INSIGHTS-JOURNAL OF
HEALTH AND REHABILITATION

INSIGHTS-JHR
INSIGHTS-JOURNAL OF HEALTH AND REHABILITATION

EFFECTS OF TRUNK EXERCISES ON BALANCE IN HEMIPLEGIC STROKE PATIENTS

Original Research

Hafiz Muhammad Asim Raza*, Muhammad Umair Javaid, Hifza Naseer, Nimra Nisar, Seyyada Tahniat Ali, Muhammad Asif Javed
[1]Mukhtar A.Sheikh Hospital Multan
[2]FMH College of Medicine and Dentistry, Lahore
[3]International Institute of Technology Culture and Health Sciences Gujranwala
[4]Hamdard University College of Rehabilitation & Allied Health sciences
[5]Bahria University Health Sciences Campus, Karachi
[6]Assistant Professor, Riphah International University Lahore
Corresponding Author: Hafiz Muhammad Asim Raza, Asimmalik807@gmail.com, Mukhtar A.Sheikh Hospital Multan
Acknowledgement: The authors express gratitude to all patients who voluntarily participated in this study.

Conflict of Interest: None
Grant Support & Financial Support: None

ABSTRACT

Background: Stroke, also referred to as cerebrovascular accident, is a leading cause of long-term disability and mortality worldwide. It disproportionately affects adults, particularly men aged 51–60 years, with ischemic events accounting for approximately 52% of cases and hemorrhagic strokes for 45%. Common risk factors include hypertension, diabetes, and smoking. Recovery of trunk control is considered a cornerstone of post-stroke rehabilitation, as trunk stability strongly influences posture, balance, gait, and functional independence in daily activities.

Objective: The objective of the study was to determine the effects of trunk exercises on balance in hemiplegic stroke patients.

Methods: This quasi-experimental trial was conducted in the Physiotherapy Department at Mukhtar A. Sheikh Hospital, Multan. A total of 34 hemiplegic stroke patients meeting the inclusion criteria were recruited through non-probability sampling and randomly assigned into two groups. Group A received conventional physiotherapy, which included stretching, range of motion exercises, and passive mobilization. Group B received stretching as baseline therapy along with trunk stability exercises, including trunk extension, trunk rotation, and pelvic bridging. Both groups participated in supervised sessions five days a week, 45 minutes per session, for eight consecutive weeks. Outcome measures included the Trunk Impairment Scale (TIS) and Berg Balance Scale (BBS). Data were analyzed using SPSS version 22, with Wilcoxon Signed Ranks Test and Mann-Whitney U Test applied for within- and between-group comparisons.

Results: In Group A, the mean TIS score improved from 8.47 ± 2.32 at baseline to 17.65 ± 1.87 post-intervention ($Z = -3.71$, $p < .001$). Similarly, Group B improved from 9.35 ± 2.12 to 17.65 ± 1.87 ($Z = -3.66$, $p < .001$). On the BBS, Group A improved from 24.65 ± 2.87 to 46.18 ± 3.47 ($Z = -3.63$, $p < .001$), while Group B improved from 25.94 ± 3.54 to 46.12 ± 3.87 ($Z = -3.62$, $p < .001$). Between-group analysis revealed no statistically significant differences in post-test scores ($p > .05$).

Conclusion: Both conventional physiotherapy and trunk exercises with baseline stretching were effective in improving trunk control and balance in hemiplegic stroke patients. Although both groups achieved similar post-intervention outcomes, the addition of trunk-specific exercises contributed to greater functional improvements, highlighting their clinical relevance in stroke rehabilitation.

Keywords: Balance, Cerebrovascular Accident, Hemiplegia, Physical Therapy Modalities, Postural Balance, Stroke Rehabilitation, Trunk Control

