

Core stabilization exercise can improve lumbar joint position sense in healthy individuals

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ABSTRACT

Background: Core stabilization exercises (CSE) are based on motor learning concepts focusing on sensorimotor function. It has been proposed that CSE can improve core stabilizer muscle function, leading to enhanced joint position sense. However, evidence to support the effects of CSE on joint position sense is still limited.

Objective: To compare the immediate effect of CSE on joint position sense of the lumbar spine using a smartphone application in healthy individuals.

Materials and methods: Fifty-six healthy individuals (9 males and 47 females) were recruited in the study. Two smartphones with the application were attached to the lumbar spine (L1) and sacrum (S2). They were asked to perform 45-degree lumbar flexion and return to neutral position, while lumbar joint position errors were recorded in each direction. They were then randomly assigned to CSE and control groups. After the intervention, they were asked to perform 45-degree lumbar flexion and return to a neutral position.

Results: The CSE group demonstrated significant improvement ($p < 0.05$) in lumbar joint position sense during the 45-degree flexion, whereas the control group did not show improvement. Both groups did not show significant improvement during the return to a neutral position.

Conclusion: Findings suggested that one session of the CSE can improve lumbar joint position sense, which could be due to the increased activities of muscle spindles and Golgi tendon organs. In addition, our findings support the clinical utility of this smartphone application in measuring lumbar joint position sense.

Introduction

Clinical observation of trunk movement is one critical part of physical therapy examination aiming to identify patterns that deviate from typical movement, including altered lumbopelvic rhythm, out-of-sagittal plane deviation, or instability catch.^{1,2} Several studies found these abnormal movements were associated with poor muscle coordination.³ Muscle coordination is necessary to achieve dynamic stability, particularly in the middle of the movement (loose-packed positions), where the ligaments and joint capsules have minimal contribution to lumbar stability.² This would suggest that the level of muscle contraction depends on feedback from muscle spindles and Golgi tendon organs within the muscles themselves rather than those ligaments and joint capsules. Muscle spindles and Golgi tendon organs are mechanoreceptors in the muscles and tendons, respectively.⁴⁻⁶ They can detect changes in muscle length and tensile load and send sensory

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information to the central nervous system to estimate position and movement in space.⁴⁻⁶ Therefore, they are critical in the lumbar joint position sense, contributing to static and dynamic stability. Making efficient movements and maintaining lumbar stability during dynamic tasks are complex actions requiring muscle coordination to provide the right force at the right time, the right duration, and the right amount of combined forces.⁷⁻⁹ Such coordination results from synergistic muscle actions with sensory, biomechanics, and motor-processing strategies with experiences and abilities to anticipate changes.^{4,10,11}

Motor control relies on proprioception from the muscles as a primary sensory mechanism.⁴ The proprioception provides three main proprioceptive inputs for sensorimotor processing.⁴ The first input is the position and orientation of joints during static position and movement. Another proprioceptive information is the perceived timing of muscle contractions necessary to optimize muscle contraction. The last key input component is the information regarding forces and efforts to handle the workload. These functions suggest the critical role of proprioception in sensorimotor integration to optimize muscle recruitment and timing for static and dynamic stability of the lumbar spine.^{4,10,11}

Core stabilization exercises (CSE) are therapeutic exercises based on the motor learning approach, which emphasizes the co-activation of the lumbar multifidus and transversus abdominis muscles.^{12,13} These stabilizer muscles are attached to the thoracolumbar fascia and produce a stabilizing effect in the lumbar spine through increased intra-abdominal pressure, further providing lumbar segmental stability.¹⁴ CSE can be used to re-train the critical functions of those stabilizer muscles and improve the accuracy of the sensory integration process for spine stability.^{4,10,11} However, evidence to support the effects of CSE on joint position sense remains limited.

In addition, studies investigating joint position sense have used advanced lab-based equipment, including an electromagnetic tracking system, a 3D kinematic motion analysis system, and an isokinetic dynamometer, which could limit clinical application.¹⁵⁻¹⁷ Recently, the growing popularity of smartphone applications in assessing joint position sense highlights their ease of use and wide availability, making them an appealing choice for measuring joint position sense.¹⁸⁻²¹ The use of a smartphone application would allow generalizability in clinical practice.

Therefore, this study aimed to determine the immediate effects of CSE on joint position sense during active trunk flexion and return to neutral position using a smartphone application in healthy individuals. We hypothesized that CSE would improve joint position sense. Our findings would provide evidence to support CSE's usefulness in improving joint position sense and help design appropriate interventions for patients with LBP. In addition, our findings would provide the clinical utility of the smartphone application in measuring joint position sense.

