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ORIGINAL ARTICLE

Effects of Task-related Trunk Training with Sensory Electrical Stimulation on Sitting Balance in Stroke Survivors: A Randomized Controlled Trial

Takuya Yada, MSc [a,b] and Kazu Amimoto, PhD [b]

Objectives: The aim of this study was to investigate the immediate effect of sensory electrical stimulation (SES) and task-related trunk training (TRTT) interventions on sitting postural control in stroke survivors. **Methods:** Acute to subacute stroke survivors were screened and recruited for this study. Patients were randomly assigned to the SES group, receiving TRTT combined with simultaneous SES of the neck and lumbar muscles, or to the sham group, receiving TRTT combined with sham stimulation. The primary outcome of the sitting task assessment was the joint angles of the neck and trunk. The outcome was measured at three time points (baseline; online effect: 10 min after the intervention started while the intervention continued; and after-effect: immediately after the intervention). **Results:** In total, 26 patients were divided into the SES (n=13) and sham (n=13) groups. The SES group showed a significant increase in the trunk joint angle for the online effect (P=0.03) and the after-effect (P=0.01) when compared with those measured at baseline. **Conclusions:** TRTT combined with simultaneous SES of the neck and lumbar muscles can immediately change the trunk angle during a sitting balancing task.

Key Words: postural balance; stroke survivors; trunk function

INTRODUCTION

Trunk function in stroke survivors has been reported to be related to standing alignment, distance to the paralyzed side in the standing position, and standing balance ability as measured by the Timed Up-and-Go test and the Berg Balance Scale[1–7] and walking ability.[8,9] Trunk function has also been shown to be a prognostic factor for activities of daily living (ADLs) in stroke survivors.[10–15] In stroke survivors, trunk function must be assessed and adequate intervention must be provided for its restoration.

Sitting imbalance in stroke survivors involves disorders of trunk function and impairment of spatial cognitive function, which often occur together. In previous studies, stroke survivors showed weakness of the trunk muscles,[16] significantly erroneous sense of trunk position,[17] and impaired coordinated muscle movement.[18] These findings suggest the importance of interventions targeting trunk function for sitting balance.[19] Furthermore, impairment of spatial cognitive function in stroke survivors also decreases sitting balance.[20] Moreover, concomitant impairment of trunk function and spatial cognitive dysfunction has been reported,[21,22] and specific interventions for patients with these syndromes have not been reported. As such, there is significant need for intervention methods for sitting balance in stroke survivors with concomitant impairment of trunk function and spatial cognitive dysfunction.

For patients with concomitant impairment of trunk function and spatial cognitive dysfunction, task-related trunk training (TRTT) combined with simultaneous sensory electrical stimulation (SES) of the neck and lumbar muscles may change sitting balance compared to TRTT alone. Pérennou

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[a] Division of Physical Therapy, Department of Rehabilitation, Tokyo Metropolitan Rehabilitation Hospital, Tokyo, Japan
[b] Graduate School of Human Health Sciences, Tokyo Metropolitan University, Tokyo, Japan
Correspondence: Kazu Amimoto, PhD, 7-2-10 Higashi-Ogu, Arakawa-ku, Tokyo 116-8551, Japan, E-mail: amimoto@tmu.ac.jp

et al.[23] reported that SES of the sternocleidomastoid neck muscles on the paralyzed side was effective for improving sitting balance in patients with unilateral spatial neglect (USN). Furthermore, SES can temporarily improve spatial cognitive function in stroke survivors[24,25] and increase the activity of the bilateral insula involved in spatial information.[26] By contrast, SES of the lumbar muscles combined with TRTT was found to improve sitting balance in stroke survivors compared with that in placebo groups,[27–30] and this intervention could change the organization of the motor-related areas in the erector spinae.[31] Therefore, an intervention combining TRTT with simultaneous SES of the neck and lumbar muscles may facilitate improvements in the erector spinae and multifidus functions while enhancing spatial cognition. However, to date, there has been no report of interventions using this combination for sitting balance in stroke survivors. Therefore, we hypothesized that an intervention combining TRTT with simultaneous SES of the neck and lumbar muscles would modify postural control during sitting compared with TRTT alone in stroke survivors, as seen in the immediate effects of this intervention.