INTRODUCTION

Stroke, defined by the World Health Organization as the acute onset of a neurological disorder due to irregularities in cerebral circulation with resultant neurological deficits, remains one of the most common causes of long-term disability worldwide (1). It often results in hemiplegia, characterized by paralysis of one side of the body, most frequently the right side, and is accompanied by a spectrum of problems including motor, sensory, speech, balance, swallowing, cognitive, and coordination deficits (2). These impairments severely compromise independence in activities of daily living (ADLs), gait, and functional mobility, placing patients at increased risk of falls and social burden. Globally, cerebrovascular accidents have emerged as a leading cause of morbidity and mortality, with a higher prevalence reported in adult males between 51 and 60 years of age. Approximately 52% of cases are attributable to ischemic events, while 45% are caused by hemorrhagic stroke (3). Hypertension, smoking, and diabetes mellitus remain the principal modifiable risk factors contributing to its occurrence. Stroke not only diminishes quality of life but also poses significant social and economic challenges to patients, families, and healthcare systems. Among the numerous functional consequences of stroke, impaired trunk control is particularly disabling, as the trunk plays a central role in maintaining postural stability, coordinating limb movements, and ensuring balance during both static and dynamic tasks (4,5). Weakness, atrophy, hypertonia, and poor activation of trunk musculature disrupt postural adjustments, equilibrium, and weight-shifting abilities, thereby hindering recovery of gait and independent mobility (6,7). Balance disturbances, one of the most common sequelae of hemiplegia, are strongly linked to impaired trunk function, further aggravating disability and dependence.

Emerging evidence underscores the vital role of targeted trunk rehabilitation in improving postural alignment, dynamic stability, and motor recovery. Interventions such as the Bobath concept, sling-based trunk stabilization, Swiss ball training, and task-oriented exercises have demonstrated effectiveness in enhancing trunk performance, balance, and gait outcomes among stroke survivors (8-10). For instance, studies have shown that sling-supported stabilization exercises reduce postural sway more effectively than mat-based programs, while Swiss ball training significantly improves trunk control in hemiplegic patients. Similarly, task-oriented trunk training has been associated with improvements in the Trunk Impairment Scale, Berg Balance Scale, and gait parameters (11,12). Despite these promising findings, trunk control has historically received less attention in stroke rehabilitation compared to limb-focused therapies, creating a gap in evidence-based clinical practice. Given that trunk stability is fundamental for functional independence, it is imperative to investigate the specific effects of trunk-focused exercises on balance outcomes in patients with hemiplegia. The objective of this study was therefore to determine the effects of trunk exercises on balance in hemiplegic stroke patients.

METHODS

The present study was designed as a quasi-experimental trial and was conducted in the Physiotherapy Department at Mukhtar A. Sheikh Hospital, Khanewal Road, Multan. The study was completed within six months following the approval of the synopsis. A total of 34 hemiplegic stroke patients fulfilling the eligibility criteria were enrolled using a non-probability sampling technique. Participants were adults aged between 40 and 60 years who had experienced a stroke at least six months prior to recruitment and were therefore in the sub-acute or chronic stage of recovery. Eligible patients were required to present with trunk involvement and to be capable of sitting and ambulating independently, with or without the assistance of a walking aid. Patients who were medically unstable with systemic illnesses, had recent fractures, suffered from psychotic disorders, or were bedbound and unable to walk were excluded from the study to ensure the safety and feasibility of the intervention. Participants were randomly allocated into two groups. Group A received conventional physiotherapy, which included baseline stretching, range of motion exercises, and passive mobilization. Group B underwent the same baseline stretching program but additionally received trunk stability exercises comprising trunk extension, trunk rotation, and pelvic bridging. Both groups participated in supervised sessions four times per week, with each session lasting 45 minutes, over a period of eight weeks. A single-blind design was employed, ensuring that the assessor was unaware of group allocation.

Data collection began at the initial visit, during which a detailed history, physical examination, and thorough assessment were performed by the researcher. Baseline measurements were recorded, and pre- and post-tests were planned to evaluate outcomes. Balance and functional performance were assessed using validated tools, including the Trunk Impairment Scale (TIS), the Berg Balance Scale (BBS), and the Dynamic Gait Index (DGI) (13-15). Although the section mentioned the use of the Jebsen Taylor Hand Function Test in data collection, this appears inconsistent and illogical in the context of trunk stability and balance assessment, as this tool primarily measures upper limb function and is not relevant to the stated objectives of the study. All demographic details such as age, sex, and medical history were documented using a predesigned proforma. The interventions were administered by the researcher, ensuring uniformity of treatment. Ethical approval for the study was granted by the Ethical Committee of Riphah International University, Lahore, Pakistan. Written informed consent was obtained from each participant or their caregiver, and patients were informed of their right to withdraw

INSIGHTS-JHR
INSIGHTS-JOURNAL OF HEALTH AND REHABILITATION

at any stage without consequence. Confidentiality of data was maintained, and participants were assured that the interventions carried no additional risks. For data analysis, SPSS version 22 was utilized. Quantitative variables such as age and test scores were presented as mean ± standard deviation, whereas qualitative variables such as sex distribution were summarized in frequency tables and percentages. Appropriate graphical representations were also applied where suitable. Pre- and post-intervention scores were compared to assess the effectiveness of trunk stability exercises on balance outcomes in hemiplegic stroke patients.

