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ORIGINAL RESEARCH

Effects of core muscle stability on kicking performance during the aerial phase of taekwondo wing kicks

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Abstract

To win a taekwondo competition, more points must be scored, and the key to scoring points is to improve the motor performance of the kick. However, the relationship between core stability and the effectiveness of athletic performance, particularly in executing the wing kick, remains ambiguous, impeding coaches and athletes in their efforts to improve athletic performance. A total of 26 male participants (height: 167.21 ± 7.29 cm; weight: 62.07 ± 8.03 kg; age: 24.69 ± 2.53 years) participated, and they have been practicing Taekwondo for more than 10 years. Kinematic and kinetic data were collected using 13 infrared cameras at 120 Hz, muscle activity data were collected using epidermal electromyography, and participants' core stability level were measured using the Sahrmann Core Stability Test (SCST) for correlation with other variables. Core stability levels showed a strong negative correlation with execution time ($r = -0.7144$, $p < 0.001$) of the aerial phase of the wing kick as did angular momentum in most lower limb segments (thigh X axis, $r = -0.6435$, $p < 0.001$, shank X axis, $r = -0.62008$, $p < 0.001$, foot X axis, $r = -0.7033$, $p < 0.001$). Bilateral rectus abdominis (RA) showed strong correlations with muscle activation (left rectus abdominis (LRA) of left foot take off-left knee max extension (LTO-LKMF) phase, $r = 0.5351$, $p < 0.001$, right rectus abdominis (RRA) of LTO-LKMF phase, $r = -0.5628$, $p < 0.001$), and high levels of core stability were associated with better core-muscle coupling. We conclude that incorporating core stability training into taekwondo training has the potential to improve wing kick performance.

Keywords

Taekwondo; Sahrmann core stability test; Execution time; Angular momentum; Muscle activation; Kicking performance

1. Introduction

Taekwondo competition is an intense full-contact combat sport that has been an Olympic combat sport since the Sydney 2000 Olympic Games. Winning the competition necessitates scoring more points than opponents within the allotted time [1]. Previous studies indicate that kicking actions often prove to be the most effective means of scoring points [2, 3]. It is crucial to recognize that scoring outcomes are contingent upon sports performance [4], influenced by various factors including execution time, core muscle activation, lower extremity segmental line velocity, and the significance of core muscles for maintaining postural control [5, 6]. The duration of execution emerges as a critical factor in athletic performance, with excellence in taekwondo depends on the ability to make the impactful contact with an opponent swiftly and efficiently [7]. Simultaneously, engagement of the core muscle group is widely acknowledged to have a significant impact on sports performance [8]. Enhanced activation of the core muscle group contributes to better ensuring stability in the proximal segments of the body. In Taekwondo, kicking actions typically involve a sequence from proximal segment to distal segment, necessitating a stronger emphasis on proximal fixation [9]. The functions of the core muscle group are core strength, core endurance, and core stability [10], with the latter playing a crucial role in promoting stability in proximal body segments. Additional research has suggested that the rectus abdominis (RA) and erector spinae (ES) muscles play a crucial role in facilitating force transfer and controlling movement. This may be because proximal stability is essential for effective distal movement [11].

Among Taekwondo kicks, the wing kick (Naraechagi) combines offense and defense, with the second kick in the air being considered the most crucial phase of the entire movement [12]. While this movement is executed in the air, it imposes higher demands on a stable proximal, particularly core stability. A more stable core is expected to provide a firmer proximal support for the rectus femoris (RF), thus enabling more efficient leverage of distal velocity [13].

In disciplines such as Muay Thai [14], boxing [11], mixed martial arts [15], research has demonstrated that core stability significantly enhances athletic performance, encompassing factors such as linear velocity of the distal segment, impact power, and other aspects relevant to combat sports. However, there is still uncertainty regarding the precise impact of core stability on performance in Taekwondo. The Sahrmann Core Stability Test [16], a pivotal assessment tool that has gained prominence in medical rehabilitation diagnostics and biomechanical research in recent years [17], stands out as an effective means of assessing core muscle stability, furnishing reliable scientific metrics.

The aim of this study was to evaluate wing kick (Naraechagi) performance of taekwondo athletes with different levels of core stability. The present study hypothesized that there was a correlation between core stability level and execution time during the aerial phase of the wing kick. Through this study, our objective was to gain a clearer understanding of how core stability influences sports performance in Taekwondo, providing appropriate theoretical support for training methods and assisting coaches and athletes in improve their performance.