MATERIALS AND METHODS

Participants

We recruited patients with cerebral infarction or hemorrhage who had hemiparesis and attended the inpatient stroke rehabilitation program at our hospital. A physician confirmed the diagnosis using computed tomography or magnetic resonance imaging. Patients who were medically stable and able to remain seated in a wheelchair for over 30 min were screened using the following inclusion criteria: (1) first-ever stroke; (2) supratentorial lesion; (3) right-handedness (right-handed cases were incorporated to unify the lateralization of the cerebral hemispheres); (4) pre-illness gait score of 6 or greater on Functional Independent Measure motor (M-FIM) items; (5) no cognitive impairment (Mini-Mental State Examination score ≥24 points) and ability to understand the purpose of the study and its measurement methods; (6) stable neurological symptoms and general condition; (7) no history of orthopedic disease or neurological disorder (Parkinson's disease, spinocerebellar degeneration, or multiple sclerosis); and (8) absence of an implanted cardiac pacemaker. Patients who presented with the following were excluded: (1) ability to walk independently within 1 week of onset of illness; (2) history of vestibular dysfunction; and (3) history of epilepsy. Participants were included in the study when they were able to hold a sitting position for at least 30 min. Demographic data, including age, sex, diagnosis, lesion, time from stroke onset, and cognitive function, as well as Stroke Impairment Assessment Set (SIAS),[32] M-FIM,[33] Functional Ambulation Classification (FAC),[34] Trunk Control Test (TCT),[10] and Trunk Impairment Scale (TIS) scores,[35] were recorded prior to the intervention.

Study Design

This double-blinded randomized controlled trial was conducted based on the CONSORT statement.[36] We recruited acute to subacute stroke survivors admitted at our hospital between January 2021 and March 2022. Patients who provided consent were allocated to the SES group or the sham group through block randomization. Randomization codes were concealed in sequentially numbered, sealed, opaque envelopes. To exclude the effects of different lesion side, we adopted a permuted-block method combined with stratified randomization using the lesion side. The principal investigator requested the allocation from the allocator who informed the interventionist of the allocation group. The principal investigator and evaluators were not informed about the allocation group until the analysis of outcome data was completed. The participants were not informed of their allocation group until the study had been concluded.

All participants provided written informed consent prior to participation. The Ethics Committees of the Tokyo Medical Center (approval number: R20-112) and the Tokyo Metropolitan University approved the study design (approval number: 20089). The study was registered in the University Hospital Medical Information Network Clinical Trials Registry (UMIN-CTR number: UMIN000045235).

TRTT Intervention

TRTT was performed in both groups using a diagonally forward-reaching task while sitting. The starting position was arranged with the hip and knee joints at 90° flexion, the plantar surfaces of the feet were on the floor, and the participant was asked to reach for a target as a motor task. The target was placed at 45° horizontally from the index finger of a non-paraplegic with the shoulder joint flexed at 90° and on the paralyzed side of the participant. The instruction was "please reach for the target as far as you can." Throughout the TRTT, the examiner assisted in preventing falls in stroke survivors with high fall risk. The intervention period, duration, and frequency were 1 day, 20 min, and once every 30 s, respectively.

Patients in the SES group underwent an intervention in which the reaching task was combined with simultaneous

