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ORIGINAL ARTICLE

Effects of Stable-Sitting Trunk Exercises on Trunk Muscle Activation and Postural Control in Stroke Survivors: A Pilot Study

ALEXANDER TAN WT[1], RAZALI MF[1]*, RIPIN ZM[1], YEO YH[1], TAY JY[1], NUR-AKASYAH J[1], RIDZWAN MIZ[1], HANAFI MH[2], YUSOF HA[3], ABD HAMID IJ[4], GHAZALI NI[3]

[1]Neurorehabilitation Engineering and Assistance Systems Research, School of Mechanical Engineering, Universiti Sains Malaysia, Penang, Malaysia
[2]Rehabilitation Medicine Unit, School of Medical Sciences, Universiti Sains Malaysia, Kubang Kerian, Malaysia
[3]Lifestyle Science Cluster, Advanced Medical and Dental Institute, Universiti Sains Malaysia, Kepala Batas, Pulau Pinang, Malaysia
[4]Primary Immunodeficiency Disease Group, Department of Clinical Medicine, Institut Perubatan dan Pergigian Termaju, Universiti Sains Malaysia, 13200 Kepala Batas, Pulau Pinang, Malaysia

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ABSTRAK

Latihan pemulihan batang tubuh selepas strok sering memerlukan peralatan tambahan atau bantuan klinikal yang menimbulkan cabaran dalam persekitaran sumber terhad. Walaupun latihan batang tubuh duduk yang stabil menawarkan alternatif kos efektif, kajian tentang kesan segeranya adalah terhad. Oleh itu, kajian ini bertujuan untuk menentukan kesan segera lima latihan asas batang tubuh duduk yang stabil pada otot erektor spina (ES) dan kawalan postur pesakit strok. Reka bentuk eksperimen pemerhatian kajian keratan lintang telah digunakan dalam kajian ini. Sejumlah 11 pesakit strok yang mengalami kelemahan di bahagian paretik dipilih untuk melaksanakan lima latihan teras duduk stabil di atas plat daya yang direka khas. Aktiviti otot individu diukur menggunakan elektromiografi (EMG). Ukuran kawalan postur seperti daya tindak balas tanah menegak (GRF), dan pusat tekanan (CoP) dinilai dengan menggunakan plat daya tersebut. Keputusan ANOVA menunjukkan latihan putaran batang tubuh (43.25 $\pm$ 19.57%RVC) telah mengaktifkan otot ES kiri yang lebih tinggi secara signifikan berbanding dengan fleksi-ekstensi (25.47 $\pm$ 17.70%RVC; $p = 0.011$) dan kecondongan-sagital (25.93 $\pm$

Address for correspondence and reprint requests: Muhammad Fauzinizam Razali. School of Mechanical Engineering, Universiti Sains Malaysia 14300 Nibong Tebal, Penang, Malaysia. Tel: +604-5996382 Email: mefauzinizam@usm.my

18.19%RVC; p = 0.017). Begitu juga, latihan putaran batang tubuh mengaktifkan lebih banyak aktiviti otot dalam otot ES kanan berbanding dengan latihan lain. Penemuan ini mencadangkan potensi latihan putaran batang tubuh sebagai tambahan yang berkesan kepada program pemulihan, terutamanya dalam persekitaran sumber terhad atau intervensi berpangkalan rumah.

Kata kunci: Kawalan batang tubuh; posisi duduk; rehabilitasi strok

ABSTRACT

Post-stroke trunk rehabilitation often necessitates additional equipment or clinical assistance, which poses challenges in resource-limited settings. Although stable-sitting trunk exercises offer cost-effective alternatives, studies on their immediate effects are limited. Hence, this study aimed to investigate the immediate effects of five common stable-sitting trunk exercises on erector spinae (ES) muscle and postural control of stroke patients. A cross-sectional observational experimental design was employed in this study. The 11 paretic stroke patients recruited were asked to perform five stable-sitting core exercises on a customised force plate. The muscle activities of the individuals were measured with electromyography (EMG). Postural control measures such as vertical ground reaction force (GRF), and centre of pressure (CoP) were evaluated utilising the force plate. The ANOVA results demonstrated that the trunk rotation exercise (43.25 $\pm$ 19.57%RVC) elicited significantly higher muscle activity in the left ES muscle than flexion-extension (25.47 $\pm$ 17.70%RVC; $p = 0.011$) and sagittal-inclination (25.93 $\pm$ 18.19%RVC; $p = 0.017$). Similarly, the trunk rotation exercise activated more muscle activity in the right ES muscle than in the other exercises. This finding suggests the potential of trunk rotation exercise as an effective addition to rehabilitation programs, especially in resource-limited settings or home-based interventions.

