of the timed up and go test for patients with stroke: A systematic review." *Top Stroke Rehabil* 21 (2014): 197-210.

45. Rausch, Matthew, Janet E. Simon, Chad Starkey and Dustin R. Grooms. "Smartphone virtual reality to increase clinical balance assessment responsiveness." *Phys Ther Sport* 32 (2018): 207-211.

46. Chinsongkram, Butsara, Nithinun Chaikeeree, Vitoon Saengsirisuwan and Fay B. Horak, et al. "Responsiveness of the Balance Evaluation Systems Test (BESTest) in people with subacute stroke." *Phys ther* 96 (2016): 1638-1647.

47. Sahin, Ilknur Ezgi, Arzu Guclu-Gunduz, Gokhan Yazici and Cagla Ozkul, et al. "The sensitivity and specificity of the Balance Evaluation Systems Test-BESTest in determining risk of fall in stroke patients." *NeuroRehabilitation* 44 (2019): 67-77.

48. Almalki, Obaid, Mansour Abdullah Alshehri, Amir Abdel-Raouf El-Fiky and Ashraf AM Abdelaal, et al. "Can the stroke impact scale 3.0 detect cognitive impairments in patients with a recent stroke?." *J Phys Ther Sci* 31 (2019): 563-568.

49. Vellone, Ercole, Serenella Savini, Roberta Fida and Victoria Vaughan Dickson, et al. "Psychometric evaluation of the stroke impact scale 3.0." *J Cardiovasc Nurs* 30 (2015): 229-241.

50. Prakash, V., Mohan Ganesan, R. Vasanthan and K. Hariohm. "Do commonly used functional outcome measures capture activities that are relevant for people with stroke in India?." *Top Stroke Rehabil* 24 (2017): 200-205.

51. Cheng, Yi-Shan, Andy Chien, Dar-Ming Lai and Ya-Yun Lee, et al. "Perturbation-based balance training in postoperative individuals with degenerative cervical myelopathy." *Front Bioeng Biotechnol* 8 (2020): 108.

52. Iruthayarajah, Jerome, Amanda McIntyre, Andreea Cotoi and Steven Macaluso, et al. "The use of virtual reality for balance among individuals with chronic stroke: A systematic review and meta-analysis." *Top Stroke Rehabil* 24 (2017): 68-79.

53. Fritz, Stacy L., Denise M. Peters, Angela M. Merlo and Jonathan Donley. "Active video-gaming effects on balance and mobility in individuals with chronic stroke: A randomized controlled trial." *Top Stroke Rehabil* 20 (2013): 218-225.