Materials and methods

Study design

This study was a single-blind, randomized controlled trial to determine the immediate effects of CSE on joint position sense during active trunk flexion and return to neutral position using a smartphone application in healthy individuals. The study protocol was approved by the university institutional review board (MU-CIRB 2016/047.0704) and registered to clinicaltrial.gov (NCT02974062). Participants provided written informed consent before collecting data.

Participants

Fifty-six participants (9 males and 47 females) were recruited from the Faculty of Physical Therapy, Mahidol University. The inclusion criteria were age between 18 and 25 years, male and female, and no low back pain in the past six months. Exclusion criteria were current musculoskeletal pain, clinical signs of systematic disease, definitive neurologic deficit, experience of CSE or Pilates, or body mass index greater than 25 kg/m². This study was part of another research project; therefore, we did not perform sample size calculations. However, post-hoc power analysis was conducted to determine the effect size and number of participants required to replicate our study.

Instruments and measures

Two smartphones (iPhone® is a trademark of Apple Inc., Cupertino, CA, USA) with a goniometer application (Goniometer Pro, Version 2.7, 5fuf5 Co., Bloomfield, NJ, USA) were attached by positioning the center of the smartphone to the lumbar spine at the L1 spinous process and sacrum at the S2 spinous process. The angle between the lumbar spine and sacrum was used to represent lumbar motion. The lumbar position error (PE) from the targets was derived. These data represented lumbar position during forward flexion and return to the starting position. Greater PE value indicated poorer lumbar position sense. Several studies validated the smartphone application while concurrently measuring the lumbar motion with a lab-based motion-tracking system. Our preliminary study demonstrated excellent test-retest reliability ($ICC_{2,k}=0.95$; $CI=0.92-0.97$) of the smartphone application to measure lumbar position sense.²² Therefore, the smartphone application is suitable for clinical use in measuring lumbar position sense in this study.

Procedure

Participants first completed demographic data questionnaires. Then, the researcher exposed the participant's lower back. Each smartphone was inserted in a transparent pocket, allowing the researcher to see the screen. These pockets were attached to the participant's lumbar spine and pelvis using Velcro straps (the center of the smartphone was aligned with L1 and S2 spinous processes).

The researcher, blinded to the group assignment, performed data collection. The participant was asked to stand with feet shoulder-width apart on the drawing paper, and the researcher drew a footprint. This footprint was used to re-position the participant at the post-test. The participant was asked to stand up straight to record starting position data, which is operationally defined as the position in which the participant feels comfortable without trying to maintain it. The participant performed three repetitions of active trunk flexion, while peak lumbar flexion for each repetition was recorded (Figure 1). Then, the researcher provided three practice trials of lumbar flexion at 45 degrees, and return to the starting position with verbal feedback to familiarize with the task. The participant was asked to perform six repetitions of 45-degree lumbar flexion and return to the starting position without verbal

feedback while the researcher recorded the lumbar angles. These data were used as a baseline pre-test. Simple randomization was performed to assign the participants to the control (CON) or CSE group. Based on the anatomy of the lumbar spine's superior and inferior articular facets, the significant movement in the lumbar spine is flexion-extension rather than lateral flexion and axial rotation.²³ Therefore, sagittal plane investigation should be relevant to the biomechanics of the lumbar spine. According to systematic reviews, most studies focused on the sagittal plane.^{24,25} However, few studies investigated lateral flexion and axial rotation and found no significant differences between healthy individuals and patients with low back pain.^{24,25} In addition, studies reported that reposition error measurement in axial rotation was unreliable.^{26,27} Therefore, we selected the sagittal plane for our study.

