Prospective Clinical Research Report

Journal of INTERNATIONAL MEDICAL RESEARCH

Journal of International Medical Research
49(11) 1–20

DOI: 10.1177/03000605211059413
journals.sagepub.com/home/imr
SAGE

Effects of intensive multiplanar trunk training coupled with dual-task exercises on balance, mobility, and fall risk in patients with stroke: a randomized controlled trial

Umair Ahmed[1], Hossein Karimi[1,2], Syed Amir[3] and Ashfaq Ahmed[1,3]

Abstract

Objective: We determined whether an exercise regime comprising high-intensity training, multi-planar trunk movements, and dual-task practice could improve trunk control, balance, functional mobility, and reduce fall risk in patients with hemiplegic stroke.

Methods: In this randomized controlled trial, 74 patients (mean age 61.71 years) were randomly assigned to the experimental and comparison groups. Primary outcome was trunk impairment scale (TIS) scores. Secondary outcomes were scores on the Berg balance scale, 10-meter walk test, Timed-up-and-go test, timed-Up-Go–cognitive, and Stroke Impact Scale-16 to measure between-group changes from baseline. We used linear mixed modeling to identify changes over time within and between groups on each scale and whether changes persisted at 6- and 12-month follow-ups.

Results: We observed significantly increased mean TIS scores from baseline to 3 months post-treatment (7.74); the increased scores were maintained at 6- and 12-month follow-ups (8.60 and 8.43, respectively). In the experimental group, all secondary outcomes showed significant and clinically meaningful results. Fall risk between groups was significantly reduced at 6 and 12 months.

[1]University Institute of Physical Therapy, University of Lahore, Lahore, Pakistan
[2]Istanbul Gelisim University, Istanbul, Turkey
[3]Allied Health Sciences, The University of Lahore, Lahore, Pakistan

Corresponding author:
Umair Ahmed, University Institute of Physical Therapy, University of Lahore, 1-KM Defense Road, Lahore 53101, Pakistan.
Email: umair.ahmed@uipt.uol.edu.pk

Conclusions: Intensive multiplanar trunk movements coupled with dual-task practice promoted trunk control, balance, and functional recovery in patients with stroke, reduced fall risk, and improved independent mobility.

Trial registration: #IRCT20200127046275N1.

Keywords

Trunk control, stroke, balance, function, mobility, fall risk

Date received: 1 May 2021; accepted: 22 October 2021

Introduction

Poor trunk control affects balance and mobility and increases fall risk in patients with stroke.[1] Trunk training exercises are considered effective in improving balance, mobility, and functional outcomes.[2] A recent systematic review confirmed the effectiveness of different trunk training strategies for trunk impairments, including selective trunk exercises, core stability training, sitting–reaching activities, and weight-shift training performed on stable, unstable, or static-inclined surfaces.[2] These strategies are recommended as a part of the standard care trunk regime (SCTR) for correcting trunk impairments. However, our clinical observations and emerging literature show that three additional therapeutic strategies—increasing the number of multiplanar trunk exercises, dual-tasking, and high-intensity training—can be incorporated into the SCTR for better outcomes in patients with stroke. In other words, a trunk regimen using various additional therapeutic strategies may lead to better improvement in trunk control and functioning of patients with stroke than a relatively less-varied therapy regime.

Three-dimensional training

A reason to reinforce the therapeutic challenge of multiplanar movements in trunk training is the loss of trunk control that occurs in all three planes and subsequently causes difficulties in functional activities following a stroke.[3] Considering that activities of daily living (ADL) are multiplanar in nature, and the fall risk is higher in lateral and diagonal directions,[4] reestablishing trunk control in all three cardinal planes should be the most important goal of stroke rehabilitation. Evidence from recent studies shows that the inclusion of three-dimensional movements is beneficial.[5,6]

Dual-task practice

The addition of dual-task (DT) practice is a promising therapeutic strategy in stroke rehabilitation to improve trunk control and balance for safe mobility because community walking and ADL typically require multitasking.[7] Nevertheless, traditional rehabilitation programs do not generally include DT as a therapeutic strategy during therapeutic training.[8]

Studies examining postural control and balance activities following a stroke have reported that DT exercises substantially deteriorate both motor and cognitive components of balance control owing to cognitive–motor interference (CMI), [9–11] that is, a decline in the performance of one or both (cognitive and motor task) components, relative to the performance of each task component separately during DT performance.

CMI also considerably affects gait parameters following stroke, such as decreased gait speed and increased stride duration.[12] Compared with healthy adults, patients with subacute stroke exhibit deterioration in motor (posture and gait control) and cognitive performance,[13] despite showing a compensatory increase in prefrontal cortex activation, indicating conscious control rather than subconscious movement generation.[14] The reinvestment theory suggests that the performance of automatic movement deteriorates when attention is diverted internally to control it, thereby making movement more conscious.[15] DT practice is therefore used to divert attention toward an external source, thereby allowing motor systems to develop more automatic and effective performance.[16] Practicing cognitive tasks together with motor training also reduces DT cost.[17] Thus, DT practice is an essential therapeutic strategy to master skill control at an unconscious level.

Longitudinal studies have reported that conventional rehabilitation is ineffective in minimizing the impact of CMI on balance and gait. Findings of a recent study suggest that DT exercises enhance trunk and posture control automation in community-dwelling patients with stroke by improving their information-processing capacity.[18] Therefore, the addition of DT practice in trunk exercise training may produce better clinical outcomes.

High-intensity training

High-intensity exercises are traditionally minimized in clinical practice in favor of normal movement patterns.[19] However, recent evidence on task-specific training suggests that therapy should be intensive, challenging, personalized, and tailored to the patients' impairment and functional levels for optimal recovery.[20] A small-scale study suggested that intensive and personalized trunk training improves trunk control and balance more in patients with stroke compared with a traditional trunk program.[21] Interestingly, such intense trunk training can reduce compensatory strategies as well.[21] Therefore, the inclusion of high-intensity training may improve clinical outcomes.

The rationale of the present study is that simple repetitive movements do not necessarily improve motor function because patients can adapt to therapeutic exercise and achieve a state of neuromuscular adaptation (therapeutic saturation).[22] These adaptive states can be overcome by modifying aspects of the regimen (e.g., increasing intensity, introducing DT exercises, challenging dynamic and reactive balance in various directions).[22] In line with this notion, van Duijnhoven et al. reported in a systematic review that weight-shift and locomotion training programs, which include additional challenges to improve balance capacity, often show significant improvements in balance scores on the Berg balance scale (BBS) compared with programs in which aspects of the regime are not varied or modified.[23] Therefore, introducing new therapeutic strategies or challenges (e.g., modified intensity, challenging multiplanar movements for dynamic balance, and DTs) to the trunk regime is essential to exploit the residual potential for recovery.[24] These added strategies are especially crucial for patients who are relatively close to or have already achieved a neuromuscular adaptation (saturation) state; performing exercises at a fixed or the same level does not benefit these patients.[25] Consequently, they are less likely to show further improvement with an unvaried exercise regime than patients who are substantially further from their treatment saturation point in traditional rehabilitation regimes. Therefore, we developed a treatment regime comprising more challenging therapeutic strategies (dual-tasking, high intensity, and more multiplanar trunk movements) for our experimental group and compared this with the SCTR. We hypothesized that trunk exercises performed with greater intensity and complexity (more multiplanar trunk movements and dual-tasking) could improve trunk control, balance, and mobility and reduce the fall risk in patients with stroke, as compared with the SCTR.

Methods

Trial registration

The design of the study was an assessor-blinded two-arm (parallel) randomized controlled trial and was registered in the World Health Organization trial registry # IRCT20200127046275N1. All the involved institutions and the Institutional Review Board of The University of Lahore, Pakistan approved the study protocols (Ref No: IRB-UOL-FAHS/293). This study was conducted in accordance with the Declaration of Helsinki and recommendations of the CONSORT Statement for non-pharmacological trials.[26] The study data supporting the findings are available from the corresponding author on request. This study was conducted between February 2017 and November 2018.