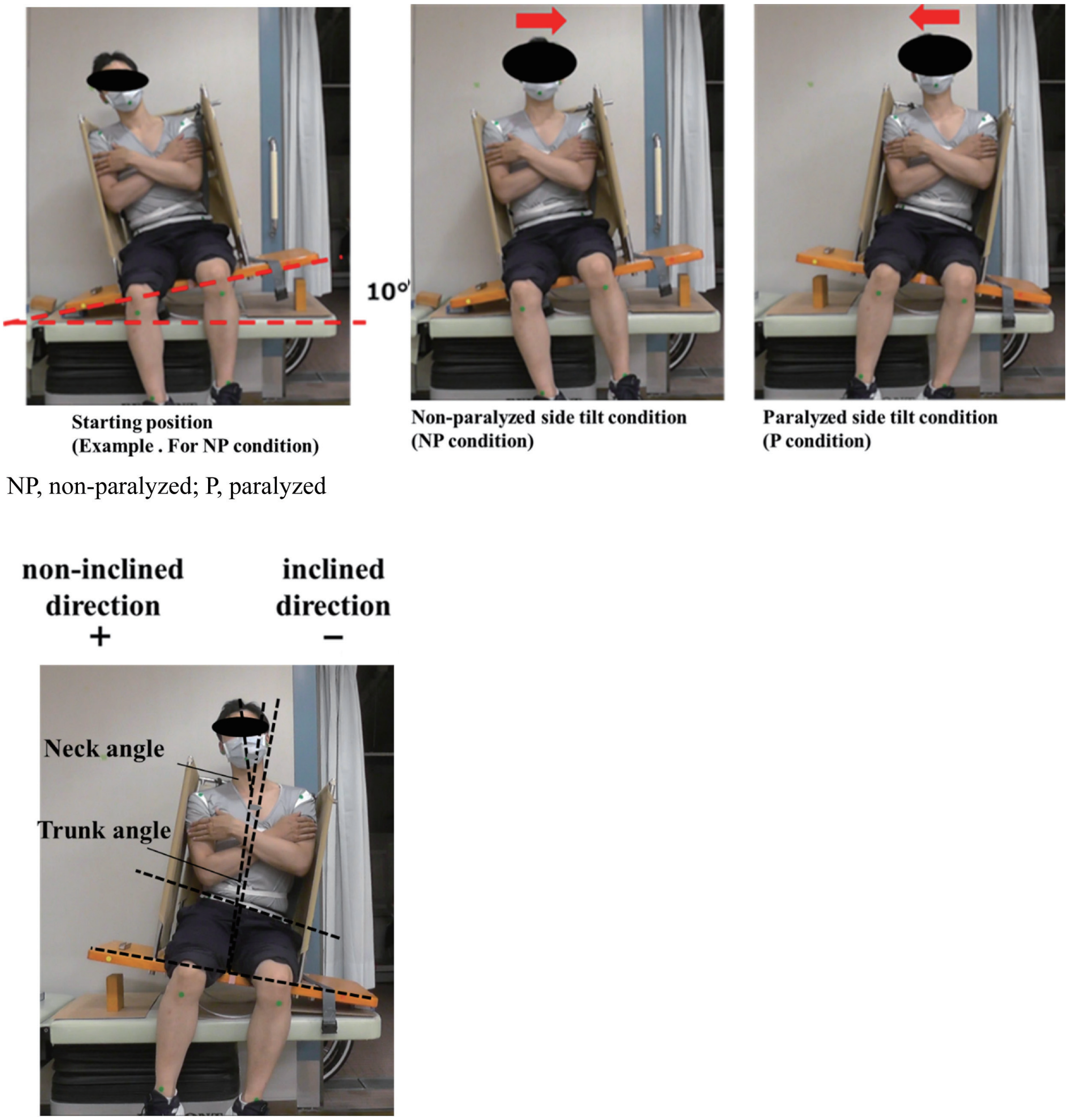

Fig. 1. Examples of sitting balance assessment with a vertical board and definition of neck and trunk angles.

SES of the neck and lumbar muscles using an SES machine (Trio300; Ito, Tokyo, Japan). Electrodes were placed on the middle part of the sternocleidomastoid[23)] and trapezius muscles[24)] in the neck region, as well as 3 and 1 cm lateral to the L2 and L5 lumbar vertebrae, respectively.[29,30)] The frequency and pulse width were set at 100 Hz and 200 μs, respectively, and stimulation intensity was set at 1.2–2 times the sensory threshold, which was below the motor threshold.[29,30)] Patients in the sham group received SES with the same parameters as those in the SES group; however, SES was switched off after 30 s and only the reaching task was performed. During the training, all patients underwent a conventional early stroke rehabilitation program that comprised physical, occupational, and speech therapy as well as nursing care.