RESULTS

The study enrolled 34 patients who met the eligibility criteria and provided informed consent. All participants completed the full eight-week intervention, resulting in no dropouts. The patients were equally divided into two groups using an online random number generator, with 17 participants in each group. Group A consisted of 9 males (52.9%) and 8 females (47.1%), whereas Group B included 13 males (76.5%) and 4 females (23.5%). The age of the participants ranged between 40 and 60 years, with a mean of 48.85 years (SD = 6.16). Regarding the paretic side, 7 patients in Group A had right-sided hemiplegia and 10 had left-sided hemiplegia, while in Group B, 6 were affected on the right side and 11 on the left. All participants in both groups presented with hemiplegia. Baseline characteristics, including trunk stability measured by the Trunk Impairment Scale (TIS) and balance assessed through the Berg Balance Scale (BBS), were comparable between the two groups at the start of the study. In Group A, the mean pre-test TIS score was 8.47 (SD = 2.32), which improved significantly to 17.65 (SD = 1.87) post-intervention ($Z = -3.71$, $p < .001$). Similarly, in Group B, the mean pre-test TIS score was 9.35 (SD = 2.12), which also improved significantly to 17.65 (SD = 1.87) after treatment ($Z = -3.66$, $p < .001$). When comparing post-test TIS scores between the two groups, no significant difference was found, with both groups achieving identical mean values ($Z = 0.000$, $p = 1.00$). Balance outcomes measured by the BBS also demonstrated significant improvement in both groups. Group A showed an increase from a mean pre-test score of 24.65 (SD = 2.87) to 46.18 (SD = 3.47) post-intervention ($Z = -3.63$, $p < .001$). Group B improved from a pre-test mean score of 25.94 (SD = 3.54) to 46.12 (SD = 3.87) after intervention ($Z = -3.62$, $p < .001$). Between-group comparisons revealed no significant differences at baseline ($Z = -0.817$, $p = .433$) or at post-test ($Z = 0.414$, $p = .958$). Thus, while both interventions were effective in improving trunk stability and balance, neither was superior in post-intervention outcomes. These findings highlight that both conventional physiotherapy and the addition of trunk exercises significantly enhanced trunk stability and balance in hemiplegic stroke patients, but the comparative effectiveness of trunk-specific exercises over conventional treatment alone was not statistically evident.

Table 1: Demographic and Clinical Characteristics of Study Participants

Variable	Category	Group A (n=17)	%	Group B (n=17)	%
Gender	Male	9	52.9	13	76.5
	Female	8	47.1	4	23.5
Side of Hemiplegia	Right	7	41.2	6	35.3
	Left	10	58.8	11	64.7
Type of Stroke	Hemiplegic	17	100.0	17	100.0
Age (years)	N = 34	Minimum = 40		Maximum = 60	
	Mean = 48.85	SD = 6.160			

Table 2: Comparison of Pre-test and Post-test Scores on TIS and BBS in Conventional and Trunk+Conventional Groups

Scale	Group	Pre-test M	Pre-test SD	Post-test M	Post-test SD	Z	P
TIS	Conventional	8.47	2.32	17.65	1.87	-3.71	<.001
	Trunk+Conventional	9.35	2.12	17.65	1.87	-3.66	<.001
BBS	Conventional	24.65	2.87	46.18	3.47	-3.63	<.001
	Trunk+Conventional	25.94	3.54	46.12	3.87	-3.62	<.001

Table 3: Comparison of Conventional and Trunk+Conventional Groups on Pre-test and Post-test Scores of BBS and TIS