Eligibility criteria

We consecutively recruited patients with stroke from the neurological rehabilitation unit of University Teaching Hospital of the University of Lahore. The chief rehabilitation specialist at the stroke rehabilitation unit enrolled all participants in this study. Patients who could sit and stand for 30 s or more and walk for at least 10 m without assistance from a therapist or caregiver were eligible. Among these patients, we included those who had experienced a stroke in the past 3 to 12 months and scored 24 or more on the Mini-mental status examination. We excluded patients who had other neurological or musculoskeletal conditions that caused severe balance problems (such as cerebellar or basal ganglia disorders), joint diseases, used braces or other instruments that limited their walking ability, a body mass index greater than 31 kg/m^2, or severe visuospatial impairment such as hemineglect or Pusher syndrome. We calculated mean and standard deviation from our previous pilot study to obtain parameter estimates of primary outcomes in this study. The sample size was calculated using the following values in OpenEpi calculator: σ 1 = standard deviation of HIMTD = 2.68, σ 2 = standard deviation of the SCTR = 2.92, Δ = difference in group means = 1.82, and an equal sample ratio in both groups = 1. The significance level and desired statistical power were set to 0.05 and 0.80, respectively. The estimated total sample size of the study was 84 participants after taking into account an attrition rate of 10%. We contacted eligible participants by telephone and invited willing participants to screen them for eligibility in person. All participants provided oral and written informed consent before starting the clinical trial.

Randomization

Randomization (allocation ratio: 1:1) was conducted using a computer-generated random number for each participant in the trial. An independent research assistant who was not involved in treating patients allocated them into HIMTD and SCTR groups at a separate site. The assistant used sealed, numbered, opaque envelopes to conceal the group allocation from the researchers. Experienced physiotherapists blinded to the group allocation evaluated the patients. The effectiveness of blinding was checked by asking the assessors about the patient group (forced-choice) after the intervention and follow-ups. However, therapists and participants were aware of the group allocation owing to the nature of the interventions.

Outcome measures

The primary outcome was scores on the trunk impairment scale (TIS), with subscales of static and dynamic trunk control and coordination. The psychometric properties of the TIS are well established in the literature.[27] Secondary outcomes included scores on a self-paced 10-meter walk test (10-MWT) for gait speed, the timed-up-and-go test (TUG), timed-up-and-go–cognitive (TUG-cognitive), and BBS for balance, and the stroke impact scale-16 to check the recovery of physical function. All these scales have demonstrated good psychometric properties in patients with stroke.[28–31] The intensity of the exercise session was assessed using the modified Borg rating of perceived exertion (mRPE). A fall risk assessment form was used to record and determine the fall risk in patients with stroke. All outcome measures were administered at baseline (T_0), at 12 weeks post-intervention (T_1), and at 6 and 12 months post-intervention (T_2 and T_3).

Interventions

Experimental versus standard interventions. There were some noticeable differences in trunk interventions of the experimental group compared with the SCTR group. First, patients in the experimental arm were encouraged to attain higher levels of exertion ("heavy") on the mRPE scale of 0 to 10. For this to happen, patients were allowed to use external resistance when required. Conversely, patients in traditional training performed exercises at a lower intensity ("somewhat heavy") on the mRPE without external resistance. However, exercise intensities of both protocols, i.e., traditional and experimental, were equivalent in terms of duration and total trunk movements. Second, the experimental group practiced more diagonal and lateral plane trunk movements than sagittal movements. Conversely, the SCTR group performed more sagittal plane movements (sagittal movements > lateral and diagonal trunk movements). However, the number of trunk movement trials performed by patients with stroke was kept similar in both groups. Finally, only the HIMTD group performed trunk exercises with DT practice at an appropriate time point.

Pre-trial training of assessors and therapists. Six therapists with more than 5 years of experience in neurological rehabilitation attended a 3-day educational program on accurate data collection, treatment delivery, and documentation of outcomes, prior to formal data collection. Therapists learned to adjust interventions for patients with different levels of motor and cognitive abilities and participated in a practical workshop with actual patients under the direct supervision of a senior therapist. Following practical sessions, senior therapists held in-depth discussions with the therapists and assessors and provided verbal and written feedback on their performance. We also established interobserver reliability among the assessors before starting data collection among patients with stroke.

Exercise sessions. Treatment was delivered in the outpatient rehabilitation center of the university hospital. The training session comprised three distinct exercise periods. After completing 5- to 8-minute warm-up exercises (Period-I), patients received 1-hour routine physiotherapy comprising interventions to manage spasticity, progressive resistance exercise, aerobic capacity and endurance training, gait training, and 45 minutes of conventional task-oriented trunk training exercises (including therapeutic strategies of selective trunk exercises, core stability training, trunk-reaching activities, and weight-shift training performed on stable and unstable surfaces). Patients in the experimental arm received a similar exercise program, except their trunk training regime included three additional therapeutic strategies, i.e., intensive training, more multiplanar movements, and DT practice. Both groups held their treatment sessions under the direct supervision of trained physiotherapists (Period-II). Finally, patients ended their exercise session with a 5- to 8-minute cool-down (Period-III). All patients also received upper extremity dexterity and ADL/Instrumental ADL training from occupational therapists as a part of routine treatment. Speech therapy was offered to eight patients. Therapists assisted patients in performing the prescribed exercise, when needed.

Exercise progression. We used the "movement component model of posture control" as the basis for the progression of trunk exercise programs within each posture.[32] Research in motor control shows that trunk control correlates with sitting balance and mobility control function.[33] The first level is focused on static trunk control exercises. The second level of trunk control involves performing basic (upper and lower trunk-initiated uniplanar flexion, extension, lateral flexion, rotation) and combined trunk movements. Third-level control requires linking extremity movement with coordinated basic trunk movements, i.e., to stabilize and adjust the trunk for extremity movements. Fourth-level control is concerned with power production and stabilizes and adjusts the trunk when the extremity delivers/receives an impetus, such as when throwing, catching, kicking, pulling, or pushing. These trunk-control levels formed the four phases of both trunk training regimes. Example exercises of each phase is presented in Figure 1. These four trunk control levels or training phases were practiced in increasingly complex postures (from sitting to kneeling, kneeling to half-kneeling, and half-kneeling to standing). This gradual reestablishment of trunk control within each phase can be effective because compared with standing, trunk control in sitting and kneeling postures is less challenging (requires fewer degrees of freedom to control). In addition, if the patient inadvertently loses control, a fall would be unlikely to result in injury because the therapist can guard the patient against falling. Additionally, the distance from the patient to the mat is not far.

Owing to differences between the experimental and standard trunk interventions, as described above, the exercise progression of HIMTD was made more challenging within each trunk control level by (1) increasing the intensity with external resistance to attain the desired level of mRPE ("heavy" for HIMTD vs. "somewhat heavy" for the SCTR); (2) adding DTs starting from successful completion of 9 to 13 repetitions of each type of trunk movement (basic, combined, coordinated, and power movements) across all trunk control levels; and (3) increasing the frequency of multidirectional movements across sessions starting from the third session (multiplanar trunk movements > sagittal plane). Conversely, the SCTR group performed more sagittal than multiplanar and lateral trunk movements. Appendix I presents the key differences between the two exercise regimes. Further details of the trunk training protocols for both groups are provided in the online data supplement.