2. Materials and methods

2.1 Participants

A total of 26 male Taekwondo athletes participated in the study (participants were all university students from South Korea and were Black belts who had been practicing Taekwondo for more than 10 years). Individuals with severe core or lower extremity muscle group injuries, as well as a history of fracture disease, were excluded from the trial. A priori power analysis for a Pearson correlation was conducted in G*Power (Version 3.1.9.4, University of Dusseldorf, Dusseldorf, Germany) to estimate an adequate sample size. With the α level set at 0.05, a large target effect size (ES) of 0.65, a power of 0.8 and two tails, it was determined that 13 participants would be required for the analysis. Participants were divided into two groups according to their Sahrmann Core Stability Test (SCST) score: a high level group and a low level group. High level was defined as SCST score $\geq$3.5 and low level was defined as SCST score $\leq$3 based on the SCST results, with each group consisted of 13 participants [18]. No statistically significant differences for height, weight, and age were observed between the two groups (Table 1, $p > 0.1$). SCST was used as the main means of evaluating the stability of core tissues, and the relationship between SCST and athletes' sports performance was found by collecting data on SCST and athletes' sports performance and conducting correlation analyses to provide a theoretical basis for subsequent studies.

2.2 Prepare for testing

Thirteen infrared highspeed video cameras (Prime 17W, OptiTrack, Natural Point Corporation, Corvallis, OR, USA) were employed to acquire experimental data, capturing the participants' movements at a sampling rate of 120 Hz. The Trigno Avanti's transducer, integrated with our muscle acquisition device (Delsys, Natick MA, USA; 3.7 cm $\times$ 2.7 cm), was utilized to record electromyography (EMG) signals. All EMG sensors (Trigno Avanti sensors system, Delsys, Natick, MA, USA) had a common mode rejection ratio of 80 dB and were synchronized with kinetics data through Motive (OptiTrack, Natural Point, Inc., Corvallis, OR, USA), which recorded EMG at a frequency of 1200 Hz. Surface EMG signals were obtained from the bilateral rectus abdominis (left rectus abdominis (LRA), right rectus abdominis (RRA)), bilateral erector spinae (left erector spinae (LES), right erector spinae (RES)), and bilateral rectus femoris (left rectus femoris (LRF), right rectus femoris (RRF)). We affixed 14 mm spherical reflective markers to each participant, totaling 57 markers, to establish a comprehensive whole-body mechanical model [19]. Data synchronization were achieved through Motive (OptiTrack, Natural Point Corporation, Corvallis, OR, USA), and the acquired experimental data were subsequently imported into visual3D software (Professional 6.0, C-Motion Inc., Corvallis, OR, USA) [20, 21].

The EMG signal collection involves the following muscle regions: bilateral Rectus Abdominis (LRA), which starts at the level of the xiphoid process on the left and terminates at the level of the anterior superior iliac spine, 90% along a line parallel to the midclavicular line; bilateral Erector Spinae (LES), located at the spinous process of the fifth lumbar vertebrae, extending 1 centimeter to the left; bilateral Rectus Femoris (LRF), defined by a line running from the superior aspect of the patella to the 50% position between the anterior superior iliac spines. Prior to placing the EMG electrodes on the participant's skin, we trimmed local hair to prevent interference with data collection. The skin was then wiped with a wet cloth and allowed to air dry naturally to maintain optimal electrode skin contact [17, 22].

2.3 Test procedure

Prior to the main experiment, ensured that the participant had not exercised strenuously 48 hours prior to the experiment, participants were introduced to the testing procedure and objectives. Essential personal information, such as age, weight, and height, was gathered. Preceding the wing kick experiment, participants underwent the Sahrmann Core Stability Test (SCST) while lying supine [17]. The Stabilizer Pressure BioFeedback device (Theratools, Zhengzhou Active& Balance Physiotherapy Technology co., Ltd., Zhengzhou, Henan, China) was used beneath the lumbar spine, with the test involving abdominal wall gutting at a pressure of 40 mmHg (Fig. 1). Successful performance, indicated by a stable pressure reading, was required for the five levels of the Sahrmann test following abdominal wall evacuation (refer to Table 2) [17]. To progress through these levels, participants needed to maintain core stability, ensuring the pressure did not fluctuate by more than 10 mmHg. During the prone position test, participants completed this step five times and recorded the highest level achieved. If the step can be completed with an increase in pressure of less than 10 mmHg, a score of 1 is awarded. A score of 0.5 was given if the step could be completed with an increase of more than 10 mmHg, and a score of 0 was given for failure to complete the step [23].