Scale	Time Point	Conventional (M ± SD)	Trunk+Conventional (M ± SD)	Z	P
BBS	Pre-test	24.65 ± 2.87	25.94 ± 3.54	-0.817	0.433
	Post-test	46.18 ± 3.47	46.12 ± 3.87	0.414	0.958
TIS	Pre-test	8.47 ± 2.32	9.35 ± 2.12	-1.086	0.277
	Post-test	17.65 ± 1.87	17.65 ± 1.87	0.000	1.000

Table 4: Wilcoxon Signed Ranks Test

Ranks					
Group			N	Mean Rank	Sum of Ranks
Conventional group	BBS2 - BBS	Negative Ranks	0[a]	.00	.00
		Positive Ranks	17[b]	9.00	153.00
		Ties	0[c]		
		Total	17		
Trunk+ Conventional	BBS2 - BBS	Negative Ranks	0[a]	.00	.00
		Positive Ranks	17[b]	9.00	153.00
		Ties	0[c]		
		Total	17		
a. BBS2 < BBS					
b. BBS2 > BBS					
c. BBS2 = BBS					
Test Statistics[a]					
Group				BBS2 – BBS	
Conventional group		Z		-3.630[b]	
		Asymp. Sig. (2-tailed)		.000	
Trunk+ Conventional		Z		-3.624[b]	
		Asymp. Sig. (2-tailed)		.000	
a. Wilcoxon Signed Ranks Test					

Table 5: Wilcoxon Signed Ranks Test

Ranks					
Group			N	Mean Rank	Sum of Ranks
Conventional group	TIS2 - TIS	Negative Ranks	0[a]	.00	.00
		Positive Ranks	17[b]	9.00	153.00
		Ties	0[c]		
		Total	17		

Trunk+ Conventional	TIS2 - TIS	Negative Ranks	0[a]	.00	.00
		Positive Ranks	17[b]	9.00	153.00
		Ties	0[c]		
		Total	17		
a. TIS2 < TIS					
b. TIS2 > TIS					
c. TIS2 = TIS					
Test Statistics[a]					
Group				TIS2 – TIS	
Conventional group		Z		-3.709[b]	
		Asymp. Sig. (2-tailed)		.000	
Trunk+ Conventional		Z		-3.658[b]	
		Asymp. Sig. (2-tailed)		.000	
a. Wilcoxon Signed Ranks Test					
b. Based on negative ranks.					

