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# Is lumbopelvic motor control associated with dynamic stability during gait, strength, and endurance of core musculatures?

## The STROBE study

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**Abstract**

Core stability has been described as the product of motor control and muscular capacity of the lumbopelvic-hip complex. Because of the wide range of functions of the lumbopelvic-hip complex, the gold standard for evaluating core stability remains controversial. The Sahrmann core stability test (SCST), used in conjunction with the stabilizer pressure biofeedback unit (PBU), is widely applied to objectively evaluate core stability as this pertains lumbopelvic motor control. However, the association between such control and other elements of core stability including core strength, endurance, and dynamic stability during gait has not been well-studied. We investigated the relationships among the ability to control the lumbopelvic complex, core strength and endurance, and gait parameters. We compared lateral core endurance, hip strengths, and gait parameters (lateral oscillation of the center of mass (COM), the single support time, and the peak ground reaction force) between good and poor core stability groups, as determined by the SCST. In addition, logistic regression analysis was used to determine whether other core stability measures correlated with the core stability status defined by the SCST. Only lateral oscillation of the COM during walking differed significantly between the good and poor core stability groups and was a significant predictor of SCST core stability status. Lumbopelvic motor control, (as defined by the SCST), affects dynamic stability during gait, but not to the strength or endurance of the core musculatures.

**Abbreviations:** BMI = body mass index, BW = body weight, COM = center of mass, GRF = ground reaction force, PBU = pressure biofeedback unit, SCST = Sahrmann core stability test, VAS = visual analog scale.

**Keywords:** core, dynamic stability, endurance, motor control, strength

## 1. Introduction

Core stability has been described as the product of motor control and muscular capacity of the lumbopelvic-hip complex.[1–5] Many studies have reported that core stability is essential to reduce low back pain.[6–10] Therefore, core stability and core strength training are elements of rehabilitation programs.[11–14] Appropriate evaluation of core stability is important to determine the intensity and quantity of core stability training required.

The Sahrmann core stability test (SCST) is used clinically in conjunction with a pressure biofeedback unit (PBU) to objectively evaluate core stability in terms of lumbopelvic motor control.[15–17] The SCST is composed of 5 progressively difficult tasks. Proximal stability must be maintained against increasing resistance (generated by lowering the legs) when completing the tasks. The SCST is able to determine whether the abdominal and lower back muscles are well-controlled during lower extremity movements.[15]

The SCST results reflect core stability, as stated above, through measurement of lumbopelvic movement while lowering the legs. However, it is unclear whether the SCST is associated with other elements of core stability, such as the endurance and strength of the lumbopelvic-hip complex. Since core stability involves motor control, as well as the endurance and strength of the lumbopelvic-hip complex,[2,5,18,19] determining the degree to which the SCST results reflect overall core stability will be useful.

The aim of this study was to examine how the SCST results relate to other measures of core stability. We investigated differences in lateral core endurance, hip strength, and dynamic stability between 2 groups distinguished based on their SCST scores. The side plank was used to measure lateral core endurance. Hip abduction and adduction isometric strength were taken as measures of core strength. Lateral oscillation of the center of mass (COM) during walking and running was considered to reflect dynamic stability. Logistic regression was used to further examine the relationships between core stability, as

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determined by the SCST, and other measures of core stability. We hypothesized that the good core stability group would perform significantly better on other measures of core stability than the poor core stability group, and that these measures would be able to predict SCST core stability.

## 2. Methods

### 2.1. Participants

This study is a cross-sectional design. This study included 52 healthy, able-bodied subjects (12 males and 40 females; mean age, 22.0 ± 1.7 years; mean weight, 57.1 ± 8.9 kg). Exclusion criteria were overweight (body mass index [BMI] > 25), current pregnancy, vestibular, neurological, cardiopulmonary, or psychological disorders, and musculoskeletal pathologies. Written informed consent was obtained from all participants, and the study was approved by the Jeonju University Institutional Review Board.