After a 5-minute interval at the end of the SCST, participants performed maximum voluntary contraction (MVC) test, which consisted of: Rectus Abdominis: Isometric contractions

TABLE 1. Basic information about the participants participating in the experiment.

	Total participants (n = 26)	High level group (n = 13)	Low level group (n = 13)
Height (cm)	167.21 ± 7.29	164.68 ± 7.06	169.73 ± 6.30
Weight (kg)	62.07 ± 8.03	61.03 ± 7.94	63.12 ± 8.21
Age (yr)	24.69 ± 2.53	24.08 ± 1.86	25.31 ± 2.84

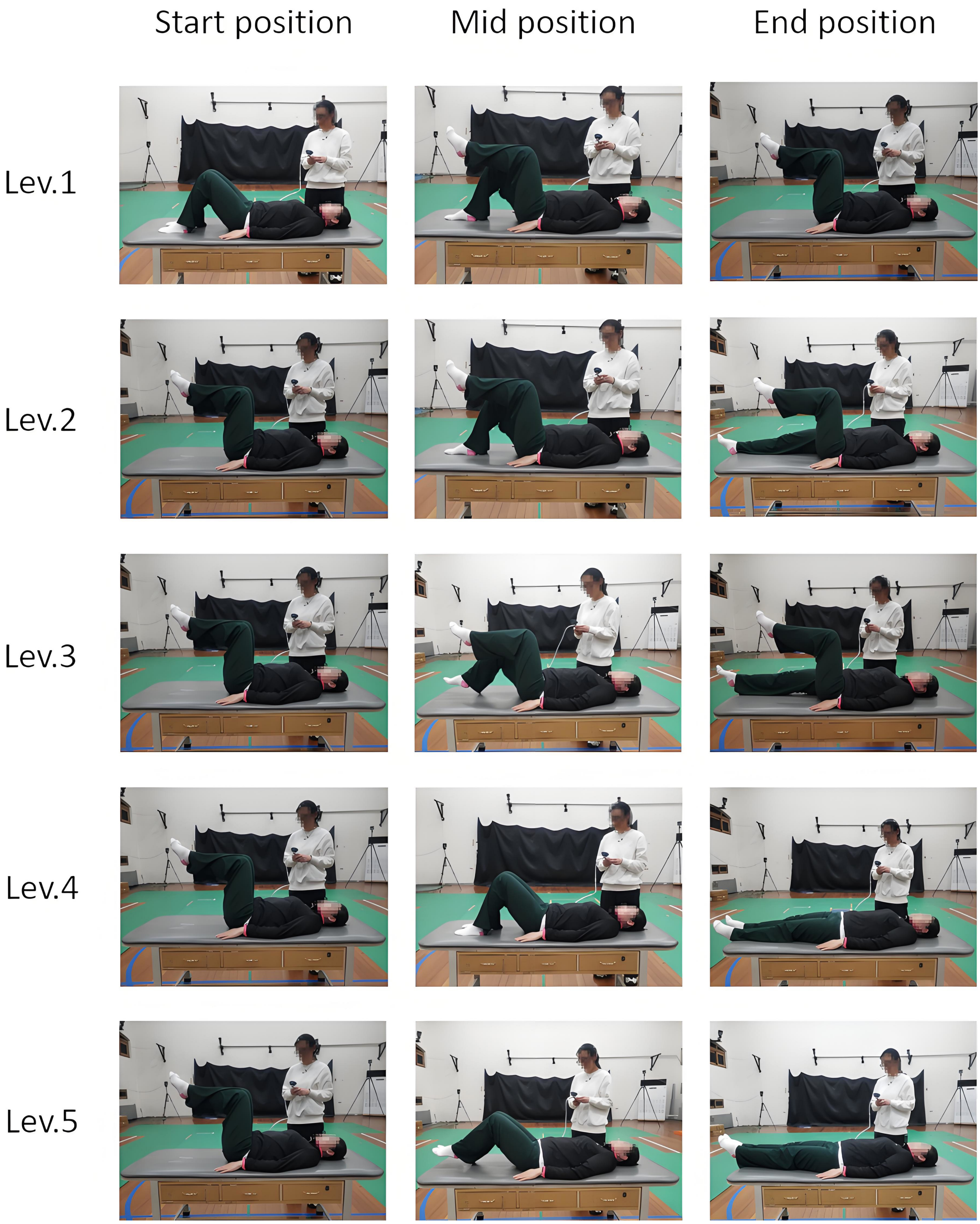

FIGURE 1. Sahrmann core stability test [24].