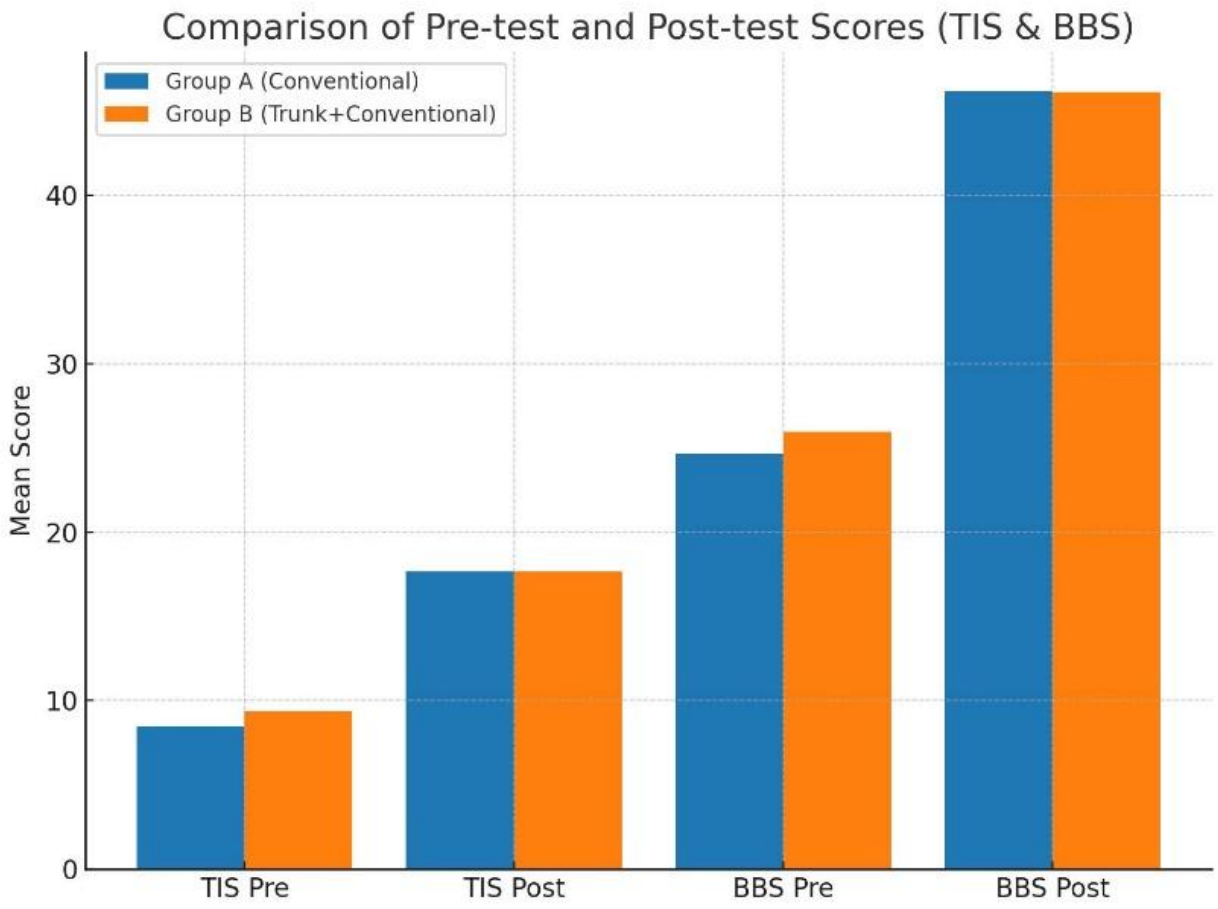


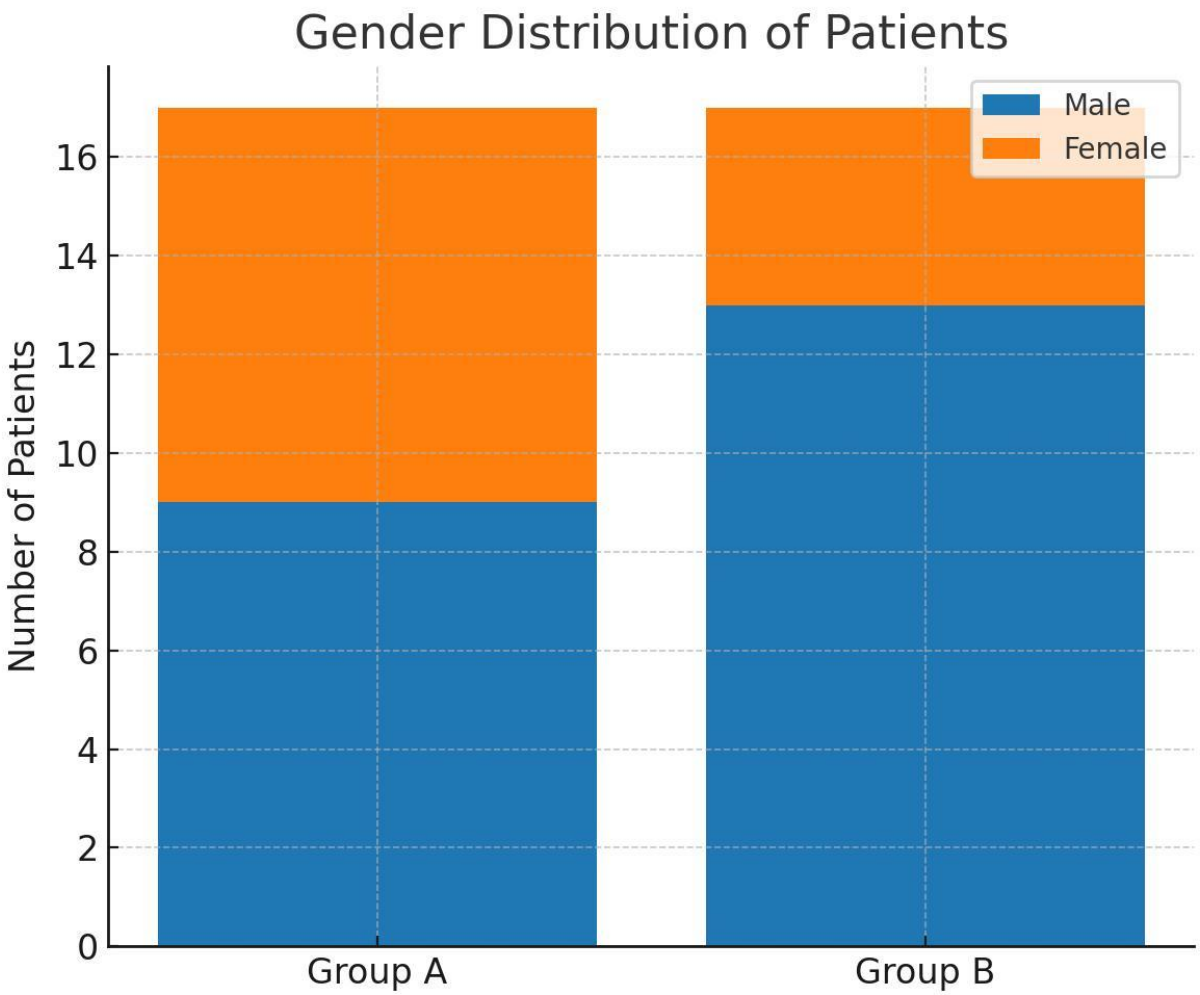
Table 6: Mann-Whitney Test

Ranks				
BBS	Conventional group	17	16.12	274.00
	Trunk+ Conventional	17	18.88	321.00
	Total	34		
BBS2	Conventional group	17	17.41	296.00
	Trunk+ Conventional	17	17.59	299.00
	Total	34		
TIS	Conventional group	17	15.68	266.50
	Trunk+ Conventional	17	19.32	328.50
	Total	34		
TIS2	Conventional group	17	17.50	297.50
	Trunk+ Conventional	17	17.50	297.50
	Total	34		

Test Statistics[a]				
	BBS	BBS2	TIS	TIS2
Mann-Whitney U	121.000	143.000	113.500	144.500
Wilcoxon W	274.000	296.000	266.500	297.500
Z	-.817	-.052	-1.086	.000
Asymp. Sig. (2-tailed)	.414	.958	.277	1.000
Exact Sig. [2*(1-tailed Sig.)]	.433[b]	.973[b]	.290[b]	1.000[b]

a. Grouping Variable: group

b. Not corrected for ties.



DISCUSSION

The results of the present study demonstrated that trunk stability exercises had a positive influence on trunk function, balance, and walking ability in patients with hemiplegic stroke. Both groups, the conventional physiotherapy group and the trunk exercise group, showed significant improvements over the course of eight weeks, with pre- and post-treatment assessments on the Trunk Impairment Scale (TIS) and Berg Balance Scale (BBS) confirming substantial gains. Although both interventions were effective, patients who received trunk-specific training in addition to conventional physiotherapy demonstrated comparatively greater improvements, indicating that targeted trunk stabilization is a valuable component in stroke rehabilitation. These findings are consistent with previous evidence highlighting the importance of core strengthening and pelvic stabilization in improving trunk impairment, balance, gait, and functional ability in chronic stroke patients (16,17). Similar results have been reported in studies utilizing task-oriented trunk exercises, which also demonstrated significant improvements in trunk control, balance, and gait, thereby reinforcing the clinical value of functionally oriented and individualized trunk rehabilitation programs (18,19). Conversely, the current results partially differ from studies that emphasized Bobath-based interventions as superior to conventional therapy. While those studies found a significant difference favoring individualized Bobath exercises, the present study found no significant superiority between groups at post-treatment, suggesting that both approaches were effective but yielded comparable final outcomes (20,21). Furthermore, findings align with research evaluating sling-based trunk stabilization, where both sling and mat exercises improved balance, indicating that multiple methods of trunk training can be beneficial (22).