Keywords: Sitting position; stroke rehabilitation; trunk control

INTRODUCTION

Stroke or cerebrovascular disease has a substantial impact on public health and is one of the leading mortality causes in Malaysia. In 2019, Malaysia reported 47,911 incidents, 19,928 deaths, and 443,995 prevalent stroke cases (Tan et al. 2022). Furthermore, low- and middle-income nations have reported a 22% and 6% rise in haemorrhagic and ischemic stroke incidences, respectively, over the past 20 years (Feigin et al. 2017). The alarming statistics highlight the urgent need for effective interventions to mitigate the increasing impact of stroke, particularly in low- and middle-income regions.

A prevalent clinical consequence

of stroke is balance dysfunction, affecting up to 80% of survivors to varying degrees (Tyson et al. 2006). Commonly, balance dysfunction results from impaired motor control in the trunk, limb, and pelvis (Oliveira et al. 2011), which compromises the activities of daily living (ADL) and elevates fall risks (Giriko et al. 2010; Houdijk et al. 2010). Trunk training could be an intervention strategy to enhance balance in stroke patients. Extensive evidence also supports the efficacy of trunk training on stable or mobile surfaces in improving trunk control, sitting balance, and mobility (Cabanas-Valdés et al. 2017; Haruyama et al. 2017; Van Criekinge et al. 2019). Furthermore, reports have underscored the predictive outcome values of trunk function for balance (Di Monaco et al. 2010), walking ability (Duarte et al. 2009), and ADL (Hsieh et al. 2002; Verheyden et al. 2007).

Although numerous trunk exercises have demonstrated benefits for post-stroke recovery, most require additional equipment, assistance, or healthcare provider supervision (Van Criekinge et al. 2019). In low- and middle-income nations, limited rehabilitation facilities and stroke rehabilitation specialists and transportation costs compound the rehabilitation burden (Kayola et al. 2023). Consequently, trunk exercises on a stable surface without equipment might be a more accessible and cost-effective alternative.

Force platform measurements offer a quantitative approach for postural control evaluations. The techniques are commonly employed in postural control assessments, such as centre of pressure (CoP) displacements, which are reliable indicators for weight-shifting tasks in a sitting position (Inoue et al. 2022; Wiskerke et al. 2021). Moreover, the force platform is utilised to evaluate lower limb compensation during trunk flexion and reaching tasks in a sitting position through vertical ground reaction forces (GRF) analyses on the feet (Dean et al. 1999; Messier et al. 2004). For instance, a report noted that foot compensation during reaching tasks in stroke patients was indicated by 2.3% ± 3.6% GRF changes in the paretic foot, while the non-paretic foot recorded 2.2% ± 2.9%. On the other hand, surface electromyography (sEMG) is a non-invasive method of quantifying muscle activity involved in trunk movements, which is commonly employed to determine specific exercises or devices effectiveness (Babyar et al. 2022). A study found that reaching tasks considerably increased activity in erector spinae (ES) muscle of stroke patients [188.38 ± 108.06 reference voluntary contraction percentage (% RVC)] than healthy controls (119.92 ± 53.39% RVC) (Winzeler-Merçay et al. 2002).

Studies on the effects of stable -sitting trunk exercises on muscle activity and postural control of stroke survivors are limited. Consequently, the present study aimed to investigate the immediate effects of five common stable-sitting trunk exercises on bilateral ES muscle activities and postural control in stroke patients. Force platform measurements were employed in this study, which allowed postural control quantitative evaluations. EMG measurements were also utilised to quantify muscle activity in trunk movements, focusing on the ES muscle due to its significance (Babyar et al. 2022) and pivotal role in vertebral rotation (Bogduk 2005). Knowledge of the most effective exercises for specific muscles would enable the customisation of rehabilitation programmes, hence optimising recovery and enhancing functional abilities.