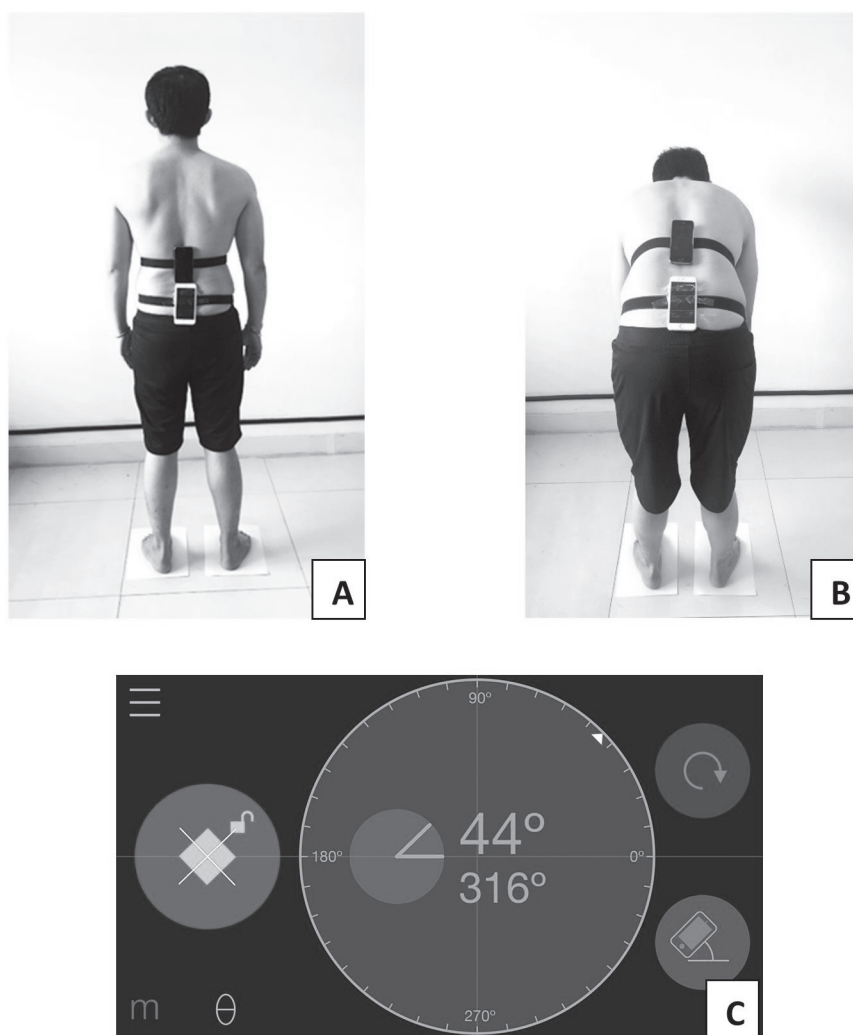


Figure 1. Smartphone placement and starting (A) and end positions during 45-degree flexion (B) and smartphone application screen (C).

The CSE group received a 30-minute CSE based on motor control learning (Figure 2), while the CON group was instructed to rest by lying down for 15 minutes. Based on our pilot study to determine changes in lumbar joint position sense between 15 and 30 minutes. We found no significant differences in lumbar position sense; therefore, we used a 15-minute protocol to minimize our data collection time. The exercise comprised three stages: 1) co-contraction of transverse abdominis and lumbar multifidus muscles, 2) co-contraction with limb movement, and 3) co-contraction with functional movement. Each participant's performance was assessed to determine the highest ability to perform CSE. Then, the researcher used that maximum performance as an initial exercise. If the participants achieved the target, they progressed to the next exercise.

Stage 1: Co-activation of the transverse abdominis and lumbar multifidus muscles. If the participants could hold co-contraction for

60 seconds without holding their breath or compensation from other muscles, they proceeded to stage 2.

Stage 2: Co-contraction with limb movement. Participants were asked to co-contrast the transverse abdominis and lumbar multifidus muscles while slowly performing upper and/or lower limb movements. If the participants could perform co-contraction with limb movements in the supine position for ten repetitions without substituting other muscles, they could proceed to the next stage.

Stage 3: Co-contraction with functional movement. Participants were asked to perform co-contraction and functional movements (e.g., sit to stand, walk in the hallway, etc.) for ten repetitions.