Setting and dose of trunk exercises. All patients received their treatment in the neurological rehabilitation unit of the university hospital. Both trunk exercise programs consisted of three sets of 9 to 13 repetitions per trial, five times per week for 3 consecutive

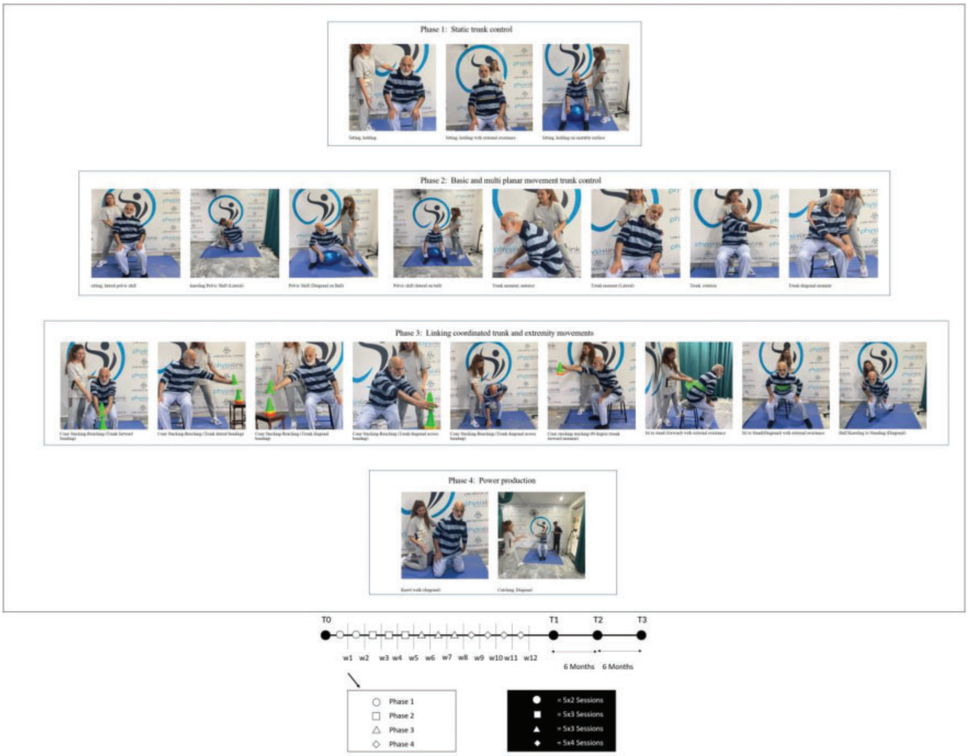

Figure 1. Example exercises.

months. With an estimated mean time of 45 minutes for a single session, an individual's maximum dose in the 60 sessions was 45 hours. Participants were encouraged to exercise within their desired level of exercise intensity.

Exercise safety and monitoring. Therapists monitored patients' oxygen saturation, blood pressure, and heart rate before, during, and after each exercise session. As a requirement, patients learned to measure their exertion level according to the mRPE and monitor the warning signs of exercise intolerance. Patients received additional rest periods or terminated their exercise session altogether when they exhibited signs of exercise intolerance. Those patients who displayed stable signs and symptoms following rest performed exercises at a lower or prescribed intensity, with clearance from the therapist or doctor. Participants were secured using a safety harness attached to a sliding rail on the ceiling during all exercises.

Exercise delivery and adherence. Investigators arranged weekly meetings with therapists to ensure accurate treatment delivery during the implementation phase. A staff external to the research maintained the daily treatment recording forms to document the exercise dose and content delivered to each patient. An independent researcher thoroughly reviewed the treatment forms and audited one or two rehabilitation sessions per patient to evaluate intervention adherence and fidelity.

Exercise tailoring and modifications. Because participants had already attained static sitting control for 30 s, they showed little interest in exercising in the supine position. In addition, conducting three planar movements in the supine position was exhaustive and caused backache in some patients with stroke; therefore, we discontinued supine exercises in the exercise model.

Contamination. Multiplanar exercises comprised one of our therapeutic strategies in the HIMTD group because our clinical observations showed that patients did not perform sufficient multiplanar movements in standard care. Surprisingly, little information exists about the number of multiplanar exercises recommended by rehabilitation specialists in standard care. Therefore, we conducted a preliminary observational mapping study to obtain baseline information on the amount and nature of multiplanar trunk exercises recommended in standard care. We used this pretrial data to develop the trial protocol so as to ensure that the HIMTD group received three times more multiplanar exercises than the SCTR group. In contrast, the SCTR received a predetermined number of uniplanar trunk training and multiplanar trunk exercises as an alternative. These pretrial findings allowed us to quantify contamination over time in the SCTR group. We constantly monitored activities during the therapy sessions to determine whether the intervention changed the magnitude of multiplanar exercises in the SCTR group. Staff who were not involved in the study maintained daily exercise logbooks to document the activity data. A 5% increase in the number of multiplanar exercises was established as the clinical index of contamination.

Data analysis

Data were analyzed using R version 3.6.2, with the package *lme4* v1.1-26 (The R Project for Statistical Computing, Vienna, Austria). Descriptive statistics were used to compare baseline characteristics between the two groups: age, sex, post-stroke duration, type of stroke, and hemiplegic side. The unpaired *t*-test and chi-square test were used to assess the effect of randomization. Linear mixed modeling was used to test changes over time in each measure within and between groups while controlling for age and sex. Model assumptions were verified using the Kolmogorov–Smirnov test for normality of residuals, and nonparametric testing of simulated relative to observed residuals (dispersion). Multicollinearity was tested by calculating the variance inflation factor for all predictors, with all in acceptable ranges (1.0–1.02). All tests were two-tailed, and the significance level was set to <0.05, with a 95% confidence interval (CI).

Data regarding episodes of falls and fall-related injuries were collected at 6- and 12-month follow-ups. The between-group difference in the proportion of patients who experienced a fall and those who sustained fall-related injuries was analyzed with the chi-square test or with the Fisher's exact test if the criteria for the chi-square test were not satisfied. The number needed to treat (NNT) and absolute risk reduction (ARR) were also calculated for the above outcomes as well as for fall risk and fall-related injuries.

The data were collected at baseline, post-intervention (after 12 weeks), and at follow-ups (6 and 12 months post-intervention). We conducted an intention-to-treat analysis, and missing values were addressed using the last observation carried forward method for every single outcome variable.

Results

We screened 147 volunteers, of which 99 met the eligibility criteria. We invited these 99 patients to participate; 12 declined and 3 were scheduled for surgery within the following 2 months. The remaining 84 participants (mean age 61.71 years) were allocated to each group (HIMTD and SCTR, 42 participants each). All 84 participants received their respective intervention. At the first follow-up, four participants were lost, three in the HIMTD group and one in the SCTR group. At the second follow-up, six participants were lost to follow-up, three in the HIMTD group and three in the SCTR group. Thus, 10 participants lost to follow-up and 74 participants completed all the assessments (T0, T1, T2, T3), as presented in Figure 2 illustrates the flow diagram of participants in the study.

Interobserver reliability

Inter-rater reliability was established before we began formal data collection. A close association was found among raters on the primary and secondary outcomes, and correlation coefficient values ranged from 0.65 to 0.97.

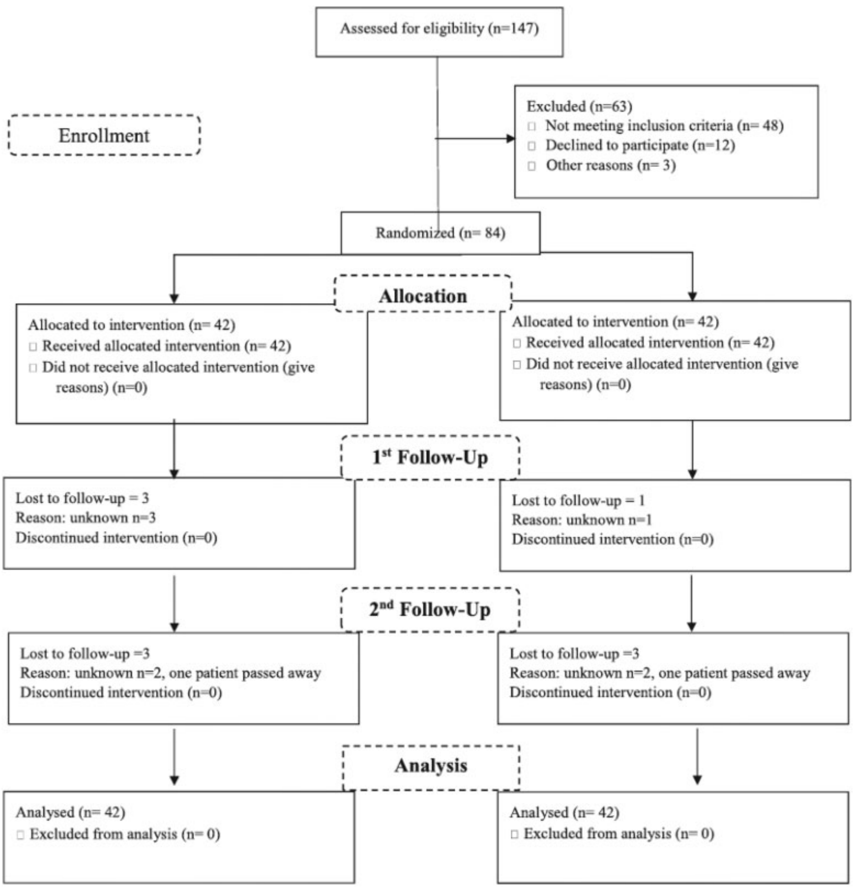

Figure 2. Flowchart of the study.