TABLE 2. Descriptive data and correlation coefficient (*r*) between the SCST levels and the peak angular momentum of the lower limb segments (n = 26).

		SCST			
Variable	Axis	r	p	R^2	95% CI
Thigh					
	X	−0.644	<0.001	0.504	−0.77–−0.47
	Y	−0.426	<0.001	0.301	−0.61–−0.19
	Z	−0.621	<0.001	0.525	−0.74–−0.41
Shank					
	X	−0.620	<0.001	0.481	−0.75–−0.44
	Y	0.145	0.241	0.009	−0.10–0.38
	Z	−0.502	<0.001	0.690	−0.67–−0.29
Foot					
	X	−0.703	<0.001	0.683	−0.81–−0.52
	Y	−0.063	0.622	0.198	−0.31–0.19
	Z	−0.239	0.057	0.469	−0.46–0.01

X-axis flexion and extension, Y-axis adduction and abduction, Z-axis internal and external rotation. CI: confidence interval; SCST: Sahrmann Core Stability Test.

are performed during trunk flexion. Erector Spinae: Prone position. An isometric contraction was then performed with the trunk extended. Rectus Femoris: The participants were seated on the edge of the table. An isometric contraction was then performed with the knee extended 80° (0° = full extension) [22]. The MVC test ended with a 10-minute rest, after which participants performed a kicking experiment (shown in Fig. 2). Participants engaged in a kicking experiment (depicted in Fig. 2). This experiment commenced with a 5-minute unrestricted warm up. Subsequently, participants were tasked with executing 3–5 kicking maneuvers to the best of their ability, documenting successful attempts. A 30 second rest interval was implemented between each maneuver to mitigate fatigue.

2.4 Data processing and statistical analysis

The variables under scrutiny encompassed the execution time of the wing kick aerial segment, the angular momentum of each segment of the left lower extremity, and the peak MVC of lower extremity muscle electromyograms (EMG). EMG data were collected from the bilateral rectus abdominis (LRA, RRA), bilateral erector spinae (LES, RES), and bilateral rectus femoris (LRF, RRF). For digital filtering, a Butterworth 4th order zero phase lag low pass filter with a cutoff frequency of 10 Hz was employed [25]. EMG data analysis was carried out using EMG Works, involving an initial application of a band pass filter within the 10–400 Hz range [26]. Subsequently, a root mean square (RMS) analysis was executed with a window length of 0.005 and a window overlap of 0.0025. The analysis culminated in the calculation of MVC (maximum voluntary contraction) percentages.

Correlations between SCST scores and kinetics variables were meticulously examined using GraphPad PRISM 8.0 (GraphPad Inc., San Diego, CA, USA). To provide a robust quantitative description, a 95% confidence interval (CI) was applied. Correlation analysis was performed using Spearman's horizontal correlation coefficient (r), and non-parametric tests were used because the data in this study were categorical. Correlation strengths were systematically categorized as follows: (0–0.3) small, (0.3–0.5) moderate, (0.5–0.7) strong, and (0.7–1) very strong [27]. After correlation analyses were performed, regression analyses were conducted using SPSS 29.0.1.0 (IBM, in Armonk, NY, USA) for predicting the relationship between SCST and athletic performance using a general linear model SCST levels as a main effect. Subsequent to the regression analyses, t-tests were conducted on both kinetics and muscular data ($p < 0.05$), comparing the high and low level SCST groups, to collect and describe the effects of core stability on the athletic performance of taekwondo athletes.

3. Results

SCST levels showed a very strong negative correlation with the execution time of the wing kick ($r = -0.714$, N = 26, $p < 0.001$, $R^2 = 0.787$, 95% CI: −0.81–−0.57) and a statistically significant difference was found when comparing high and low level groups ($p < 0.001$) (Fig. 3).