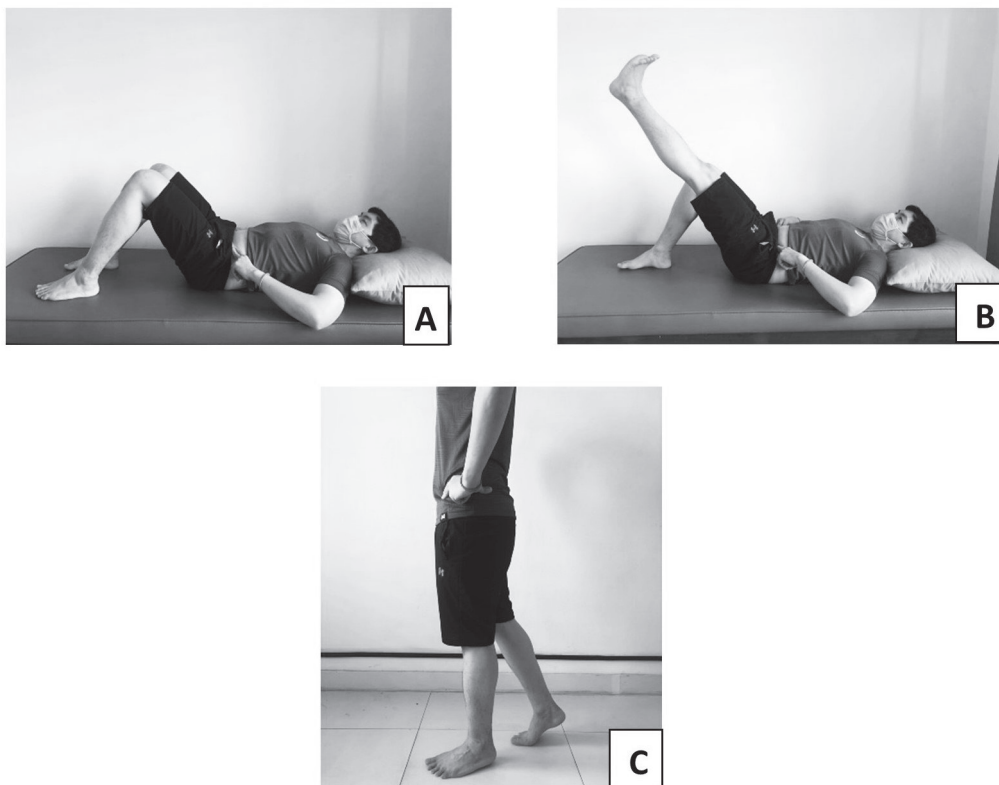


Figure 2. Core stabilization exercise. Example of level 1 (A) co-contraction of the transverse abdominis and lumbar multifidus muscles, level 2 (B) co-contraction with limb movement, and level 3 (C) co-contraction with functional movement

These low-intensity exercises aimed to develop the ability to perform precise co-contraction of the transverse abdominis and lumbar multifidus muscles via sensory-motor integration. After performing CSE in the CSE group

and resting in the CON group, post-test data collection was performed using the same protocol as pre-test data collection. Figure 3 demonstrates a flow chart of the study.