Table 1. Baseline characteristics.

Demographics and baseline scores	HIMTD	SCTR	p-value
Sex, N (%)	42 (50.00)	42 (50.00)	0.37†
Female	22 (52.38)	25 (59.52)	
Male	20 (47.62)	17 (40.48)	
Paretic side, N (%)			
Right	19 (45.24)	17 (41.46)	0.80†
Left	23 (54.76)	25 (59.52)	
Stroke type			
Hemorrhagic	15 (35.71)	18 (42.86)	0.69†
Ischemic	27 (64.29)	24 (57.14)	
Age, mean ± SD	61.21 ± 7.78	62.21 ± 8.20	0.57‡
Stroke duration (months), mean ± SD	07.21 ± 3.27	07.30 ± 3.03	0.89‡
Body mass index, mean ± SD	25.90 ± 2.32	26.69 ± 2.50	0.14‡
Functional assessment, mean ± SD			
MRS	02.33 ± 0.98	02.29 ± 0.86	0.81‡
TIS	11.69 ± 3.01	11.67 ± 2.92	0.97‡
TUG	22.74 ± 5.20	23.48 ± 4.49	0.49‡
TUGC	25.95 ± 5.34	26.50 ± 4.68	0.62‡
10-MWT	00.44 ± 0.14	00.47 ± 0.16	0.32‡
BBS	35.83 ± 7.10	35.93 ± 7.46	0.95‡
SIS-16	58.52 ± 13.35	59.48 ± 14.54	0.78‡
MMSE	27.19 ± 02.13	26.74 ± 02.08	0.99‡

MRS, modified Rankin scale; TIS, trunk impairment scale; TUG, timed-up-&-go; TUGC, timed-up-&-go–cognitive; BBS, Berg balance scale; SIS-16, stroke impact scale-16; MMSE, mini-mental state examination; HIMTD, high-intensity multiplanar trunk training coupled with dual-task; SCTR, standardized trunk care regime; 10-MWT, 10-meter walk test; SD, standard deviation.
‡ Unpaired *t*-test. †Chi-square test.

Within- and between-group comparisons

Both patient groups were similar in terms of baseline characteristics (Table 1). Mean and standard deviation for all functional stroke outcome measures at baseline, post-intervention, and 6- and 12-month follow-ups for each group are presented in Table 2. Multiple regression was used to identify changes over time in each scale, while controlling for age and sex. Three models were calculated for each scale to test scores at baseline relative to post-intervention, 6-month follow-up, and 12-month follow-up. Changes over time are shown in Table 3, both within each group and comparing the two groups over time by group interaction. TIS Static was excluded as its model residuals were not normally distributed, potentially invalidating their accuracy. All other scale scores are shown in Table 3. Briefly, both interventions showed significant improvements over time. Additionally, the time by group interaction was significant in all models, showing that the HIMTD intervention resulted in significantly stronger improvements than the SCTR intervention for all scales.

Multiplanar exercises

The mean difference between the number of multiplanar sessions administered as part of routine treatment and the pretrial observational study was <5%, indicating no contamination occurred in the control group. Overall, patients in the HIMTD group engaged in three times more multiplanar

Table 2. Mean (SD) scores for all functional stroke outcome measures at baseline, 12 weeks, and 6- and 12-month follow-ups for each group.

Functional scale	Groups	Baseline| mean ± SD	Post-intervention mean ± SD	6-month follow-up mean ± SD	12-month follow-up mean ± SD
TIS Total (0–23)	HIMTD	11.69 ± 3.01	19.43 ± 2.17	20.29 ± 2.03	20.12 ± 2.31
	SCTR	11.67 ± 2.92	16.64 ± 2.69	17.83 ± 2.65	17.83 ± 2.70
TIS Static control	HIMTD	5.69 ± 1.09	6.95 ± 0.22	7	7
	SCTR	5.60 ± 1.01	6.90 ± 0.30	7	7
TIS Dynamic control	HIMTD	4.07 ± 1.28	7.76 ± 1.46	8.21 ± 1.46	8.17 ± 1.58
	SCTR	4.02 ± 1.22	5.95 ± 1.85	6.57 ± 1.99	6.48 ± 2.07
TIS/Coordination	HIMTD	1.93 ± 0.92	4.69 ± 1.00	5.07 ± 1.02	5.29 ± 1.45
	SCTR	2.05 ± 0.94	3.79 ± 1.22	4.29 ± 1.17	4.52 ± 1.25
TUG (s)	HIMTD	22.74 ± 5.20	12.12 ± 3.60	12.32 ± 3.82	12.77 ± 4.28
	SCTR	23.48 ± 4.49	15.86 ± 5.46	15.55 ± 5.04	15.77 ± 4.82
TUGC (s)	HIMTD	25.95 ± 5.34	14.95 ± 5.41	15.43 ± 5.15	15.88 ± 5.56
	SCTR	26.50 ± 4.68	17.95 ± 6.04	18.52 ± 6.33	18.98 ± 6.39
10-MWT, m/s	HIMTD	0.44 ± 0.14	0.79 ± 0.17	0.78 ± 0.17	0.78 ± 0.16
	SCTR	0.47 ± 0.16	0.64 ± 0.16	0.63 ± 0.17	0.64 ± 0.17
BBS (0–56)	HIMTD	35.83 ± 7.10	45.14 ± 6.56	45.54 ± 6.58	45.90 ± 6.27
	SCTR	35.93 ± 7.46	40.76 ± 7.90	41.36 ± 7.82	41.71 ± 7.83
SIS-16	HIMTD	58.52 ± 13.35	80.40 ± 14.33	80.10 ± 14.28	78.21 ± 14.45
	SCTR	59.48 ± 14.54	69.07 ± 14.65	68.55 ± 14.87	69.10 ± 15.12

TIS, trunk impairment scale; TUG, timed-up-&-go; TUGC, timed-up-&-go–cognitive; BBS, Berg balance scale; SIS-16, stroke impact scale-16; HIMTD, high-intensity multiplanar trunk training coupled with dual-task; SCTR, standardized trunk care regime; 10-MWT, 10-meter walk test; SD, standard deviation.

exercises (79.5 ± 4.95 vs. 22.93 ± 3.66) than those in the SCTR group, who practiced uniplanar trunk exercises as an alternative therapy. One exercise session consisted of three sets of 9 to 13 repetitions each. The typical patient received five treatment sessions per week for 3 consecutive months. The average time to complete one session was 38 minutes.