### 2.2. Sahrmann core stability test

To objectively evaluate core stability, all participants completed the SCST using the inflatable pad of the Stabilizer PBU device (Chattanooga Group, Inc., Hixson, TN). The participants were placed in the supine position with the PBU placed in the natural lordotic curve. The pad was inflated to 40 mm Hg, and the participants were asked to perform the SCST. While performing the 5 progressively difficult tasks, the participants drew in their abdomen to maintain pressure. A deviation of > 10 mm Hg was considered to reflect loss of stabilization by the stabilizer muscles. After familiarization trials, the participants performed the 5-level SCST, with the PBU providing biofeedback (Fig. 1). Performance, that is, the ability to complete tasks without a deviation of > 10 mm Hg, was scored on a 5-point scale. The participants were assigned to poor and good core stability groups based on their SCST scores (poor: 0–1; good: 2–5). The 5-level SCST are as follows (Fig. 1).[15]

Level 1: The subject lies in the crook position in 60° hip flexion, slowly raises 1 leg to approximate 90° of hip flexion with 90° knee flexion, and then raises the other leg to the same position in the same manner.

Level 2: From the final position of Level 1, the subject slowly lowers 1 leg until the heel contacts the ground, and then fully extends the leg with the heel in contact with the ground.

Level 3: From the final position of Level 1, the subject slowly lowers 1 leg until the heel is approximately 12 cm above the

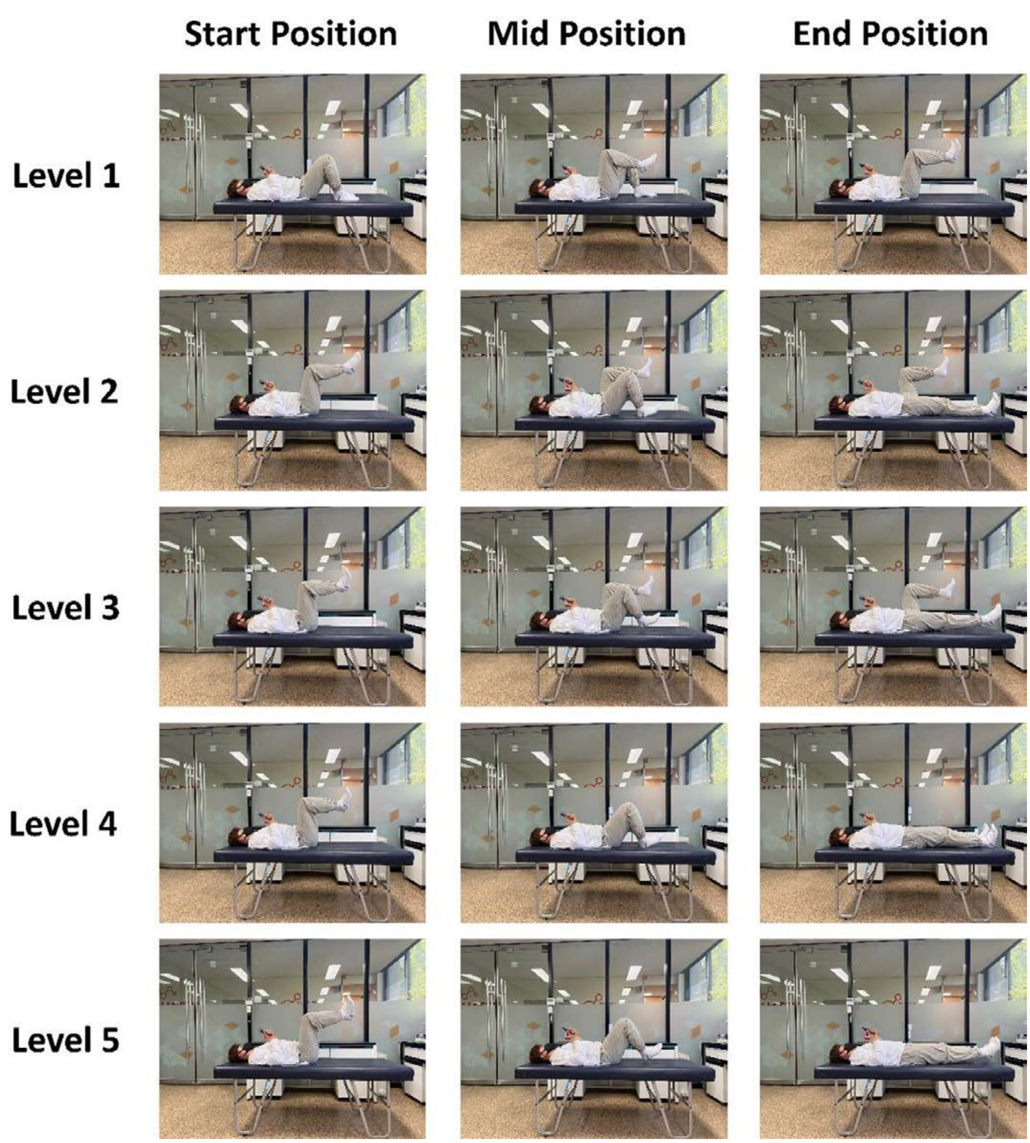


Figure 1. The 5 levels of the Sahrmann core stability test.

ground, and then fully extends the leg while maintaining the distance between the heel and the ground.