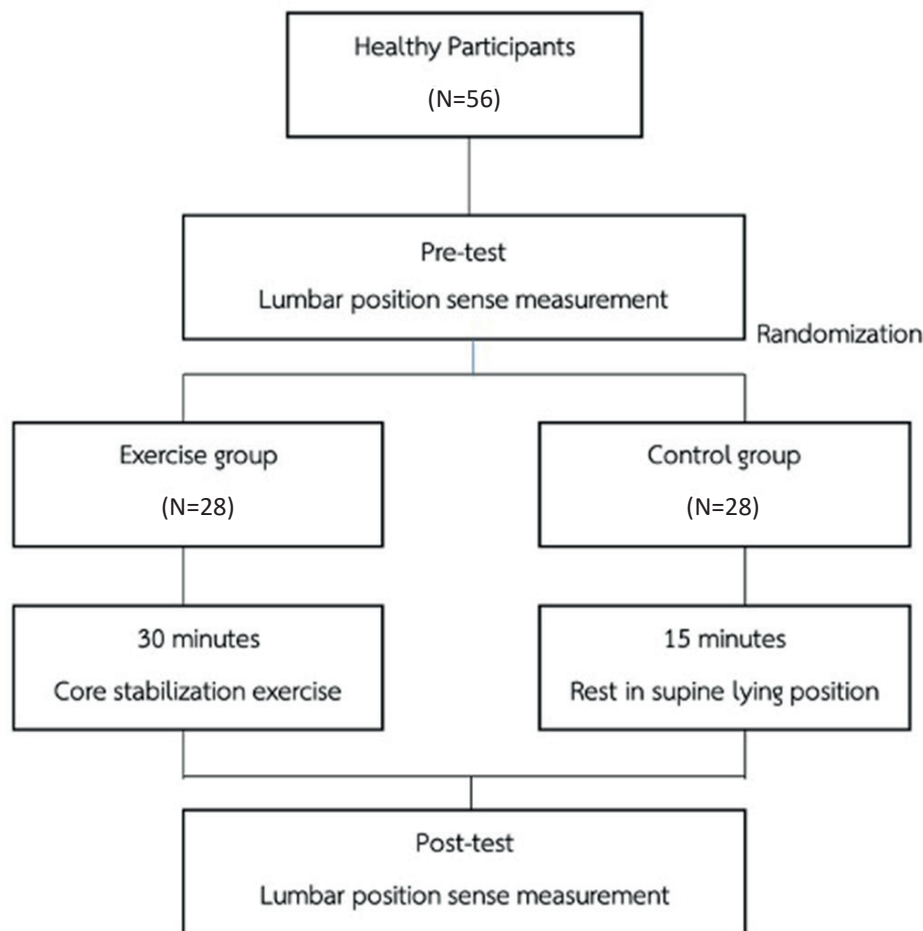


Figure 3. Flow chart of this study.

Data analysis

Lumbar position error was calculated by taking the absolute value of the difference between the actual lumbar flexion and 45-degree target angle ($PE_{flexion}$) and the actual position during upright and starting (PE_{start}). These parameters were used to represent lumbar position sense. Averaged $PE_{flexion}$ and PE_{start} across six repetitions were used for statistical analyses.

Statistical analysis

Statistical analyses were performed using the SPSS Program (IBM SPSS Statistics for Windows, Version 21.0, Armonk, NY, USA). The Shapiro-Wilk test was conducted to determine the normality of the data. An independent t-test was used to determine demographic (age and BMI) and baseline (lumbar range of motion, $PE_{flexion}$, and PE_{start}) data, while the chi-square test was used to assess sex between groups. A two-way mixed ANOVA with post-hoc pairwise comparison was used to determine the effect of group (CON vs. CSE) and time (Pre vs. Post) on lumbar

position sense. The significance level was held at 0.05 for all statistical analyses.

Results

Demographic data are presented in Table 1. Statistical analysis demonstrated no significant differences ($p>0.05$) between groups regarding sex, BMI, lumbar range of motion, or position errors during flexion and return to neutral position. However, CSE group members were significantly older than CON group members ($p<0.05$).

Our data were normally distributed; therefore, a two-way mixed ANOVA was performed for statistical analysis. Results demonstrated no Time*Group interaction ($p=0.085$), while the significant main effect of Time was found ($p<0.05$) in $PE_{flexion}$. Post-hoc pairwise comparison (Table 2) demonstrated significant improvement in $PE_{flexion}$ in the CSE group but not in the CON group. However, no significant Time*Group interaction and the main effect of Group and Time were found ($p>0.05$) in PE_{start} .

Table 1. Demographic data.

Variable	CON (N=28)	CSE (N=28)	p value
Age (years)	20.5±1.3	21.4±1.0	0.01
Gender (%female)	93	75	0.07
BMI (kg/m ²)	21.2±2.7	21.3±2.4	0.81

Note: CON; control group, CSE: core stabilization exercise group.

Table 2. Post-hoc pairwise comparisons between groups (CON vs CSE) and times (Pre vs Post) during forward flexion at 45 degrees and return to neutral position.

		Pre Mean±SD (deg)	Post Mean±SD (deg)	Difference (deg)
PE _{flexion}	CON	5.31±3.80	4.76±3.78	0.55
	CSE	6.65±3.21	4.52±4.12	2.13*
	Difference	-1.34	0.24	
PE _{start}	CON	3.00±1.98	2.44±1.72	0.56
	CSE	2.74±2.63	1.94±1.48	0.80
	Difference	0.26	0.50	

Note: CON: control group, CSE: core stabilization exercise group, PE_{flexion}: position error during flexion, PE_{start}: position error during return to starting position, SD: standard deviation, deg: degrees, *significant difference between pre and post-test ($p < 0.05$).

Discussion

These results partially support our hypothesis that one-session CSE can improve joint position sense during trunk flexion at 45 degrees. The CSE is designed to improve co-contraction of the transverse abdominis and lumbar multifidus muscles following three stages from beginning to challenging levels. CSE can enhance proprioceptive sense from the muscle spindle, which is necessary to increase the precision of muscle contraction, thereby decreasing absolute errors. Our finding provides evidence to support improved sensory-motor integration mechanisms. According to the spinal reflex pathway, co-contraction of the transverse abdominis and lumbar multifidus muscles would cause increased muscle tension, thereby enhancing the sensitivity of muscle spindles in the muscles. This would increase proprioceptive signals or information to the spinal reflex pathway to provide a more precise co-contraction at the target angle.⁴

Improved joint position sense during trunk flexion was consistent with the study by Kim *et al.*, in which they found that 8 weeks of CSE could improve the proprioception of passive lumbar motion at 20 degrees flexion and 10 degrees extension.¹⁵ Although our study investigated the immediate effects of CSE, we found that participants could actively perform trunk flexion with less position error. Our findings and their studies imply that CSE could enhance joint position sense in active and passive movements.