Fall risk

We collected fall data from 80 and 74 participants at the first and second follow-ups, respectively. Using a fall risk assessment form, fall and fall-related injuries were recorded. Three and 11 stroke survivors reported at least one fall at the first follow-up in the HIMTD and SCTR groups, respectively, accounting for a total of 14 fall episodes. Five of these falls resulted in injuries; however, no injurious falls occurred in the experimental group. Twenty-three falls (HIMTD = 6, SCTR = 17) occurred by the second follow-up, of which 11 were injurious (HIMTD = 2, SCTR = 9). We found a significantly reduced risk of fall and fall-related injuries in the HIMTD group as compared with the SCTR group. The ARR of fall risk was 19.10% (95% CI 3.23–35.07) and 28.10% (95% CI 8.12–48.02) at first and second follow-ups, respectively. The ARR of fall-related injuries at the first and second follow-ups was 12.20% (95% CI 2.18–22.21) and 18.10% (95% CI 2.68–33.57), respectively. Finally, the NNT to prevent one fall episode was 3.56 (95% CI 2.08–12.32) at 6-month and 5.52 (95% CI 2.98–37.34) at 12-month follow-up (data not shown).

Table 3. Changes over time within and between groups at post-intervention, 6-month, and 12-month follow-up, controlling for age and sex.

	HIMTD	SCTR	HIMTD > SCTR
Baseline vs. post-intervention			
TIS Total (0–23)	$\beta = 7.74$, SE = 0.34; t(87) = 22.82, p < 0.001	$\beta = 4.98$, SE = 0.34; t(87) = 14.68, p < 0.001	F(1,87) = 33.18, p < 0.001
TIS Dynamic	$\beta = 3.69$, SE = 0.17; t(85) = 21.61, p < 0.001	$\beta = 1.93$, SE = 0.17; t(85) = 11.29, p < 0.001	F(1,85.3) = 53.23, p < 0.001
TIS Coordination	$\beta = 2.76$, SE = 0.17; t(85) = 16.61, p < 0.001	$\beta = 1.74$, SE = 0.17; t(85) = 10.45, p < 0.001	F(1,85.5) = 18.96, p < 0.001
BBS (0–56)	$\beta = 9.43$, SE = 0.69; t(88) = 13.76, p < 0.001	$\beta = 4.83$, SE = 0.69; t(88) = 7.05, p < 0.001	F(1,87.8) = 22.48, p < 0.001
10-MWT (m/s)	$\beta = 0.35$, SE = 0.02; t(88) = 22.24, p < 0.001	$\beta = 0.17$, SE = 0.02; t(88) = 10.78, p < 0.001	F(1,87.7) = 65.69, p < 0.001
TUG (s)	$\beta = -10.59$, SE = 0.7; t(88) = −15.21, p < 0.001	$\beta = -7.62$, SE = 0.7; t(88) = −10.95, p < 0.001	F(1,88) = 9.09, p = 0.003
TUGC (s)	$\beta = -11$, SE = 0.58; t(88) = −19.06, p < 0.001	$\beta = -8.55$, SE = 0.58; t(88) = −14.81, p < 0.001	F(1,87.8) = 9.03, p = 0.003
SIS-16 (16–100)	$\beta = 21.88$, SE = 1.4; t(86) = 15.59, p < 0.001	$\beta = 9.6$, SE = 1.4; t(86) = 6.83, p < 0.001	F(1,86.4) = 38.28, p < 0.001
Baseline vs. 6-month follow-up			
TIS Total (023)	$\beta = 8.6$, SE = 0.35; t(87) = 24.26, p < 0.001	$\beta = 6.17$, SE = 0.35; t(87) = 17.41, p < 0.001	F(1,87.1) = 23.5, p < 0.001
TIS Dynamic	$\beta = 4.14$, SE = 0.17; t(87) = 23.73, p < 0.001	$\beta = 2.55$, SE = 0.17; t(87) = 14.59, p < 0.001	F(1,86.9) = 41.74, p < 0.001
TIS Coordination	$\beta = 3.14$, SE = 0.18; t(86) = 17.16, p < 0.001	$\beta = 2.24$, SE = 0.18; t(86) = 12.22, p < 0.001	F(1,85.7) = 12.2, p = 0.001
BBS (056)	$\beta = 9.81$, SE = 0.7; t(88) = 14.01, p < 0.001	$\beta = 5.43$, SE = 0.7; t(88) = 7.75, p < 0.001	F(1,87.7) = 19.57, p < 0.001
10-MWT (m/s)	$\beta = 0.34$, SE = 0.02; t(88) = 21.02, p < 0.001	$\beta = 0.16$, SE = 0.02; t(88) = 10.18, p < 0.001	F(1,87.6) = 58.74, p < 0.001
TUG (s)	$\beta = -10.4$, SE = 0.74; t(89) = −14.06, p < 0.001	$\beta = -7.92$, SE = 0.74; t(89) = −10.72, p < 0.001	F(1,89.1) = 5.6, p = 0.020
TUGC (s)	$\beta = -10.52$, SE = 0.6; t(88) = −17.53, p < 0.001	$\beta = -7.98$, SE = 0.6; t(88) = −13.28, p < 0.001	F(1,87.6) = 9, p = 0.004
SIS-16 (16100)	$\beta = 21.57$, SE = 1.33; t(86) = 16.21, p < 0.001	$\beta = 9.07$, SE = 1.33; t(86) = 6.82, p < 0.001	F(1,85.6) = 44.1, p < 0.001
Baseline vs. 12-month follow-up			
TIS Total (0–23)	$\beta = 8.71$, SE = 0.39; t(87) = 22.4, p < 0.001	$\beta = 6.17$, SE = 0.39; t(87) = 15.85, p < 0.001	F(1,87.2) = 21.43, p < 0.001
TIS Dynamic	$\beta = 4.17$, SE = 0.21; t(86) = 19.84, p < 0.001	$\beta = 2.45$, SE = 0.21; t(86) = 11.68, p < 0.001	F(1,85.8) = 33.3, p < 0.001
TIS Coordination	$\beta = 3.36$, SE = 0.23; t(87) = 14.64, p < 0.001	$\beta = 2.48$, SE = 0.23; t(87) = 10.8, p < 0.001	F(1,86.8) = 7.38, p = 0.008
BBS (0–56)	$\beta = 10.24$, SE = 0.7; t(88) = 14.59, p < 0.001	$\beta = 5.79$, SE = 0.7; t(88) = 8.25, p < 0.001	F(1,87.7) = 20.14, p < 0.001
10-MWT (m/s)	$\beta = 0.35$, SE = 0.01; t(88) = 22.79, p < 0.001	$\beta = 0.17$, SE = 0.01; t(88) = 11.28, p < 0.001	F(1,87.9) = 66.28, p < 0.001
TUG (s)	$\beta = -9.99$, SE = 0.66; t(87) = −15.23, p < 0.001	$\beta = -7.7$, SE = 0.66; t(87) = −11.74, p < 0.001	F(1,87) = 6.09, p = 0.016
TUGC (s)	$\beta = -10.07$, SE = 0.63; t(87) = −15.95, p < 0.001	$\beta = -7.52$, SE = 0.63; t(87) = −11.91, p < 0.001	F(1,87.3) = 8.14, p = 0.005
SIS-16 (16–100)	$\beta = 20.59$, SE = 1.39; t(86) = 14.82, p < 0.001	$\beta = 9.62$, SE = 1.39; t(86) = 6.92, p < 0.001	F(1,85.8) = 31.2, p < 0.001

TIS, trunk impairment scale; TUG, timed-up-&-go; TUGC, timed-up-&-go–cognitive; BBS, Berg balance scale; SIS-16, stroke impact scale-16; HIMTD, high-intensity multiplanar trunk training coupled with dual-task; SCTR, standardized trunk care regime; 10-MWT, 10-meter walk test; SD, standard deviation; SE, standard error.

Adverse events

We monitored adverse events throughout the intervention period. Serious adverse events during training were not observed in any group. Both groups had similar rates of adverse events in all categories recorded (cardiac disorders, light-headedness, nausea, musculoskeletal pain, fatigue, fall, and fall-related injuries during treatment), except fatigue. In the first month, more patients felt fatigued in the HIMTD group than in the SCTR group. Overall, 46 participants complained of fatigue or tiredness, among which 40 (57%) were in the experimental group. However, this difference in fatigue became non-significant in the later stages of treatment. One patient felt nausea, and one non-injurious fall occurred in the HIMTD group during the treatment; the patient experienced syncope owing to increased exercise intensity. Three participants in the experimental group also experienced musculoskeletal pain, as compared with one participant in the SCTR group.