MATERIALS AND METHODS

Ethical Approval

The current study received ethical approval from the Universiti Sains Malaysia (USM) Human Research Ethics Committee (JEPeM) under the code USM/JEPeM/22120824. The custom-developed force plate utilised in the study received a usage exemption from the Medical Device Authority (MDA), Ministry of Health Malaysia, under protocol number FS-GMD-20230308-4.

Participant Selection

The current study was a within-participant repeated measures cross-sectional pilot investigation that involved 11 stroke patients (eight males and three females). Participants receiving standard treatment under the rehabilitation unit of Advanced Medical and Dental Institute (AMDI), USM, were considered for this study. Only individuals (i) aged 18 years and above, (ii) experiencing paretic status from a single stroke, and (iii) who could understand and execute simple instructions and maintain a stable-sitting position were included. Conversely, patients who were (i) suffering from comorbidities that could potentially interfere with the experiment, (ii) undergoing other treatments that could influence the effects of the interventions, and (3) having cardiac pacemaker implants were excluded. All participants provided informed consent before participating in the current study.

Experimental Setup

The demographic and clinical data of the participants were collected before beginning the experiment to ensure compliance with inclusion criteria. Figure 1 illustrated the experimental setup utilised by the participants to execute all five stable-sitting trunk exercises. The CoP velocity and the GRF exerted by the participants were measured with a custom-developed NEAR3 Force Platform (USM, Penang, Malaysia), while a Shimmer3 EMG unit (Shimmer, Dublin, Ireland) was employed to record EMG data.

The electrode placement over the lumbar ES muscles during EMG data collection was per surface electromyography for the non-invasive assessment of muscles (SENIAM) guidelines (Hermens et al. 1999). A reference electrode was also placed on C7 spinous processes (Hermens et al. 1999). Figure 2 illustrated the electrode placements and the Shimmer3 EMG unit on the back of the participants. The participants performed the RVC procedure for the ES muscle to

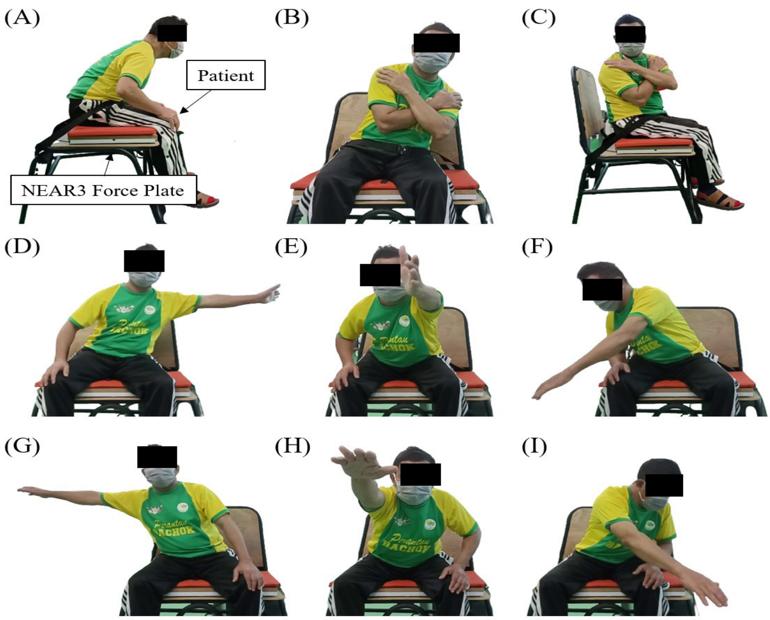

FIGURE 1: Stable sitting trunk exercises carried out by stroke patient. (A) Trunk flexion-extension; (B) trunk sagittal inclination; (C) upper trunk rotation; forward reach in three directions with the left limb including (D) left lateral, (E) anterior, (F) left diagonal; and forward reach in three directions with the right limb including (G) right lateral, (H) anterior, (I) right diagonal

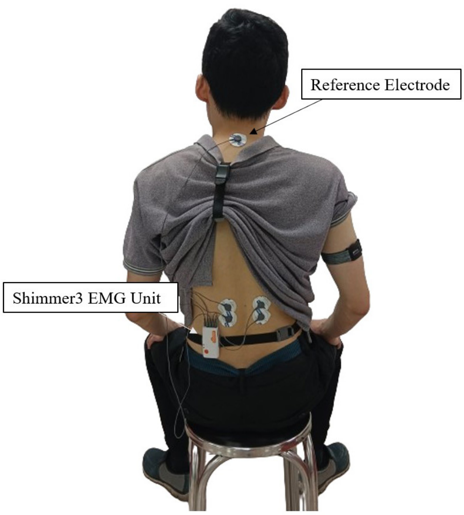

FIGURE 2: Measurement setup for surface EMG electrodes

establish their baseline values after the electrodes were situated (Chen et al. 2021).