In contrast, a previous study showed no significant difference in lumbar position sense after 8-week CSE.¹⁶ The discrepancy between studies could be because their study assessed the absolute error of passive lumbar rotation (passive structure), while our study focused on the ability of muscles (active structures). We selected trunk flexion at 45 degrees to differentiate muscle feedback from ligaments and joint capsule feedback. CSE was designed

to improve muscle performance, including joint position sense from muscle spindles and Golgi tendon organs. This should result in improved joint position sense during active movement. On the other hand, their study measured joint position sense during passive lumbar rotation, where trunk muscles have minimal contribution to proprioception.¹⁶ In this case, proprioceptive signals from active muscles would be minimal or inadequate to determine joint position sense.

Regarding joint position sense at the neutral position, our result did not show significantly improved joint position sense when returning to the starting position. Our result differed from a previous study that found improved joint position sense during the upright sitting position after CSE.¹⁷ However, our study aimed to determine the effect of one-session CSE which might have been inadequate to induce change in joint position sense. Further analysis may be required to determine the most appropriate amount of CSE to improve joint position sense. Another potential explanation for such different findings is that our healthy participants had no low back symptoms or were familiar with the neutral position, evidenced by fewer position errors than flexion. This reduced error could also have caused the ceiling effect or limited space for improvement. Therefore, applying CSE in patients with impaired joint position sense can clarify this issue.

Although we found a significant difference in age between the CON and CSE groups, they were relatively young, implying that they were still in homogeneous groups. In addition, no significant difference was observed in absolute errors between groups during 45-degree flexion and return to upright position at baseline. These would imply that both groups were comparable, and changes in absolute error could be interpreted as the effect of one-session CSE.

We used a smartphone with a goniometer application to measure lumbar joint position sense during forward flexion and return to the starting position. Our preliminary study established excellent test-retest reliability of the smartphone application, suggesting that changes in lumbar joint position sense were likely to be actual changes rather than changes from measurement errors. One study determined the concurrent validity of a smartphone application to measure shoulder joint position sense using an electromagnetic tracking system as a reference standard. The findings indicated that the smartphone application could replace the electromagnetic tracking system to measure shoulder joint position sense.¹⁹ One study attached a smartphone to the right arm rather than the lumbar spine.¹⁸ Therefore, their joint position sense was the output from several body segments.¹⁸ We attached the smartphone to the lumbar spine and pelvis and used the difference between the two segments, which should better represent the lumbar joint position sense. Our findings support the clinical utility of smartphone applications in measuring lumbar joint position sense.

The study encountered limitations. First, we investigated the effects of CSE among healthy individuals who may have better proprioceptive sense than patients with LBP. Further, our sample size was underpowered, which could explain nonsignificant findings in the joint position sense when returning to the upright position. Therefore, further studies should recruit a larger sample size and include patients with LBP to confirm our findings. Second, this study aimed to determine the immediate effect of CSE on the lumbar position sense of trunk flexion at 45 degrees and return to the starting position. This would limit the generalizability to other movements or angles. However, our finding at 45-degree flexion could represent movement in the middle range where the contribution of proprioceptive sense from muscles is critical to minimize the risk of injury. Further study should include CSE in other movements and angles to explore the potential effects of CSE on joint position sense before applying it to clinical practice. In addition, we investigated the immediate effects of CSE without following up on the residual effect. Therefore, it would limit the insight into the optimal frequency to provide CSE to induce permanent improvement in joint position sense. Therefore, future studies should include the retention effects of CSE to provide insight into the impact of CSE.

Conclusion

Our study aimed to determine the immediate effects of CSE on absolute position error at 45-degree flexion and return to an upright position. Our findings demonstrated a significant decrease in absolute position error during 45-degree flexion, while no significant difference was found when returning to the upright position. Our findings suggest the ability of CSE to improve joint position sense in the middle of the movements, implying the potential clinical utility of CSE in minimizing the risk of low back injury.

Conflict of interest

The authors acknowledge that we do not have any financial or personal relationships with other people or organizations that could inappropriately influence the work described in the current manuscript.

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