Level 4: From the final position of Level 1, the subject slowly lowers both legs together until the heels contact the ground, and then fully extends the legs with the heels in contact with the ground.

Level 5: From the final position of Level 1, the subject slowly lowers both legs together until the heels are approximately 12 cm above the ground, and then fully extends the legs while maintaining the distance between the heels and the ground.

### 2.3. Instruments

The Beflex Coach (Beflex, Inc., Daejeon, South Korea) wireless ear-worn device was used to collect gait parameter data. All participants wore the wireless device on their left ears while walking and running for 1 minutes. The collected data were transferred to the mobile Beflex app (Beflex, Inc.) via Bluetooth and then uploaded on its server. The Beflex system provides means of temporal, spatial, and kinetic data, such as single support time, swing time, lateral oscillation of the COM, and peak ground reaction force (GRF) at 0.5 Hz. The parameters were estimated from the GRF.

### 2.4. Procedure

Each participant performed the core endurance test, dynamic balance and strength tests, and walking and running tests in a random order. Before the experimental procedure, the participants underwent general preparations, including a 5-minute indoor cycling as a warm-up exercise.

***2.4..1. General preparations.*** All participants answered questions regarding demographic characteristics and provided a visual analogue scale (VAS) pain score. Anthropometric data (height, weight, and leg length) were obtained using a measuring tape. After completing anthropometric measurements, all participants performed the 5-minute indoor cycling warm-up exercise.

***2.4..2. Core endurance test.*** The participants performed left and right plank tests in a random order, with a 5-minute rest between tests. For the side plank test, the participants were asked to maintain the spine and legs in a straight line while supporting the other side using their elbows and feet. The top foot was placed on the lower foot, and the top arm was held at the side with the hand placed on the hip (Fig. 2). Each test was terminated when the participant was unable to maintain a straight line or the knees dropped toward the floor. The hold duration for each side plank test was recorded in seconds, up to a maximum of 120 seconds.

***2.4..3. Strength test of hip abductors and adductors.*** The maximal isometric strength of the hip abductors and adductors on both sides was measured using a tensiometer with a non-elastic band (Smart KEMA pressure sensor; Factorial Holdings Co., Seoul, Korea). Participants were placed in the non-tested side-lying position. The non-tested hip and knee were slightly flexed to maintain the side-lying position, and the tested hip and knee were extended with 10° of hip abduction. While performing the isometric contraction, pelvic rotation and elevation were prevented to minimize compensatory movements (Fig. 3). The participants were encouraged to produce as much isometric force as possible, thrice in the side-lying position (for 5 seconds each time). The highest force was normalized according to the height of each participant and recorded for data analysis.

***2.4..4. Walking and running.*** The participants walked and ran for 1 minutes on a treadmill (Xiaomi, Inc., Beijing, China) while wearing the Beflex device on the left ear. The walking and running speeds were 4.5 and 9 km/h, respectively. Before the test, the participants practiced for 30 seconds to familiarize themselves with the speeds. The time spent walking and running at the target speed was transferred to the Beflex app.

### 2.5. Statistical analysis

The core endurance test and hip adductor and abductor strength tests generated the dominant and non-dominant side parameters. The means of the temporal, spatial, and kinetic parameters during walking and running were analyzed. The 2-sample *t* test was used to compare parameters between the poor and good core stability groups. The significance level was set at $P < .05$.

Stepwise logistic regression was used to determine which core stability tests were associated with the SCST core stability status. All parameters in the core endurance, hip strength, and walking and running tests were entered into the regression model as predictors. The response variable of the model was core stability status (1 = good core stability [SCST score > 1], 0 = poor core stability [SCST score of 0 or 1]). Forward and backward stepwise procedures were used to add variables to the constant model.

## 3. Results

Among the 52 participants, 18 (males: 7, females: 11; mean age, 22.2 ± 2.1 years; mean BMI, 21.4 ± 1.7; mean VAS pain

**Figure 2.** Core endurance testing of the lateral trunk using the side plank test. Right side test position shown here.