During the experiments, the participants sat with knees fixed at a 90° angle and feet gently supported on a footrest. The individuals were also instructed not to make contact with the seat backrest during the exercises. The activities selected were based on the report by (Cabanas-Valdés et al. 2021) and physiotherapist recommendations. The exercise sequence was randomised and repeated thrice.

The postures assumed by the participants while performing the exercises were demonstrated in Figures 1(A) to (I). Figure 1(A) depicted the trunk flexion extension, which involved alternately curling and arching the trunk forward. The sagittal trunk inclination exercise included lateral flexion and extension by pivoting the pelvis as shown in Figure 1(B). The upper trunk rotation that involved shoulder turns with arms crossed was illustrated in Figure 1(C). Figures 1(D) to 1(F) demonstrated the forward-reaching exercise with the left limb, targeting balance and reaching the lateral, anterior, and diagonal directions, while exercises for the right limb were demonstrated in Figures 1(G) to (I).

Outcome Measures

The ES muscle EMG amplitudes were recorded at 1024 Hz and processed with a 20 Hz fourth-order high-pass Butterworth filter before employing a 511 Hz low-pass cutoff. Line noise elimination was performed with a multi-taper sinusoidal component estimate. Subsequently, the signal was rectified before applying a fourth-order, zero-phase-lag low-pass Butterworth filter with a 10 Hz cutoff for a smooth linear envelope. The present study employed the maximum figure from three RVC trials as the 100% RVC value for EMG normalisation. The root mean square (RMS) of the normalised EMG was also calculated.

Vertical GRF and CoP alterations were measured with the force plate throughout each exercise at 80 Hz, utilising a custom C++ data collection software. Subsequently, the GRF from the force plate was determined as a percentage of the GRF during quiet sitting (see Equation 1). In the current study, the GRF changes represented an equivalent pressure redistribution from the buttocks and thighs to the feet in a stable-sitting position without backrest contact. Consequently, the data offered an alternative approach for assessing lower limb compensation (Sheehy et al. 2020). On the other hand, the CoP velocity was derived based on a previous report (Prieto et al. 1996), which offered valuable insights into trunk movement velocity (Sheehy et al. 2020).

Equation 1:

GRF% = (Specific exercise GRF – GRF during quiet sitting)/(GRF during quiet sitting) x 100%

Statistical Analysis

Statistical analyses in the current study were performed with Statistical Package for the Social Sciences (SPSS) v27.0 for Windows (SPSS, Chicago, Illinois). The normal distribution of the data obtained was confirmed through the Shapiro-Wilk assessment. Furthermore, Mauchly’s test of sphericity was utilised to evaluate the sphericity assumption in the present study, while violations were corrected with the Greenhouse-Geisser correction.

The RMS of EMG amplitudes and postural control data for all five exercises were compared with one-way repeated measures analysis of variance (ANOVA). The effect size for each main effect and interaction was also determined by calculating the partial eta-squared (η^2). At the same time, post-hoc pairwise comparisons were conducted with Bonferroni corrections to establish specific differences between the exercises. The corrections were crucial to minimise the risk of type I errors during multiple comparisons. Variations in paretic and non-paretic ES muscle activities during the physical activities were established through paired t-test assessments as they were well-suited for comparing two related groups with the statistical significance level set at $\alpha = 0.05$.