Outcome Measure

The outcome measure was sitting balance assessment using a vertical board (VB) (**Fig. 1**). VB has been used to evaluate postural verticality in stroke survivors with pusher behavior.[37)] This device can tilt the patient in the frontal plane and has fabric walls on the sides and back to prevent the patient from falling. This study included participants who required assistance in maintaining a sitting position, which was difficult to assess using ordinal balance assessment. Therefore, the VB was used for assessment in this study. The primary outcome was the joint angle of the neck and trunk during the weight shift in sitting balance assessment using the VB. Markers were placed on the bilateral earlobe, acromion, anterior superior iliac spine (ASIS), tibial tuberosity, midpoints of the medial and lateral malleolus, and the midpoint of the upper edge of the VB sitting surface. A video camera (HC-V520M; Panasonic, Osaka, Japan) was placed 2 m in front of the participant and at the height of the participant's xiphoid process to capture video during the seated balance evaluation. The captured video images were recorded on a personal computer (ENVY 13, HP Japan, Tokyo, Japan), and image analysis software (ImageJ) was used to measure the angles according to the definition described below.[38,39] The neck angle was defined as the angle between the lines connecting the midpoints of the bilateral earlobe, acromion, and ASIS. The trunk angle was defined as the angle formed by the line connecting the bilateral acromion, ASIS, and the midpoint of the seat. Defined as a perpendicular line to VB as the reference line, the non-inclined side of the VB was considered positive, and the inclined side was considered negative. This assessment has good test–retest reliability [intraclass correlation coefficient (ICC), 0.84–0.97] and inter-rater reliability (ICC, 0.82–0.90).[40]

In the starting position, the participant was seated on a VB inclined at 10° to the paralyzed or non-paralyzed side with eyes open, with bilateral upper limbs crossing at the chest, and without the plantar surfaces of the feet on the floor. The patient was seated in the middle of the VB and was allowed to lean against the rear wall during the evaluation. As a sitting balance task, the participant was asked to shift the weight to the non-inclined side and hold the position for 10 s. The VB was tilted to the non-paralyzed side (NP condition) and paralyzed side (P condition), respectively, and maximum weight shift was requested after tilting (**Fig. 1**). During measurement, the center of pressure during weight shift was observed using a body pressure distribution sensor that was placed on the seat surface, and it was confirmed whether the maximum weight shift was achieved. In addition, the participant was instructed not to move the shoulder joint or scapula. If any movement of the shoulder joint or scapula was observed during the measurement, the measurement was stopped and the participant was asked to repeat the measurement. The 10° tilt angle was based on a previous study in which a reaching task was performed to the non-inclined side with the seat surface inclined at 10°.[41] Furthermore, in a preliminary study conducted on healthy participants, we performed the test with inclination angles of 10°, 15°, and 20°. In tests performed at 15° and 20°, participants indicated that they felt unsafe and could not be assessed appropriately. Therefore, the measurements in this study were conducted with the tilt angle set at 10°. The ABBA method was used for the measurements, which were performed four times in the following order: non-paralyzed-side tilt, paralyzed-side tilt, paralyzed-side tilt, and non-paralyzed-side tilt. This measurement sequence was performed in accordance with previous studies.[42] Before this assessment, the participants practiced several times to ensure their understanding of the procedure. The average of two measurements for each of the NP and P conditions was adopted as the outcome (**Fig. 1**).

The outcome was measured at three time points (baseline, online effect, and after-effect). The online effect was measured 10 min after the intervention started while the intervention continued, and the after-effect was measured immediately after the intervention.

Data Analysis

The demographic data of both groups were compared using an unpaired t-test for continuous data and the chi-square test for categorical variables. Generalized linear mixed models were used to compare outcome measures between the groups at the three different time points. When an interaction was observed, the between-groups factor was determined using a two-sample t-test or Mann–Whitney U test after the Shapiro–Wilk test. The within-group factor analysis was performed using the Bonferroni method. When no interaction was observed and a main effect was observed in any of the factors, a two-sample t-test or the Mann–Whitney U test was performed after the Shapiro–Wilk test or the Bonferroni method for each level of the factor in which a main effect was observed. Statistical analysis was performed using SPSS Statistics version 26.0 (IBM, Armonk, NY, USA) with the significance level set at 5%. Missing data were handled by intention-to-treat analysis, which was an average value imputation approach.