During the aerial phase of the wing kick, in the correlation analysis between SCST level and the angular momentum of the lower limb segments, we found that only the shank Y-axis, the foot Y-axis, and the foot Z-axis showed weak correlations, whereas their results were all moderately to very strongly correlated (Table 2).

There was a statistically significant difference between the high and low level groups in angular momentum in all three axes of the thigh segment, whereas in the shank and foot segments, only the Y-axis did not show a significant difference, and the rest of the X-axis and Z-axis also showed statistically significant differences (Table 3).

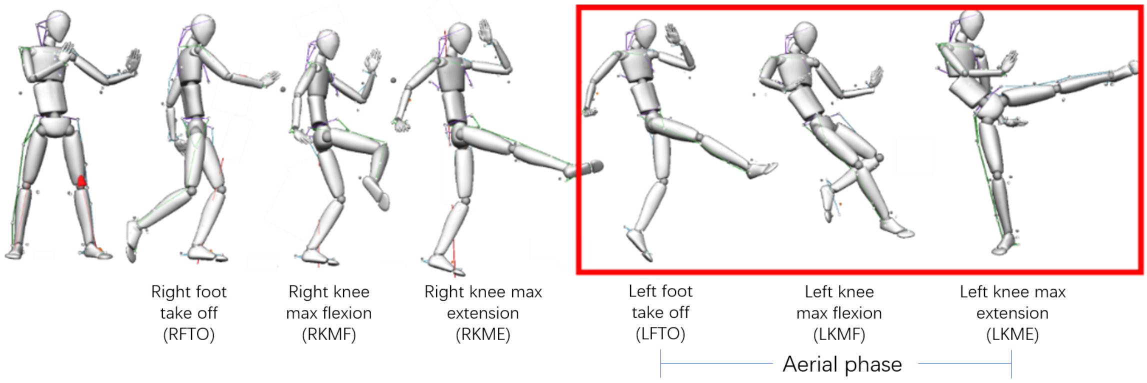

FIGURE 2. Wing kick movement phase division [12]. Red boxes indicate the phase of analysis in this study.

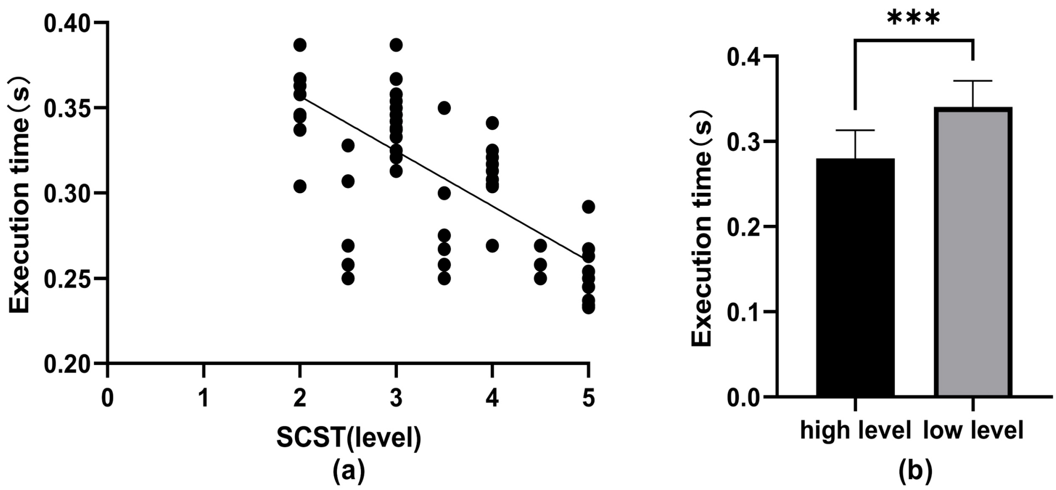

FIGURE 3. Correlation and comparison analysis of SCST with execution time. (a) Correlation analysis between SCST and execution time of the aerial phase of the wing kick. (b) Comparative analysis of execution time of the aerial phase of the wing kick at high and low levels of SCST. SCST: Sahrmann Core Stability Test. (***: $p < 0.001$).

TABLE 3. Comparative analysis of lower limb segmental peak angular momentum in the high SCST and low SCST groups (mean ± s; high level group n = 13; low level group n = 13).