TABLE 1: Demographic and clinical characteristics of the participants

Characteristics	**Participants (n=11)**
Mean age in years ± SD	46 ± 10
Male/Female (n)	8/3
Left hemisphere stroke, n (%)	6 (54.5%)
Berg Balance Scale Score (mean ± SD)	45.5 ± 9.6
Time post-stroke (mean months ± SD)	9.11 ± 6.05
BMI (mean kg/m^2 ± SD)	26.22 ± 3.37

RESULTS

Table 1 summarised the demographic and clinical characteristics overview of the participants in this study. The eight males and three females were between 32 and 58 years, with a mean age of 46 (SD = 10). The left and right RMS EMG muscle activities during various exercises ANOVA results were listed in Table 2. The RMS EMG amplitude ranged between 48.44 ± 34.76 and 25.47 ± 17.70% RVC for the

TABLE 2: Descriptive outcomes of RMS EMG output, GRF, mean CoP velocity (mean & SD) and ANOVA results

	EXERCISE					**ANOVA**		
	Trunk flexion-extension	**Trunk sagittal inclination**	**Forward reach in three directions with left limb**	**Forward reach in three directions with right limb**	**Upper trunk rotation**	**F-Stat**	**p-value**	**Effect Size (η^2)**
EMG								
ES Left RMS EMG (%RVC)	26.76 (18.81)	23.71 (14.40)	36.60 (21.00)	29.86 (11.56)	41.19 (20.55)	$F[1.821, 16.386] = 5.817$	$p = 0.014$	0.393
ES Right RMS EMG (%RVC)	26.76 (18.81)	23.71 (14.40)	36.60 (21.00)	29.86 (11.56)	41.19 (20.55)	$F[4, 28] = 4.160$	$p = 0.009$	0.373
Postural control								
GRF (%)	-3.29 (2.15)	0.11 (0.98)	-3.87 (2.24)	-5.85 (2.89)	1.06 (1.54)	$F[1.810, 14.482] = 17.789$	$p < 0.001$	0.690
Mean CoP Velocity (cm/s)	4.50 (1.26)	6.01 (2.44)	8.19 (4.01)	7.86 (3.70)	5.15 (1.64)	$F[1.517, 15.166] = 11.316$	$p = 0.002$	0.531

Note: ES: erector spinae; RMS: root mean squared; RVC: reference voluntary contraction; GRF: ground reaction force; CoP: centre of pressure left ES muscle, while the right muscle recorded between 41.19 ± 20.55 and 23.71 ± 14.40% RVC.

The postural control results in Table 2 demonstrated that the highest lower limb compensation occurred during the right-sided reaching exercises, evidenced by the reduced GRF (-5.85 ± 2.89%). Conversely, trunk rotation exercise led to lower limb lowest compensation (1.06 ± 1.54%). Similarly, CoP velocity was relatively higher during reaching exercises on the left (8.19 ± 4.01 cm/s) and right (7.86 ± 3.70 cm/s) sides than other exercises.

The ANOVA results recorded significant differences between exercises for the left ($F[1.821, 16.386] = 5.817$; $p = 0.014$) and right ($F[4, 28] = 4.160$; $p = 0.009$) ES muscles. The force plate ANOVA data also demonstrated significant differences, particularly GRF ($F[1.810, 14.482] = 17.789$; $p<0.001$) and CoP velocity ($F[1.517, 15.166] = 11.316$; $p = 0.002$). Post-hoc evaluations with Bonferroni corrections were performed to interpret the observed differences, and the results were illustrated in Figure 3.

The boxplots in Figure 3 exhibited the left and right ES muscle RMS EMG, GRF, and CoP velocity for all five exercises, where the asterisks (*) denoted statistically significant differences. Based on Figure 3(A), trunk rotation exercises (43.25 ± 19.57% RVC) induced notably superior left ES muscle activation than flexion-extension (25.47 ± 17.70% RVC; $p = 0.011$) and sagittal-inclination