The sample size was calculated using G*Power version 3.1.9.2.[43] The required sample size was 28 participants (effect size=0.25, α=0.05, power=0.80). However, we failed to reach the target sample size owing to restrictions on the timeframe for participant enrollment. Therefore, a post hoc power calculation was performed to determine the power (1−b) using G*Power version 3.1.9.2.[43] Power was calculated from the sample size and effect size, with the significance set

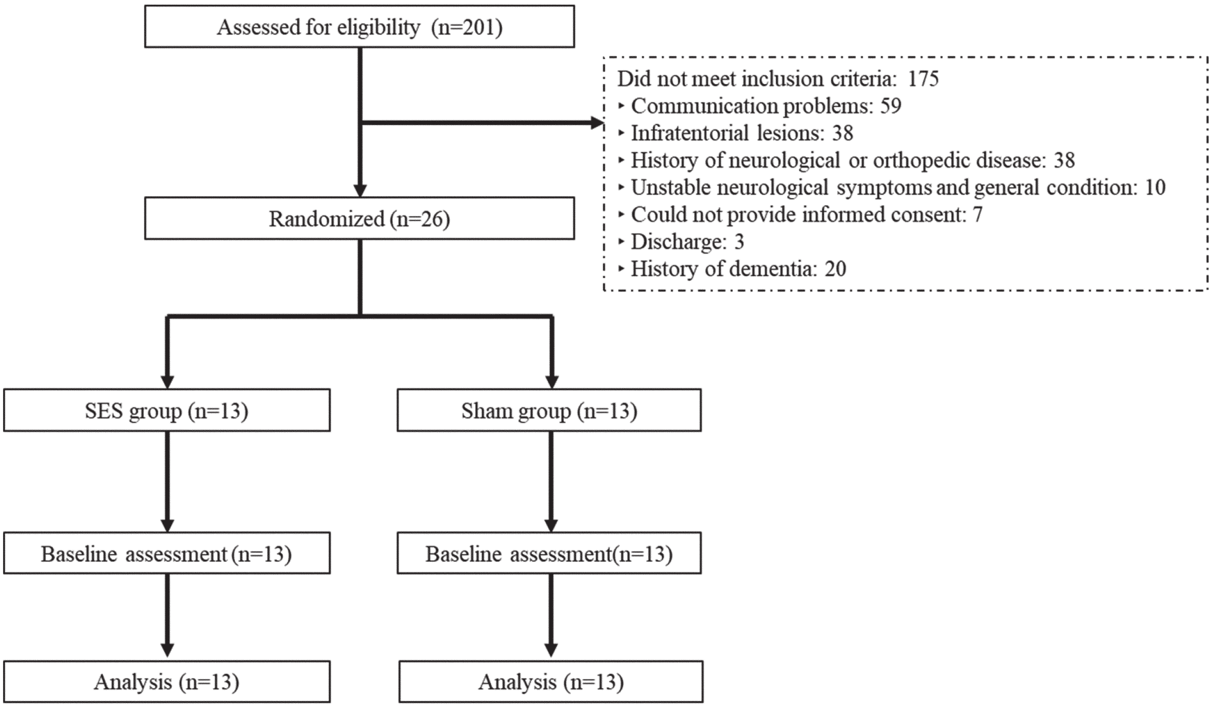

Fig. 2. Flow diagram for the inclusion of study participants.

at 5%. The effect size for between-group mean differences in before–after intervention differences was calculated with Cohen's d, and guidelines for interpretation of effect size were set with reference to Cohen: 0.20, small effect size; 0.50, medium effect size; 0.80, large effect size.[44]

RESULTS

The flow diagram of patient selection for this study is shown in **Fig. 2.** A total of 201 patients were screened between January 2021 and March 2022. Twenty-six patients (recruitment rate, 12%) were randomly assigned to the SES group (n=13) and the sham group (n=13). All patients were able to perform the interventions and analyses were conducted. Therefore, an intention-to-treat analysis was not performed. No adverse events occurred during the study. The demographic data of the two groups are presented in **Table 1**. There was a significant difference in diagnoses between the groups (P=0.04). Results of the outcome measurements are presented in **Tables 2 and 3**.