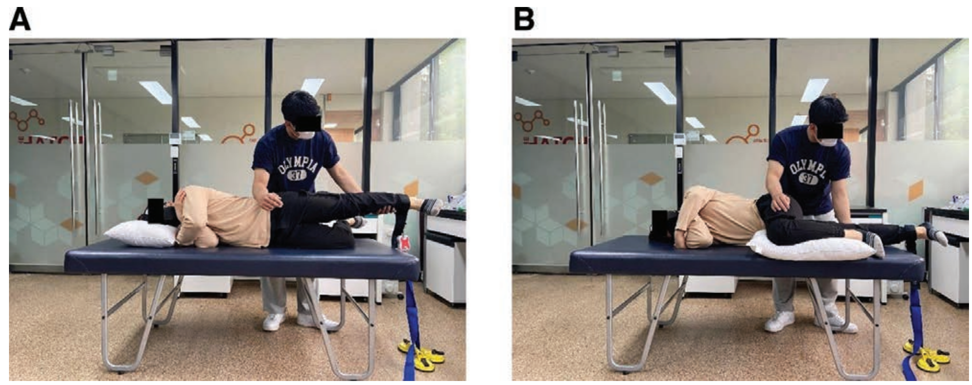


**Figure 3.** Hip isometric strength testing of (A) hip abduction and (B) hip adduction using a tensiometer with a non-elastic band (Smart KEMA pressure sensor; Factorial Holdings Co., Seoul, Korea).

score, 4.0 ± 2.6) had a SCST score of 0 or 1, while 34 (males, n = 5; females, n = 29; mean age, 21.9 ± 1.3 years; mean BMI, 20.8 ± 1.9; mean VAS, 3.1 ± 3.2) had scores > 1. The participants who scored 0 or 1 were assigned to the poor core stability group, while the remaining participants were assigned to the good stability group. The post hoc power analysis test yielded a power of 0.96 in a setting of effect size 1.09 as determined by the COM excursions during walking. There were no significant differences in age, height, weight, BMI, or VAS between the 2 groups (Table 1).

In the lateral core endurance test, the dominant and non-dominant side plank durations did not differ significantly between the good (38.3 ± 27.4 and 31.6 ± 26.0 seconds, respectively) and poor (32.3 ± 16.5 and 36.1 ± 18.5 seconds, respectively) core stability groups ($P > .05$, Table 2). The hip abduction strength on the dominant and non-dominant sides also did not significantly differ between the good (12.0 ± 3.9% and 11.3 ± 3.7% body weight [BW], respectively) and poor (12.1 ± 5.4% and 12.0 ± 5.5% BW, respectively) groups ($P > .05$, Table 3).

The magnitude of lateral oscillation of the COM during walking in the poor group (19.0 ± 6.2 cm) was significantly greater than in the good group (14.1 ± 3.2 cm) ($P < .01$, Table 4). In contrast, the magnitude of lateral oscillation of the COM during running did not differ significantly between the good (11.1 ± 1.4 cm) and poor (12.6 ± 2.6 cm) groups ($P = .08$, Table 5). There were no significant differences between the good and poor groups in either the peak GRF or the single support times during walking and running (all $P > .05$, Tables 4 and 5).

Stepwise logistic regression showed that the magnitude of lateral oscillation of the COM during walking was the only significant predictor of core stability according to the SCST (odds ratio = 0.80, $t = -2.87$, $P = .004$). The regression equation fit our data well (likelihood ratio = 11.7) and predicted core stability status with 71.1% accuracy (Table 6).

## 4. Discussion

We investigated whether core stability defined based on the SCST is associated with other measures of core stability. We compared the scores on several tests between 2 groups distinguished based on the SCST. The main findings of this study were as follows: the poor core stability group had significantly greater lateral oscillation of the COM than the good core stability group during walking, but not running; hip abduction and adduction strengths in the good core stability group did not significantly differ from those in the poor core stability group; there was no significant difference in the core endurance test between the good and poor core stability groups; and lateral oscillation of the COM during walking was a useful predictor of SCST core stability status.