Exercise intensity

Data on exercise intensities suggested that patients perceived the exertion level as "somewhat heavy" and "heavy" in 85% and 83% of exercise sessions in the SCTR and HIMTD groups, respectively. The mean mRPE in the HIMTD group was 6.58 ± 0.96 versus 4.90 ± 0.83 in the SCTR group ($p = 0.02$).

Compliance with and adherence to exercise

Exercise adherence was not significantly different between groups. The mean number of sessions received per participant was 55.71 ± 3.35 out of 60 sessions. Overall, participants received 4680 out of 5040 sessions (92.85%).

Discussion

We hypothesized that trunk exercises performed with sufficient intensity and complexity (carried out together with a cognitive task and multiplanar movements) could increase functional outcomes and reduce fall risk among patients with stroke. Our results were in line with this hypothesis, showing that an increase in HIMTD exercises improved balance, mobility, and fall risk compared with standard treatment regimes. Our participants had an excellent exercise adherence rate, suggesting that trunk exercises are safe and practical in patients with stroke. The overall TIS scores favored the HIMTD (experimental) group.

Our pretrial data showed that the number of sessions doing multiplanar activities was three-fold lower than expected. A larger number of multiplanar exercise sessions were carried out in the HIMTD group than in the SCTR group. Trial and pretrial data revealed that the mean number of multiplanar sessions in the conventional rehabilitation program was 23 sessions per patient during the 3-month treatment course. According to our results, we recommend increasing the number of sessions to 60 to 70 per patient.

Trunk control

Our results showed that an intensive multidirectional training program resulted in significantly better trunk coordination and dynamic control, with an average increase of 8 points on the TIS. The between-group difference in effect size on the dynamic balance subscale was 1.09, favoring HIMTD therapy. The increased scores in the HIMTD group were mainly owing to improvement in both dynamic balance and coordination subscales. In contrast, progress in the SCTR group was mainly owing to dynamic balance, which is congruent with previous studies.[2] Notably, our experimental group performed much better on the coordination scale than those in other studies,[34] suggesting that combining multiplanar and cognitive tasks might be responsible for this improvement. However, there was no significant improvement in the static sitting balance subscale of the TIS. These effects persisted in both treatment groups at the follow-ups, which is in line with previous investigations.[2] Trunk trajectory (directional control) is a critical variable to be stabilized in stroke rehabilitation. Patients with stroke have deficits in selectively using combinations of trunk muscles that stabilize the trunk's trajectory. A potential explanation for the improved result is that HIMTD exercises minimize those combinations of trunk muscles that destabilize the trunk's trajectory.[35] Ryerson suggested that retraining patients with stroke to achieve trunk control in all three directions should be an important goal of rehabilitation.[36] Our findings are in line with those of previous studies showing that three-dimensional trunk training is superior to conventional treatment in improving balance and gait in patients with subacute stroke.[5,6,37] Therefore, the observed improvements in HIMTD patients may be because they received more multidirectional exercises, which may have improved anticipatory postural adjustments (dynamic balance and coordination) in all directions. This also implies that HIMTD maximizes the combination of good muscle synergies and minimizes the effect of destabilizing muscle synergies, leading to improved trunk control.

Balance capacity

We assessed the balance capacity of our sample using the TUG, TUGC, and BBS. The between-group analysis revealed a significant difference in favor of the HIMTD group. As expected, the time for the TUGC in our patients was longer than that for the TUG alone. Given that the HIMTD group exhibited significantly better improvement on the TUGC and a reduced effect of CMI on motor performance time than the SCTR group, the enhanced performance in balance capacity was likely owing to dual-tasking.[18] However, we did not concurrently evaluate the effect of CMI (DT effect percentage) on cognitive performance. Therefore, it is unclear whether participants learned to properly allocate attentional resources to both motor and cognitive components of the tasks or that only a cognitive–motor trade-off (movement prioritization strategy) was responsible for this improved performance. However, previous research supports that the DT strategy improves both motor and cognitive performance in patients with stroke.[18] Another possible explanation for the better clinical outcomes is that practicing more movements in various directions may lead to increased postural control and balance confidence in the HIMTD group, as reported in previous research.[6]

We considered an improvement of 2.9 s in the TUG as the minimal detected change and 6.4 s as a clinically relevant difference.[38] These reference values indicated that the within-group difference of both groups exceeded the clinically relevant value on both the TUG and TUGC scales. Furthermore, a more than minimal detectable difference existed between the means of the two groups. From a clinical point of view, TUG cutoff values, suggested by Podsiadlo and Richardson, indicate that most participants in both groups at T_0 were dependent on or required assistance in most ADL (cutoff >20 s), possibly owing to their balance deficits.[39] Reduced times at T_1, T_2, and T_3 indicated that these patients had become more independent for main transfers and activities after engaging in trunk exercises, leading to improved balance. However, a substantial mean difference of −3.73 existed in favor of the HIMTD group, indicating that HIMTD more effectively improved balance on the TUG scale than the SCTR.

The BBS score increased from 35 to 45 in the HIMTD group, indicating an improvement of 17.85% compared with 10% in the SCTR group. These improved results are notable for two reasons. First, the between-group mean difference exceeded the minimal detectable difference (5 points or 10%) in favor of the experimental group.[40] Second, the HIMTD group attained the threshold score of 45, indicating that the fall risk was significantly reduced from high to low in this group as compared with the SCTR group.[41] However, the accuracy of the BBS in predicting falls is less than 75% at best. Therefore, we also recorded fall and fall-related injuries and found a significantly decreased risk of fall and fall-related injuries in the HITMD group.

There are several possible reasons for the improved trunk and balance control and reduced fall risk in the HIMTD group. First, patients in the experimental group practiced more intensive trunk and balance training than those in the control group, which allowed them to experience more difficult trunk control tasks.[6] Therefore, these patients may have been better able to coordinate trunk and extremity movements for balance activities in sitting, standing, during transitional movements and mobility tasks. Second, patients in the HIMTD group performed frequent movements in those directions that are most critical for functioning, i.e., lateral and diagonal (forward trunk rotation to the uninvolved side) trunk movements.[42] These controls are typically abnormal in patients with stroke, and added retraining of trunk movements in these directions might have helped to overcome these deficits in control. In additional, the multiplanar exercises with DTs served to develop more automatic balance control in the HIMTD group than the SCTR group, possibly owing to proper allocation of attentional resources.[16,43] Therefore, fewer falls and fall-related injuries were the result of better handling of distractions and complex multiplanar movements in ADL. We also observed that patients in the HIMTD group could better shift and bear weight and recover balance on the more affected leg. Furthermore, their lateral and diagonal trunk control was better during sitting, standing, and walking. Finally, motor performance in the HIMTD group was less affected by distractions, potentially owing to DT practice.

Self-paced gait speed performance

Our results showed that the benefits of trunk regimes had a carry-over effect on mobility and physical functions; the increased trunk and balance control matched the improvement in gait speed and perceived functional recovery. A statistically and clinically significant difference occurred in speed gains in the HIMTD group in comparison with the SCTR group. This between-group difference exceeded the 0.10 meters/s considered to be a clinically minimally important change in the 10-MWT. The gait speed in the HIMTD regime progressed from 0.44 to 0.79 meters/s compared with the improvement in speed of the SCTR regime from 0.47 to 0.64 meters/s. By considering functional ambulation categories according to walking speed,[44] a total of 33 patients in the experimental group transitioned their walking status compared with 22 in the comparison group. This higher ambulation status reflects improved health, function, and community integration among patients with stroke.[45] This finding has an important clinical implication for patients with stroke; gait speed slower than 0.6 meters/s may indicate a higher risk of disability, institutionalization, and mortality.[46] Both trunk regimes passed this cutoff level; therefore, the likelihood of participants' function and survival was high. Although trunk exercises are beneficial in any form, more favorable outcomes are possible with the HIMTD regime.