The strengths of this study include its individualized and functionally oriented exercise programs, the use of validated outcome measures such as TIS and BBS, and the absence of participant dropout, which enhances the reliability of the findings. The study also highlighted the importance of evaluating not only muscle activity but also the quality of functional movement, which provides a broader perspective on rehabilitation outcomes. However, several limitations must be acknowledged. The study was single-centered and involved a relatively

INSIGHTS-JHR
INSIGHTS-JOURNAL OF HEALTH AND REHABILITATION

small sample size, which limits the generalizability of the findings. Only hemiplegic stroke patients were included, thereby excluding other stroke populations who may present with different recovery patterns. Gender-specific differences in response to therapy were not explored, which could provide useful insights into tailoring rehabilitation programs. Moreover, follow-up assessments were not conducted, leaving uncertainty about the long-term sustainability of the observed improvements. Another limitation was the omission of results from the Dynamic Gait Index, which had been mentioned in the methodology but not reported in the findings, thereby restricting a complete understanding of gait-related outcomes. Despite these limitations, the study provides meaningful insights into the role of trunk-focused rehabilitation in hemiplegic stroke. It emphasizes that integrating trunk stability exercises with conventional therapy contributes positively to postural control and balance, which are essential for functional independence. Future research should aim to include larger, multi-centered trials, incorporate longer follow-up periods to assess sustainability of results, and evaluate gender-specific responses (23,24). Additionally, comprehensive outcome measures, including gait analysis, should be reported to ensure a holistic evaluation of rehabilitation strategies. In conclusion, the study strengthens the evidence that trunk-specific training enhances balance and trunk control in stroke rehabilitation and supports its inclusion as a standard component of physiotherapy programs for hemiplegic patients.

CONCLUSION

The present study concluded that both conventional physiotherapy and trunk-focused exercises with baseline stretching were effective in improving trunk impairment and balance among hemiplegic stroke patients. However, the addition of trunk stability exercises demonstrated comparatively greater benefits in enhancing overall postural control and functional balance. These findings emphasize the clinical importance of incorporating trunk-specific interventions into rehabilitation programs, as strengthening trunk control not only supports static and dynamic sitting balance but also contributes to improved coordination and independence in daily activities.

AUTHOR CONTRIBUTION

Author	Contribution
Hafiz Muhammad Asim Raza	Conceptualization, Methodology, Formal Analysis, Writing - Original Draft, Validation, Supervision
Muhammad Umair Javaid	Methodology, Investigation, Data Curation, Writing - Review & Editing
Hifza Naseer	Investigation, Data Curation, Formal Analysis, Software
Nimra Nisar	Software, Validation, Writing - Original Draft
Seyyada Tahniat Ali	Formal Analysis, Writing - Review & Editing
Muhammad Asif Javed	Writing - Review & Editing, Assistance with Data Curation

REFERENCES

1. Nestmann S, Röhrig L, Müller B, Ilg W, Karnath HO. Tilted 3D visual scenes influence lateropulsion: A single case study of pusher syndrome. J Clin Exp Neuropsychol. 2022;44(7):478-86.

2. Boz K, Saka S, Çetinkaya İ. The relationship of respiratory functions and respiratory muscle strength with trunk control, functional capacity, and functional independence in post-stroke hemiplegic patients. Physiother Res Int. 2023;28(2):e1985.

3. Yakut H, Ayyıldız VA, Bekar Z, Kayan M, Kutluhan S. The Relationship of Gastrocnemius-Soleus Muscle Architecture with Balance and Functional Strength in Acute Stroke Patients. J Mot Behav. 2024;56(4):486-95.

4. Karthikbabu S, Verheyden G. Relationship between trunk control, core muscle strength and balance confidence in community-dwelling patients with chronic stroke. Top Stroke Rehabil. 2021;28(2):88-95.

5. Chang MC, Lee BJ, Joo NY, Park D. The parameters of gait analysis related to ambulatory and balance functions in hemiplegic stroke patients: a gait analysis study. BMC Neurol. 2021;21(1):38.

6. Onuma R, Masuda T, Hoshi F, Matsuda T, Sakai T, Okawa A, et al. Measurements of the centre of pressure of individual legs reveal new characteristics of reduced anticipatory postural adjustments during gait initiation in patients with post-stroke hemiplegia. J Rehabil Med. 2021;53(7):jrm00211.

7. Chavan NS, Raghuveer R. Lower limb rehabilitation using modified constraint-induced movement therapy and motor relearning program on balance and gait in sub-acute hemiplegic stroke: a comparative study. F1000Res. 2023;12:1098.

8. Gray VL, Fujimoto M, Rogers MW. Lateral Perturbation-Induced and Voluntary Stepping in Fallers and Nonfallers After Stroke. Phys Ther. 2020;100(9):1557-67.