Temporal and spatial gait parameters were obtained using the Beflex ear-worn device while walking at 4.5 km/h and running at 9 km/h. The parameters were in agreement with those reported in previous studies using high-speed cameras and force plates.[20–23] The single support time in healthy participants has been reported as approximately 0.43 seconds while walking at 5.1 km/h[21] and 2.7 seconds while running at 10.8 km/h.[23] These results were similar to those of our study, where the single support time was about 0.4 seconds at 4.5 km/h (Table 4) and about 0.25 seconds at 9 km/h (Table 5). Peak GRFs during walking and running were also similar to those reported in previous studies. In our study, the GRFs during walking and running were about 1.1 and 2.5 BW, respectively (Tables 4 and 5). GRFs during walking and running by healthy participants were reported as 1.17 BW[22] and 2.51 BW,[23] respectively. Furthermore, the magnitude of lateral oscillation of the COM was similar to previous results obtained using force plates.[20] In the current study, lateral oscillation ranged from 11 cm at 9 km/h to 19 cm at 4.5 km/h (Tables 4 and 5). The previous study reported that the COM in healthy participants laterally oscillated by about 25 cm at 4.75 km/h.[20]

**Table 1**

**Comparison of characteristics and demographic data between core stability groups distinguished based on the Sahrmann core stability test.**

| | Poor | Good | *P* value |
|---|---|---|---|
| Males (n) | 7 | 5 | - |
| Females (n) | 11 | 29 | |
| Age (yr) | 22.2 ± 2.1 | 21.9 ± 1.3 | .90 |
| Height (cm) | 165.0 ± 8.4 | 163.8 ± 7.3 | .82 |
| Weight (kg) | 58.8 ± 8.7 | 56.2 ± 8.8 | .69 |
| BMI | 21.4 ± 1.7 | 20.8 ± 1.9 | .90 |
| VAS pain score | 4.0 ± 2.6 | 3.1 ± 3.2 | .30 |

BMI = body mass index, VAS = visual analog scale.

**Table 2**

**Comparison of side plank duration between core stability groups.**

| | Poor | Good | *P* value |
|---|---|---|---|
| **Side plank** | | | |
| Dominant side duration (s) | 38.3 ± 27.4 | 32.3 ± 16.5 | .31 |
| Non-dominant side duration (s) | 31.6 ± 26.0 | 36.1 ± 18.5 | .47 |

**Table 3**

**Comparison of isometric hip abduction and adduction strength between core stability groups.**

| | Poor | Good | *P* value |
|---|---|---|---|
| **Abduction** | | | |
| Dominant side (% weight) | 12.1 ± 5.4 | 12.0 ± 3.9 | .99 |
| Non-dominant side (% weight) | 12.0 ± 5.5 | 11.3 ± 3.7 | .62 |
| **Adduction** | | | |
| Dominant side (% weight) | 10.3 ± 5.0 | 9.8 ± 4.5 | .79 |
| Non-dominant side (% weight) | 13.4 ± 13.6 | 9.0 ± 4.1 | .056 |

**Table 4**

**Comparison of GRF, single support time, and magnitude of COM oscillation during walking between core stability groups.**

| | Poor | Good | *P* value |
|---|---|---|---|
| **Average peak GRF** | | | |
| Dominant side (BW) | 1.12 ± 0.04 | 1.11 ± 0.05 | .81 |
| Non-dominant side (BW) | 1.12 ± 0.04 | 1.10 ± 0.05 | .90 |
| **Average single stance** | | | |
| Dominant side time (s) | 0.41 ± 0.02 | 0.40 ± 0.03 | .78 |
| Non-dominant side time (s) | 0.40 ± 0.03 | 0.39 ± 0.02 | .99 |
| **COM oscillation** | | | |
| Average lateral oscillation (cm) | 19.0 ± 6.2 | 14.1 ± 3.2 | .0014 |

BW = body weight, COM = center of mass, GRF = ground reaction force.

**Table 5**

**Comparison of GRF, single support time, double limb unsupported duration, and magnitude of COM oscillation during running between core stability groups.**

| | Poor | Good | *P* value |
|---|---|---|---|
| **Average peak GRF** | | | |
| Dominant side (BW) | 2.4 ± 0.3 | 2.5 ± 0.3 | .40 |
| Non-dominant side (BW) | 2.5 ± 0.3 | 2.7 ± 0.3 | .41 |
| **Average single stance** | | | |
| Dominant side time (s) | 0.25 ± 0.03 | 0.25 ± 0.03 | .82 |
| Non-dominant side time (s) | 0.25 ± 0.03 | 0.25 ± 0.03 | .99 |
| **Average double limb unsupported** | | | |
| Dominant side duration (s) | 0.10 ± 0.02 | 0.10 ± 0.03 | .79 |
| Non-dominant side duration (s) | 0.10 ± 0.03 | 0.10 ± 0.03 | .95 |
| **COM oscillation** | | | |
| Average lateral oscillation (cm) | 12.6 ± 2.6 | 11.1 ± 1.4 | .08 |

BW = body weight, COM = center of mass, GRF = ground reaction force.