There are some potential explanations for the greater improvement on the 10-MWT in the experimental group. Intensive and coordinated trunk extremity exercises causes better weight-bearing control of the lower extremities in these functional tasks owing to improved trunk adjustments, mainly when a lower extremity delivers impetus to the ground.[47] Furthermore, increased frequency of multiplanar exercises potentially promotes better segmental trunk and body movements in various directions than uniplanar movements.[48] Various trunk and gait training programs emphasize this type of control to improve balance and functional mobility skills in stroke rehabilitation.[49] Furthermore, a more significant improvement in patients' balance capacity also leads to better walking ability because better balance is related to improved mobility.[2,50]

It is also possible that all observed improvements in the HIMTD group may have been owing to the increased dose of exercise therapy in general and not the specific effect of the additional therapeutic challenges, i.e., DT or multiplanar training. However, researchers highlight that performance of a motor task could be enhanced by practicing a specific task together with "challenges or variations" added to a training regimen.[22,51] The evidence on upper-extremity training in patients with stroke convincingly demonstrates that saturation of treatment regimens can be overcome by adding various novel challenges to exercise therapy and that these results are not influenced by time.[23] This finding is congruent with our results; our sample mainly consisted of patients with chronic stroke, which showed that the effects might not be owing to natural recovery. Therefore, we believe that added variations or complexity in the HIMTD program was also a key reason for the improved outcomes. However, future research is needed to confirm the interactive effect of these variables.

There are several strengths in our study. Our findings are clinically relevant for patients with stroke who have poor trunk control, balance, and mobility. However, to benefit from our proposed technique, patients should be able to sit, stand, and walk for a short distance. Furthermore, participants with moderate fall risk can practice HIMTD exercises using an overhead harness when needed. Finally, our program does not require expensive equipment, which is important in the current climate of limited health care and economic resources.

This study also has some limitations. First, our findings primarily apply to community-dwelling patients with stroke who have relatively good function, few comorbidities, and mild-to-moderate cognitive impairments. We did not measure the effect of DT practice on both motor and cognitive performance. Therefore, it is unclear whether the benefits are owing to improved performance in both motor and cognitive components or only in motor components. We also did not account for specific activities that patients with stroke might perform in their homes or community; however, this is a general limitation of monitoring and is not specific to this study. Second, we did not measure the change in kinematics and muscle activity over time. Therefore, we recommend that future research should include physiological measures to determine the effectiveness of HIMTD therapy. Further research using a factorial design is needed to determine which of the three therapeutic strategies is primarily responsible for improving patient outcomes.

Conclusion

In this study, we provided evidence that incorporating high-intensity training, more multi-dimensional trunk movements, and DT practices into a traditional exercise regime for patients with stroke effectively promotes trunk control, balance, and functional recovery and reduces their fall risk. Our method can substantially improve independent mobility and reduce the fall risk in patients with moderate-to-mild stroke.

Acknowledgements

The authors would like to express their gratitude to all participants who were committed to this study during this critical period.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ORCID iD

Umair Ahmed https://orcid.org/0000-0002-2275-0115

References

1. Di Monaco M, Trucco M, Di Monaco R, et al. The relationship between initial trunk control or postural balance and inpatient rehabilitation outcome after stroke: a prospective comparative study. *Clin Rehabil* 2010; 24: 543–554.
2. Van Criekinge T, Truijen S, Schröder J, et al. The effectiveness of trunk training on trunk control, sitting and standing balance and mobility post-stroke: a systematic review and meta-analysis. *Clin Rehabil* 2019; 33: 992–1002.
3. Duarte E, Marco E, Muniesa JM, et al. Trunk control test as a functional predictor in stroke patients. *J Rehabil Med* 2002; 34: 267–272.
4. van Dijk MM, Meyer S, Sandstad S, et al. A cross-sectional study comparing lateral and diagonal maximum weight shift in people with stroke and healthy controls and the correlation with balance, gait and fear of falling. *PLoS One*. 2017; 12: e0183020.
5. Cabanas-Valdés R, Bagur-Calafat C, Girabent-Farrés M, et al. The effect of additional core stability exercises on improving dynamic sitting balance and trunk control for subacute stroke patients: a randomized controlled trial. *Clin Rehabil* 2016; 30: 1024–1033.
6. Noh HJ, Lee SH and Bang DH. Three-dimensional balance training using visual feedback on balance and walking ability in subacute stroke patients: A single-blinded randomized controlled pilot trial. *J Stroke Cerebrovasc Dis* 2019; 28: 994–1000.
7. Robinson CA, Shumway-Cook A, Ciol MA, et al. Participation in community walking following stroke: subjective versus objective measures and the impact of personal factors. *Phys Ther* 2011; 91: 1865–1876.
8. Al-Yahya E, Dawes H, Smith L, et al. Cognitive motor interference while walking: a systematic review and meta-analysis. *Neurosci Biobehav Rev* 2011; 35: 715–728.
9. Harley C, Boyd J, Cockburn J, et al. Disruption of sitting balance after stroke: influence of spoken output. *J Neurol Neurosurg Psychiatry* 2006; 77: 674–676.
10. Plummer P, Eskes G, Wallace S, et al. Cognitive-motor interference during functional mobility after stroke: state of the science and implications for future research. *Arch Phys Med Rehabil* 2013; 94: 2565–2574.e6.
11. Subramaniam S, Hui-Chan CWY and Bhatt T. Effect of dual tasking on intentional vs. reactive balance control in people with hemiparetic stroke. *J Neurophysiol* 2014; 112: 1152–1158.
12. Plummer-D'Amato P, Altmann LJ, Saracino D, et al. Interactions between cognitive tasks and gait after stroke: a dual task study. *Gait Posture* 2008; 27: 683–688.
13. Tsang CSL and Pang MYC. Association of subsequent falls with evidence of dual-task