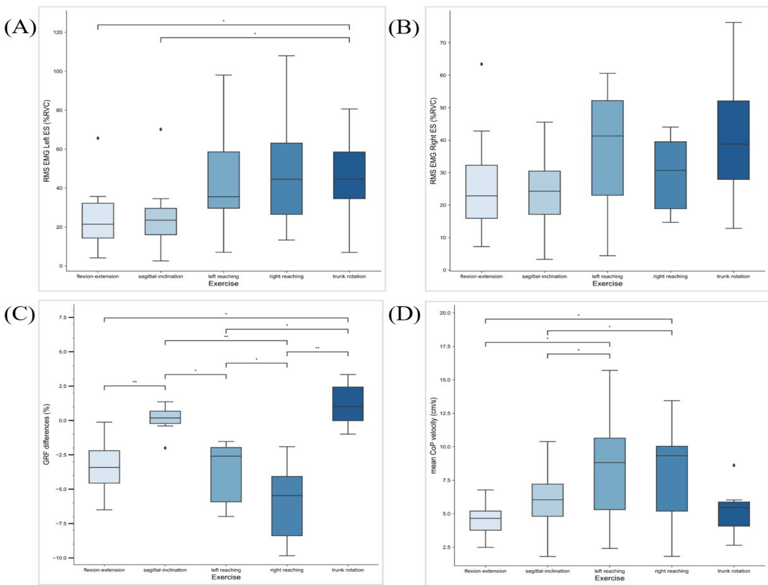

FIGURE 3: Boxplots for the (A) RMS EMG amplitude of left ES muscle, (B) RMS EMG amplitude of right ES muscle, (C) GRF differences, and (D) mean CoP velocity for different exercises in stroke patients. The box plots were constructed using data trials of all participants. Note: p-value at *<.05, **<.01, and ***<.001.

(25.93 ± 18.19% RVC; p = 0.017) exercises. Although ANOVA indicated considerable overall group variation, subsequent Bonferroni-adjusted pairwise comparisons revealed non-significant individual contrasts, demonstrated in Figure 3(B).

Vertical GRF pairwise comparisons in Figure 3(C) revealed significantly reduced GRF during flexion extension and reaching activities than other exercises (all pairwise p<0.05), indicating increased lower limb compensation. Based on Figure 3(D), a considerably higher CoP velocity during reaching exercises than flexion-extension and sagittal-inclination activities (all pairwise p<0.05), denoting rapid trunk movements.

Table 3 summarised paretic and non-paretic ES muscle activity RMS EMG comparison. Nevertheless, the data excluded participants with bilateral paretic for a more focused analysis of specific variations during particular exercises. The results suggested no statistically significant distinction in ES muscle activities between non-paretic and paretic sides. Nevertheless, the trunk flexion-extension exercise demonstrated comparable mean values between the non-paretic (24.78 ± 19.83%RVC) and paretic (23.02 ± 13.68%RVC) sides, recording a 0.453 non-significant t-statistic and 0.666 p-value. Similarly, trunk sagittal inclination, upper trunk rotation, and forward-reaching exercises in left and right directions exhibited no statistically notable variation between sides.

DISCUSSION

The current study investigated the ES muscle activities and postural control of stroke patients during stable-sitting trunk exercises commonly employed in clinical practice. The EMG values obtained were measured as % RVC to accommodate the limitations of stroke patients in performing maximal voluntary isometric contraction (MVIC) tasks (Sousa et al. 2012).

The left ES muscle recorded RMS EMG between 48.44 ± 34.76 and 25.47 ± 17.70% RVC, while the right muscle ranged between 41.19 ± 20.55 and 23.71 ± 14.40% RVC. Muscle activity exceeding 50% MVIC is classified

TABLE 3: Comparison of non-paretic and paretic side ES muscle activity

Exercise	Non-paretic side ES	Paretic side ES	T-statistics	p-value
	Mean (SD)	Mean (SD)		
Trunk flexion-extension	24.78 (19.83)	23.02 (13.68)	0.453	0.666
Trunk sagittal inclination	25.26 (22.07)	21.35 (11.22)	0.679	0.522
Upper trunk rotation	37.75 (28.19)	42.88 (29.99)	-0.579	0.584
Forward reach in three directions with left limb	36.75 (31.27)	34.39 (19.81)	0.213	0.838
Forward reach in three directions with right limb	42.82 (25.07)	38.37 (16.47)	0.737	0.489

Note: ES: erector spinae

as high and demanding for healthy individuals (Townsend et al. 1991). The outcomes of this study suggested that stable-sitting trunk exercises are less strenuous. Consequently, the activities could be employed in ES muscle-strengthening exercises for stroke patients, particularly when performed without direct supervision from clinicians.

This study reveals that the trunk rotation activities elicited higher ES muscle activation in the both sides in contrast to flexion-extension and sagittal-inclination activities as shown in Figure 3(A). The findings in this study aligned with the pivotal role of the ES muscles in vertebral rotation across the coronal and transverse planes (Bogduk 2005). Increased torque occurs around the spine during rotational movements, necessitating significant erector activation for effective spinal stability and twisting motion control. Muscle effort also rises with trunk rotation degree, explaining the higher ES activity observed with trunk rotation exercises (Torén 2001).