Lateral oscillation of the COM is crucial for dynamic gait stability.[24–26] To prevent falls, the COM should be positioned within the base of support.[27–31] Our findings indicate that control of the core promotes dynamic gait stability, as indicated by the greater lateral oscillation of the COM seen during walking in our poor than good core stability group. Previous studies reported that activity of deep muscles, including the multifidus and transverse abdominis (i.e., the core muscles), occurs prior to voluntary extremity movements.[32] When core stability is poor, these deep muscles are unable to keep the lumbopelvic segment stable. Lateral oscillation of the COM could be increased by unwanted trunk motion, depending on extremity movements. Therefore, core stability, as determined by the SCST, may be strongly associated with lateral oscillation of the COM during gait.

Stepwise logistic regression showed that lateral oscillation of the COM during walking, but not running, significantly predicted core stability status (Table 6). This does not conflict with the

**Table 6**

**Stepwise logistic regression results (response variable = core stability status determined using the Sahrmann core stability test).**

| Variable | Coefficient | t | P | Odds ratio |
|---|---|---|---|---|
| Constant | 4.18 | 3.31 | <.001 | |
| Lateral COM oscillation during walking | −0.22 | −2.87 | .004 | 0.80 |
| Likelihood ratio [df] | 11.7 [1] | | <.001 | |
| % Correct prediction | 71.1% | | | |

COM = center of mass, df = degree of freedom.

finding that only lateral oscillation of the COM during walking was significantly different between the good and poor core stability groups (Tables 4 and 5). Evaluation of core stability usually requires time and effort on the part of the participant, as well as a well-educated trainer. The lateral oscillation of the COM described in this study was conveniently estimated using a wearable ear bud. The current findings imply that core stability can be assessed outside of the laboratory environment, without the need for a trainer.

Core stability, as defined by the SCST, may not represent the capacity of the lateral core muscles to support side plank exercises. The side plank duration, on both the dominant and non-dominant sides, was not significantly different between our core stability groups (Table 2). The side plank exercise evaluates the endurance of abdominal muscles against constant resistance while maintaining the body posture.[4,33,34] The time required for the SCST is shorter (<10 seconds). Although both measures are used to evaluate core stability, the different processes and aims render the results incompatible. The ability to maintain a neutral lumbar position is not dependent on the endurance of lateral core muscles.

Core stability assessed using the SCST did not reflect the hip joint strength in our study; there was no significant difference in hip abduction or adduction strength between the groups (Table 3). To measure hip strength, the participants were asked to maximally contract the hip muscles. However, low activity of the core muscles is required to accomplish the 5 SCST tasks (<40% maximal isometric voluntary contraction).[35] As with lateral core endurance, hip strength was also incompatible with SCST core stability.

One of the limitations of this study is that the age range was relatively small (most subjects were young). Aging affects strength and endurance; the associations between the SCST score and those of other core tests change. Therefore, our results should be generalized to other age groups only with caution. Furthermore, all participants were healthy. Elite players may yield different results depending on the characteristics of their sports. To enhance generalizability, we will investigate the relationship between the motor control abilities of the lumbopelvic segment and several core test scores in persons of a wider age range and elite players.

In summary, the SCST only represented dynamic stability during walking, and not the strength or endurance of the lumbopelvic-hip complex. This implies that caution is needed when evaluating overall core stability using a single SCST, because the results are not compatible with other measures of core stability. However, the SCST is related to lateral oscillation of the COM during gait. Training to promote core stability may enhance dynamic stability during gait. Furthermore, step-wise logistic regression showed that lateral oscillation of the COM, as measured using a wireless ear-worn device, may be useful for predicting core stability. Outside of the laboratory environment, core stability could be estimated by walking, without the need for a well-educated trainer.

## Author contributions

**Conceptualization:** Kyue-Nam Park.
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**Funding acquisition:** Kyue-Nam Park.
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**Writing – original draft:** Siwoo Jeong, Si-Hyun Kim.
**Writing – review & editing:** Siwoo Jeong, Si-Hyun Kim, Kyue-Nam Park.

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