The neck angle had no significant main effect or interaction in the NP and P conditions. The trunk angle had no significant main effect or interaction in the P condition. The trunk angle had significant interactions in the NP condition (F=3.28, P=0.04), and the main effects of time were significant (F=9.06, P=0.01) (**Table 2**). The results of the post hoc analysis showed a significant difference in the online effect (P=0.03) and the after-effect (P=0.01) when compared with baseline in the SES group (**Table 3**). The effect size of the trunk angle in the NP condition was 0.60 with a power of 0.99.

DISCUSSION

To the best of our knowledge, this study is the first randomized controlled trial to examine the immediate effects of TRTT combined with simultaneous SES of the neck and lumbar muscles on postural control during sitting in stroke survivors. There were significant differences in the trunk angle in the online effect and after-effect when compared with that at baseline in the SES group. By contrast, there was no difference in the trunk angle in the sham group. Pozzo et al.[45] reported that the trunk was more involved in postural equilibrium than the neck in balance tasks among healthy participants, indicating the importance of the trunk in postural control. In a previous study, trunk movement decreased in postural equilibrium during sitting in stroke survivors.[46] Furthermore, the center of pressure and reaching distance was reduced during the sitting reaching task in stroke survivors.[47] These findings suggest that it is important to increase

Table 1. Demographic data: main analysis

Variable	Score range	Sham group (n=13)	SES group (n=13)	P-value
Age, years		62.5 ± 11.7	69.4 ± 11.2	0.15[a]
Sex (men/women)		9/4	5/8	0.23[b]
Time from stroke onset, days		29.0 ± 25.0	27.7 ± 17.8	0.81[c]
Diagnosis (ischemia/hemorrhage)		11/2	5/8	0.04[b]*
Lesion side (right/left)		8/5	7/6	0.98[b]
Cognitive function		2 cases (USN; mean BIT score 90)	3 cases (USN; mean BIT score 99.6, pusher behavior in 2 cases)	
SIAS score	0–76	55.1 ± 15.3	57.3 ± 16.9	0.57[c]
M-FIM score	13–91	57.0 ± 19.9	56.5 ± 24.7	0.95[a]
FAC score	0–5	1.8 ± 1.7	1.6 ± 1.5	0.69[c]
TCT score	0–100	85.3 ± 19.7	84.3 ± 26.0	0.98[c]
TIS score	0–23	12.0 ± 6.8	11.8 ± 6.8	0.93[a]

Data presented as mean±standard deviation or as number.
[a] Independent t-test; [b] chi-square test; [c] Mann–Whitney U test.
* P<0.05.

Table 2. Joint angles of the two groups

	Group	Outcome (degrees)		
		Baseline	Online effect	After-effect
Neck angle				
NP condition	Sham group	11.8 ± 8.8	10.1 ± 8.7	8.2 ± 10.8
	SES group	11.7 ± 14.3	11.1 ± 12.9	11.1 ± 12.2
P condition	Sham group	12.4 ± 12.2	12.1 ± 13.0	14.7 ± 12.0
	SES group	13.6 ± 9.4	11.6 ± 12.6	14.5 ± 7.4
Trunk angle				
NP condition	Sham group*	11.5 ± 5.5	11.8 ± 7.0	13.3 ± 7.1
	SES group*	12.6 ± 4.4	16.7 ± 5.0	17.8 ± 4.0
P condition	Sham group	10.7 ± 7.0	9.0 ± 6.7	8.6 ± 5.7
	SES group	13.3 ± 7.1	13.0 ± 7.0	11.8 ± 8.0

Data presented as mean±standard deviation.
* Significant interactions (P<0.05).