interference while walking in community-dwelling individuals after stroke. *Clin Rehabil* 2020; 34: 971–980.
14. Hawkins KA, Fox EJ, Daly JJ, et al. Prefrontal over-activation during walking in people with mobility deficits: interpretation and functional implications. *Hum Mov Sci* 2018; 59: 46–55.
15. Masters R and Maxwell J. The theory of reinvestment. *Int Rev Sport Exerc Psychol* 2008; 1: 160–183.
16. Wulf G, McNevin N and Shea CH. The automaticity of complex motor skill learning as a function of attentional focus. *Q J Exp Psychol A* 2001; 54: 1143–1154.
17. Baek CY, Chang WN, Park BY, Lee KB, Kang KY and Choi MR. Effects of dual-task gait treadmill training on gait ability, dual-task interference, and fall efficacy in people with stroke: A Randomized Controlled Trial. *Phys Ther*. 2021; 101: pzab067.
18. Pang MYC, Yang L, Ouyang H, et al. Dual-task exercise reduces cognitive-motor interference in walking and falls after stroke: a randomized controlled study. *Stroke* 2018; 49: 2990–2998.
19. Kleim JA and Jones TA. Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. *J Speech Lang Hear Res* 2008; 51: S225–S239.
20. Carey JR, Bhatt E and Nagpal A. Neuroplasticity promoted by task complexity. *Exerc Sport Sci Rev* 2005; 33: 24–31.
21. De Luca A, Squeri V, Barone LM, et al. Dynamic stability and trunk control improvements following robotic balance and core stability training in chronic stroke survivors: a pilot study. *Front Neurol* 2020; 11: 494.
22. Page SJ, Gater DR and Bach-y-Rita P. Reconsidering the motor recovery plateau in stroke rehabilitation. *Arch Phys Med Rehabil* 2004; 85: 1377–1381.
23. Van Duijnhoven HJ, Heeren A, Peters MA, et al. Effects of exercise therapy on balance capacity in chronic stroke: systematic review and meta-analysis. *Stroke* 2016; 47: 2603–2610.
24. Mehrholz J, Thomas S and Elsner B. Treadmill training and body weight support for walking after stroke. *Cochrane Database Syst Rev* 2017; 8: CD002840.
25. Häkkinen K, Alen M, Kallinen M, et al. Neuromuscular adaptation during prolonged strength training, detraining and re-strength-training in middle-aged and elderly people. *Eur J Appl Physiol* 2000; 83: 51–62.
26. Schulz KF, Altman DG, Moher D, et al. CONSORT 2010 statement: updated guidelines for reporting parallel group randomised trials. *Trials* 2010; 11: 32.
27. Verheyden G, Nieuwboer A, Mertin J, et al. The Trunk Impairment Scale: a new tool to measure motor impairment of the trunk after stroke. *Clin Rehabil* 2004; 18: 326–334.
28. Duncan P, Lai S, Bode R, et al. Stroke Impact Scale-16: A brief assessment of physical function. *Neurology* 2003; 60: 291–296.
29. Flansbjer UB, Holmbäck AM, Downham D, et al. Reliability of gait performance tests in men and women with hemiparesis after stroke. *J Rehabil Med* 2005; 37: 75–82.
30. Tyson S and Connell L. The psychometric properties and clinical utility of measures of walking and mobility in neurological conditions: a systematic review. *Clin Rehabil* 2009; 23: 1018–1033.
31. Ahmed U, Karimi H, Gilani SA, et al. Translation and validation of the stroke impact scale 3.0 into Urdu for Pakistan. *NeuroRehabilitation* 2021: 1–12.
32. Levit K. Trunk control during functional performance. *American Occupational Therapy Association Annual Conference*. 1997.
33. Lee K, Lee D, Hong S, et al. The relationship between sitting balance, trunk control and mobility with predictive for current mobility level in survivors of sub-acute stroke. *PLoS One* 2021; 16: e0251977.
34. Cabanas-Valdés R, Cuchi GU and Bagur-Calafat C. Trunk training exercises approaches for improving trunk performance and functional sitting balance in patients with stroke: a systematic review. *NeuroRehabilitation* 2013; 33: 575–592.
35. Gera G, McGlade KE, Reisman DS, et al. Trunk muscle coordination during upward

and downward reaching in stroke survivors. *Motor Control* 2016; 20: 50–69.
36. Ryerson S and Levit K. *Functional movement reeducation: a contemporary model for stroke rehabilitation*. Churchill Livingstone, 1997.
37. Jung KM, Joo MC, Jung YJ, et al. The effects of the three-dimensional active trunk training exercise on trunk control ability, trunk muscle strength, and balance ability in sub-acute stroke patients: A randomized controlled pilot study. *Technol Health Care* 2021; 29: 213–222.
38. Buvarp D, Rafsten L and Sunnerhagen KS. Predicting longitudinal progression in functional mobility after stroke: a prospective cohort study. *Stroke* 2020; 51: 2179–2187.
39. Podsiadlo D and Richardson S. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J Am Geriatr Soc* 1991; 39: 142–148.
40. Hiengkaew V, Jitaree K and Chaiyawat P. Minimal detectable changes of the Berg Balance Scale, Fugl-Meyer Assessment Scale, Timed "Up & Go" Test, gait speeds, and 2-minute walk test in individuals with chronic stroke with different degrees of ankle plantarflexor tone. *Arch Phys Med Rehabil* 2012; 93: 1201–1208.
41. Alghadir AH, Al-Eisa ES, Anwer S, et al. Reliability, validity, and responsiveness of three scales for measuring balance in patients with chronic stroke. *BMC Neurol* 2018; 18: 141.
42. Verheyden G, Van Duijnhoven HJ, Burnett M, et al. Kinematic analysis of head, trunk, and pelvis movement when people early after stroke reach sideways. *Neurorehabil Neural Repair* 2011; 25: 656–663.
43. Pichierri G, Wolf P, Murer K, et al. Cognitive and cognitive-motor interventions affecting physical functioning: a systematic review. *BMC Geriatr* 2011; 11: 29.
44. Schmid A, Duncan PW, Studenski S, et al. Improvements in speed-based gait classifications are meaningful. *Stroke* 2007; 38: 2096–2100.
45. Cesari M, Kritchevsky SB, Penninx BW, et al. Prognostic value of usual gait speed in well-functioning older people—results from the Health, Aging and Body Composition Study. *J Am Geriatr Soc* 2005; 53: 1675–1680.
46. Van Kan GA, Rolland Y, Andrieu S, et al. Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people an International Academy on Nutrition and Aging (IANA) Task Force. *J Nutr Health Aging* 2009; 13: 881–889.
47. Ryerson, S. Movement Dysfunction Associated with Hemiplegia. Umphred DA, Lazaro RT, Roller ML and Burton GU, eds. Umphred's Neurological Rehabilitation. 5Th ed. St. Louis: Elsevier Mosby. 2013. pp. 711–752.
48. Hacmon RR, Krasovsky T, Lamontagne A, et al. Deficits in intersegmental trunk coordination during walking are related to clinical balance and gait function in chronic stroke. *J Neurol Phys Ther* 2012; 36: 173–181.
49. Karthikbabu S, Chakrapani M, Ganesan S, et al. Efficacy of trunk regimes on balance, mobility, physical function, and community reintegration in chronic stroke: a parallel-group randomized trial. *J Stroke Cerebrovasc Dis* 2018; 27: 1003–1011.
50. Chung EJ, Kim JH and Lee BH. The effects of core stabilization exercise on dynamic balance and gait function in stroke patients. *J Phys Ther Sci* 2013; 25: 803–806.
51. Shah PK, Gerasimenko Y, Shyu A, et al. Variability in step training enhances locomotor recovery after a spinal cord injury. *Eur J Neurosci* 2012; 36: 2054–2062.

Appendix I Exercises performed in trunk training protocols

Trunk control level	Sitting/kneeling/half-kneeling/standing: trunk training exercises
I	Posture holding, posture holding with resistance*
II	Pelvic shifting to anterior/posterior/lateral*/diagonal*
II	Pelvic clock (rotation) exercise*
II	Trunk movement (anterior, posterior, lateral,* rotation, diagonal rotation*)
III	Reaching, with one or both upper extremities, forward (shoulder flexion) or to the side straight (shoulder abduction) or diagonal* or across* (scaption or adduction); for objects placed down to pick up an object (e.g., cones, cup, book) from the floor or from a small stool or normal height tabletop or reaching overhead (a high shelf)
III	Lifting a ball with both hands and moving it diagonally up/down* and across the body*
III	Forward/side*/diagonal* stepping only in kneeling/half-kneeling/standing
III	Mini-squats with diagonal* trunk rotation from standing or sitting
III	Lunge, forward/backward/diagonal bending * to the right/left (only in standing)
IV	Throwing and catching a ball (forward, lateral,* and diagonal*)
IV	Bouncing a ball (forward, lateral,* and diagonal*)
IV	Tossing and catching a ball/balloon (forward, lateral,* and diagonal*)
IV	Walking diagonal,* lateral,* forward, backward (only in kneeling & walking)
IV	Cross stepping*/braiding* with trunk rotation to the opposite side (only in standing)

Characteristics of exercise regimes	SCTR-group exercises	HIMTD-group exercises
Plane	Mainly sagittal plane	Mainly in diagonal & lateral plane
Direction	Unidirectional > multidirectional & lateral	Multidirectional & lateral > unidirectional
Dual-task practice	No dual-task	Dual-task included
Intensity	Normal intensity (somewhat heavy) on mRPE	Higher intensities (heavy) on mRPE

*These exercises were performed more frequently in the HIMTD than the SCTR group.

Note: Exercises performed on both firm and labile surfaces (physioball and compliant surfaces, such as both sides up [BOSU] equipment).

HIMTD, high-intensity multiplanar trunk training coupled with dual-task; SCTR, standardized trunk care regime; mRPE, modified rating of perceived exertion.