		SCST		
Variable	Axis	High level group	Low level group	*p*
Thigh				
	X	6.16 ± 2.05	9.20 ± 2.48	<0.001
	Y	5.57 ± 1.55	7.86 ± 2.47	<0.001
	Z	−0.17 ± 0.88	2.93 ± 2.83	<0.001
Shank				
	X	6.18 ± 1.75	10.82 ± 3.54	<0.001
	Y	6.77 ± 2.28	6.50 ± 2.22	0.625
	Z	3.78 ± 1.50	7.43 ± 4.29	<0.001
Foot				
	X	6.09 ± 1.44	10.40 ± 3.32	<0.001
	Y	5.74 ± 1.57	6.30 ± 1.66	0.172
	Z	2.80 ± 1.93	5.60 ± 4.47	0.002

X-axis flexion and extension, Y-axis adduction and abduction, Z-axis internal and external rotation. Unit = $kg \times m^2 \times s^{-1}$. SCST: Sahrmann Core Stability Test.

LRA (left rectus abdominis) and RRA (right rectus abdominis) show strong correlations in both the front and back segments of the aerial, and LRF has strong correlations in the front part of the aerial segment. Apart from that, LRF had strong correlation in the first half of the movement (LTO-LKMF) and only weak correlation in the rest of the muscles (Table 4).

There was no statistically significant difference in the LES MVC comparison between the high and low level groups (LTO-LKMF phase $p = 0.145$, LKMF-LKME phase $p = 0.92$) (Fig. 4).

There was also no statistically significant difference in the RES MVC comparison between the high and low level groups (LTO-LKMF phase $p = 0.164$, LKMF-LKME phase $p = 0.406$) (Fig. 5).

There was a statistically significant difference in the comparison of LRA and muscle activation showed alternation between the different groups in the pre (Fig. 6a) and post phases (Fig. 6b) (LTO-LKMF phase $p < 0.001$, LKMF-LKME phase $p < 0.001$).

Muscle coupling also occurs on the RRA and is similar to the coupling that occurs on the LRA (LTO-LKMF phase $p < 0.001$, LKMF-LKME phase $p < 0.001$) (Fig. 7).

LRF activation showed statistically significant differences in LTO-LKMF segments (LTO-LKMF: $p = 0.012$ LKMF-LKME: $p = 0.753$) (Fig. 8).

4. Discussion

In this study, we assessed the core stability of each participant using the Sahrmann Core Stability Test (SCST), correlating kinematic, kinetic and muscular data with SCST level to investigate how core stability affects athletic performance in taekwondo athletes. Strong correlations were found for most results and core stability level. Participants were then divided into two groups based on SCST level. The findings showed statistically significant differences in most of the kinetics and muscle activation between the different SCST groups.

In our study, a strong negative correlation between SCST level and execution time of the wing kick aerial phase was found. This suggests that the higher SCST is associated with the shorter execution time of the wing kick aerial phase, consistent with findings from Muay Thai and boxing [11, 14]. The results from the present study found that the execution time was faster at the high level than at the lowest level. This indicates that the higher SCST corresponds to shorter execution time of the wing kick aerial phase, which is similar to findings from other projects [14]. By providing stability and balance to the body, core stability facilitates the effective coordination of different muscle groups [28]. Higher SCST enables athletes to swiftly and accurately adjust their body position at critical moments, resulting in shorter execution times and improved performance. Efficient core stability not only improves movement execution, it seems to have an impact on improving competition performance.

The results of the angular momentum of the lower limb segments showed that the correlations were mostly strongly negative. In particular, the X- and Z-axis of the thigh and shank segments and the X-axis angular momentum of the foot segments showed strong and negative correlations. In the comparative analyses, the high-level group showed less significant differences in angular momentum than the low-level group, and only the Y-axis of the shank segment and the Y-axis of the foot segment were not significant, while the

TABLE 4. Correlation analysis between SCST level and peak MVC in muscles.