Table 3. Trunk joint angles: post hoc analysis

	Group	Outcome (degrees)		
		Baseline	Online effect	After-effect
NP condition	Sham group	11.5 ± 5.5	11.8 ± 7.0	13.3 ± 7.1
	SES group	12.6 ± 4.4	16.7 ± 5.0 *	17.8 ± 4.0 *

* Significant difference (compared with that at baseline in the SES group).

the trunk angle to improve sitting balance in stroke survivors. Therefore, TRTT combined with simultaneous SES of the neck and lumbar muscles has been suggested because this intervention may provide benefits in the form of postural control changes during sitting in stroke survivors.

The results of this study suggest that TRTT with simultaneous SES of the neck and lumbar muscles could immediately alter the trunk angle during a sitting balance task. Pérennou et al. performed a task in which patients with stroke survivors were asked to sit in a sitting position on a seesaw-like surface tilted to the right and left while receiving electrical stimulation to the neck and to hold their bodies in the center.[23] They reported that the patients whose bodies were tilted toward the paralyzed side were significantly closer to the center of the body by the electric stimulation. SES of the neck muscles temporarily improves the impairment of spatial cognitive function in stroke survivors with USN.[23,24] By contrast, SES of the lumbar muscles changes brain activities in motor-related areas.[31] Therefore, we speculated that TRTT with simultaneous SES of the neck and lumbar muscles would temporarily improve spatial cognitive function and change the motor-related areas of the lumbar muscles in participants with stroke, resulting in an increased trunk angle during sitting balance.

However, the neck angle was not changed by TRTT combined with simultaneous SES of the neck and lumbar muscles. The reason for the lack of change in neck angle may be attributed to the difference in angles between the neck and trunk during reaching training. Verheyden et al.[39] compared neck and trunk joint angles during a lateral center-of-gravity shift task in a sitting position in stroke survivors who were independent in ADLs within 12 weeks of onset and in normal participants. In addition to a decrease in trunk angle in the stroke survivors, the authors reported that the trunk angle (22.18°) was larger than the neck angle (6.61°) in the stroke survivors. Pozzo et al.[45] reported that the trunk is more involved in postural equilibrium than the neck during balance tasks in healthy patients. This finding suggested that the neck was less involved than the trunk in the seated reaching training used in this study and that no change was observed in the neck angle because the neck motor learning was not enhanced by reaching training.

Because SES is an involuntary intervention, it can be applied to patients with dementia or higher brain dysfunction, who have difficulty understanding instructions. Furthermore, because SES can be easily combined with exercise therapy, this intervention may be applied as sitting balance training for patients with severe stroke.

This study has some limitations. First, the sample size was small because of restrictions on the timeframe for participant enrollment. Second, the effectiveness of this intervention in stroke survivors with concomitant impairment of trunk function and spatial cognitive dysfunction could not be determined. Third, the outcome measure was the sitting balance assessment conducted using a VB because this study included participants who required assistance in maintaining a sitting position; therefore, the results may differ from those of a normal sitting balance assessment. Fourth, we discuss the impact of the content of the TRTT conducted in this study on the results. The number and frequency of training sessions in this study were less than those in previous studies, and there is potential to increase the effectiveness of training by increasing the number and frequency of training sessions. However, because this study included stroke survivors who required assistance, the number and frequency of training sessions were set low to ensure that the intervention was feasible. Fifth, the severity of USN may have influenced the results. The mean score of the Behavioral Inattention Test (BIT), which indicated the degree of USN in each group, was 90 in the sham group and 99.6 in the SES group, indicating that the severity of USN in the two groups was almost the same. However, the number of cases was small, and the possibility that the severity of USN affected the results cannot be ruled out. Lastly, we reported only the immediate effects of the intervention, and the long-term effects remain to be determined.

CONCLUSION

TRTT combined with simultaneous SES of the neck and lumbar muscles was demonstrated to improve the trunk angle in participants with stroke while sitting. This intervention may change postural control during sitting in stroke survivors.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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