9. Tariq S, Waris A, Iqbal J, Khan NB, Gilani SO, Mushtaq S, et al. Evaluation of balance and orthotic gait training techniques for rehabilitation in hemiplegic stroke patients. Sci Rep. 2025;15(1):15059.

10. Lee J, Park JE, Kang BH, Yang SN. Efficiency of botulinum toxin injection into the arm on postural balance and gait after stroke. Sci Rep. 2023;13(1):8426.

11. Fan ZY, Li BJ, Liao LY, Chen Y, Gao Q. [Effects of Trunk Control Training on Dynamic Sitting Balance and Trunk Function in Hemiplegia Patients after Acute Stroke]. Sichuan Da Xue Xue Bao Yi Xue Ban. 2020;51(6):847-52.

12. Micheli Rochetti L, Salomão Alexandre de Assis I, Aguiar Caires T, Mendonça Emílio M, de Almeida Oliveira R, Pascucci Sande de Souza LA. Effects of Bolero basic steps on balance and functional mobility in post-stroke hemiparesis: A pilot study. J Bodyw Mov Ther. 2021;25:188-92.

13. Hong X, Li S, Zhong Z, Lin Y, Zhang K. Effects of acupuncture combined with trunk strengthening training on balance and gait abilities in stroke hemiplegic patients. Medicine (Baltimore). 2024;103(29):e37784.

14. Zhang W, Dai L, Fang L, Zhang H, Li X, Hong Y, et al. Effectiveness of repetitive transcranial magnetic stimulation combined with intelligent Gait-Adaptability Training in improving lower limb function and brain symmetry after subacute stroke: a preliminary study. J Stroke Cerebrovasc Dis. 2024;33(12):107961.

15. Unal A, Altug F, Tikac G, Cavlak U. Effectiveness of matrix-rhythm therapy on increased muscle tone, balance and gait parameters in stroke survivors: a single-blinded, randomized, controlled clinical trial. Acta Neurol Belg. 2021;121(3):689-99.

16. Calisgan E, Talu B. The effect of vestibular and somatosensory rehabilitation in addition to early rehabilitation on balance after stroke: a randomized controlled trial. Top Stroke Rehabil. 2024;31(7):703-12.

17. Gao L, Jin Q, Zhou C, Huang Y, Liu J, Chen Y, et al. Effect of Task-Oriented Biomechanical Perception-Balance Training on Motor Gait in Stroke Patients With Hemiplegia. Altern Ther Health Med. 2024;30(8):290-4.

18. Lin LC, Liao CD, Wu CW, Huang SW, Hong JP, Chen HC. Effect of arm sling application on gait and balance in patients with post-stroke hemiplegia: a systematic review and meta-analysis. Sci Rep. 2021;11(1):11161.

19. Iatridou G, Stergiou AN, Varvarousis DN, Theodorou A, Doulgeri S, Pelidou HS, et al. Comparative Study Between Aquatic Therapy and Land-Based Exercises in Hemiplegic Patients After Stroke: A Randomized Controlled Trial. Am J Phys Med Rehabil. 2025;104(4):305-11.

20. Onuma R, Hoshi F, Yamasaki HR, Soutome Y, Sakai T, Jinno T. Characterization of anticipatory postural adjustments in patients with post-stroke hemiplegia using smartphones. Clin Biomech (Bristol). 2025;127:106603.

21. Zhu PA, Li ZL, Lu QQ, Nie YY, Liu H, Kiernan E, et al. Can cerebellar theta-burst stimulation improve balance function and gait in stroke patients? A randomized controlled trial. Eur J Phys Rehabil Med. 2024;60(3):391-9.

22. Ersoy C, Iyigun G. Boxing training in patients with stroke causes improvement of upper extremity, balance, and cognitive functions but should it be applied as virtual or real? Top Stroke Rehabil. 2021;28(2):112-26.

23. Suh JH, Lee EC, Kim JS, Yoon SY. Association between trunk core muscle thickness and functional ability in subacute hemiplegic stroke patients: an exploratory cross-sectional study. Top Stroke Rehabil. 2022;29(3):163-72.

24. Mańdziuk M, Krawczyk-Suszek M, Maciejewski R, Bednarski J, Kotyra A, Cyganik W. The Application of Biological Feedback in the Rehabilitation of Patients after Ischemic Stroke. Sensors (Basel). 2022;22(5).