Although statistically non-significant, the results demonstrated that ES muscle activity during reaching exercises is relatively higher than extension exercises. The observation aligned with previous reports that highlighted the issues faced by stroke patients in seated reaching tasks (Verheyden et al. 2011). The combined demands of maintaining balance and extending the arm could promote ES muscle activity to ensure trunk stability and control during the exercises.

The participants exhibited a higher trunk movement velocity and lower limb compensation during the reaching exercises, as indicated by CoP velocity and GRF alterations in Table 2, respectively. The lower limb compensatory mechanism was evident through GRF changes, which reflected weight transferred to the feet during exercises. Reaching exercises involve coordinated upper limb movements, encompassing shoulder flexion, abduction, internal rotation, and elbow flexion (Tang et al. 2018). The movements require a higher control complexity level and degree of freedom in the musculoskeletal system than rotational and extension exercises. On the other hand, forward and upward upper limb acceleration during reaching motions necessitate reactive movements that challenge balance (Tokuda et al. 2016), leading to enhanced trunk movement and lower limb compensation.

The study revealed no statistically notable distinction between paretic and non-paretic ES muscle activities across the performed exercises. The findings contradicted a report that noted higher activation levels in ES muscles of the paretic side (Winzeler-Merçay et al. 2002). The study attributed the improved muscle activation to collateral reinnervation, leading to enlarged motor units and heightened muscle responses in paretic muscles (Pinto et al. 2023). The observation discrepancy could be due to the relatively healthy (mean Berg Balance Scale score = 45.6) and young participants in this study (mean age = 46) as recorded in Table 1, thus might have less pronounced asymmetry than studies involving individuals with more severe disabilities. Falling concerns during trunk exercises on a force plate might have promoted compensatory actions, particularly in flexion-extension and reaching activities, as evidenced by the significant reduction in GRF recorded in Table 2 and Figure 3(C). The compensatory movements could impact muscle activation patterns and contribute to the absence of considerable variation between the paretic and non-paretic sides in this study.

Generally, stroke patients regain sitting ability before standing during the early stages of rehabilitation (Sommer et al. 2023). Consequently, early application of trunk training in a seated position is crucial to provide a safer and more accessible starting point for patients to begin their rehabilitation journey (Sommer et al. 2023). Furthermore, several reports have indicated seated trunk training effectiveness during rehabilitation therapy in improving trunk control (Dean et al. 2007; Veerbeek et al. 2014). Various observational studies have also explored the effects of dynamic sitting exercises on unstable surfaces on ES muscle activation, such as on mobile seats (Haas et al. 2022) and Swiss balls (Pereira et al. 2011). Nevertheless, the tools pose several concerns, including increased falling risks, the financial burden of rehabilitation equipment, and the costly supervision required during early rehabilitation phases. Incorporating stable-sitting trunk exercises in stroke rehabilitation protocols could considerably contribute to improving recovery outcomes, particularly in resource-limited settings.

Some limitations in this study warrant consideration. The sample size of the present study was relatively small, compromising the generalisability of the results. The constraints due to the coronavirus-2019 (COVID-19) pandemic affected the recruitment process, limited physical contact, and reduced interaction time with the participants. Consequently, the sample size, exercise intensity, and muscle groups observed in the present study were constrained. The limited sample size and scope of muscle groups studied might result in overlooking potential contributions from other muscles involved in trunk movements. Future studies could examine the activity of additional trunk muscles responsible for trunk movements to enhance comprehension of the obtained results.

CONCLUSION

The current study evaluated ES muscle and postural control activation in stroke patients during five common stable-sitting trunk exercises. The results revealed that trunk rotation activities exhibited higher ES muscle activating efficacy (43.25 $\pm$ 19.57% RVC) than flexion-extension (25.47 $\pm$ 17.70% RVC; $p = 0.011$) and sagittal inclination (25.93 $\pm$ 18.19% RVC; $p = 0.017$) exercises. Furthermore, postural control analysis indicated that reaching activities demanded increased trunk control and compensation due to their challenging nature. These findings suggest the integration of trunk rotation exercise into rehabilitation programs, particularly those designed for home-based or resource-limited settings, as an effective means to enhance trunk muscle.

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AUTHOR DISCLOSURE STATEMENT

No competing financial interests exist.

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