		SCST			
Muscle	Phase	r	p	R^2	95% CI
LES					
	LTO-LKMF	−0.297	0.026	0.319	−0.52–−0.03
	LKMF-LKME	−0.235	0.087	0.282	−0.48–0.04
RES					
	LTO-LKMF	−0.149	0.279	0.131	−0.40–0.13
	LKMF-LKME	0.109	0.428	0.177	−0.17–0.37
LRA					
	LTO-LKMF	0.535	<0.001	0.363	0.32–0.70
	LKMF-LKME	−0.591	<0.001	0.355	−0.74–−0.39
RRA					
	LTO-LKMF	−0.563	<0.001	0.346	−0.72–−0.34
	LKMF-LKME	0.593	<0.001	0.535	0.38–0.75
LRF					
	LTO-LKMF	−0.523	<0.001	0.403	−0.69–−0.31
	LKMF-LKME	−0.192	0.129	0.292	−0.42–0.06

LES: left erector spinae; RES: right erector spinae; LRA: left rectus abdominis; RRA: right rectus abdominis; LRF: left rectus femoris; SCST: Sahrmann Core Stability Test. LTO-LKMF: Left Foot Take off-Left Knee Max Extension.

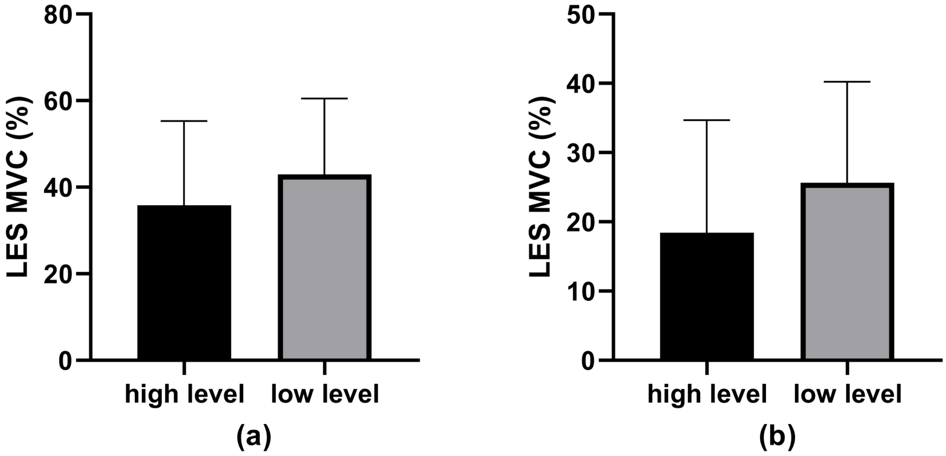

FIGURE 4. Comparison of left erector spinae (LES) muscle activation levels between high level SCST group and low level SCST group. (a) Peak MVC of LES during the LTO-LKMF phase. (b) Peak MVC of LES during the LKMF-LKME phase. MVC: maximum voluntary contraction.

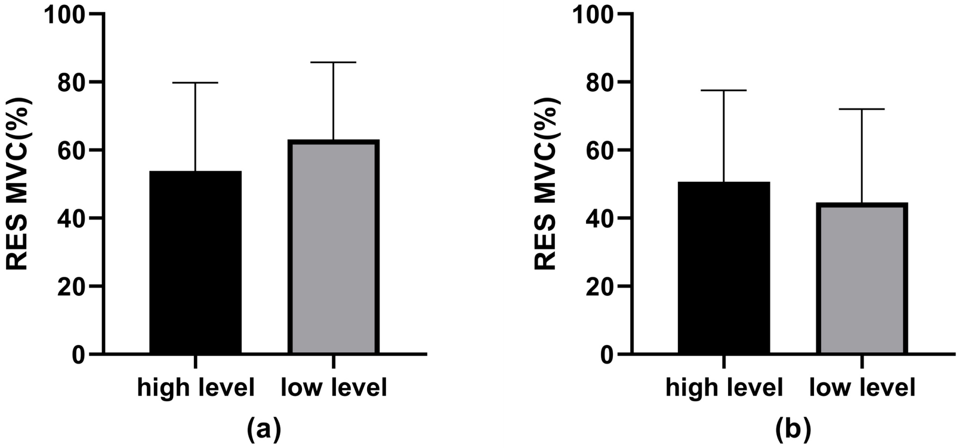

FIGURE 5. Comparison of right erector spinae (RES) muscle activation levels between high level SCST group and low level SCST group. (a) Peak MVC of RES during the LTO-LKMF phase. (b) Peak MVC of RES during the LKMF-LKME phase. MVC: maximum voluntary contraction.

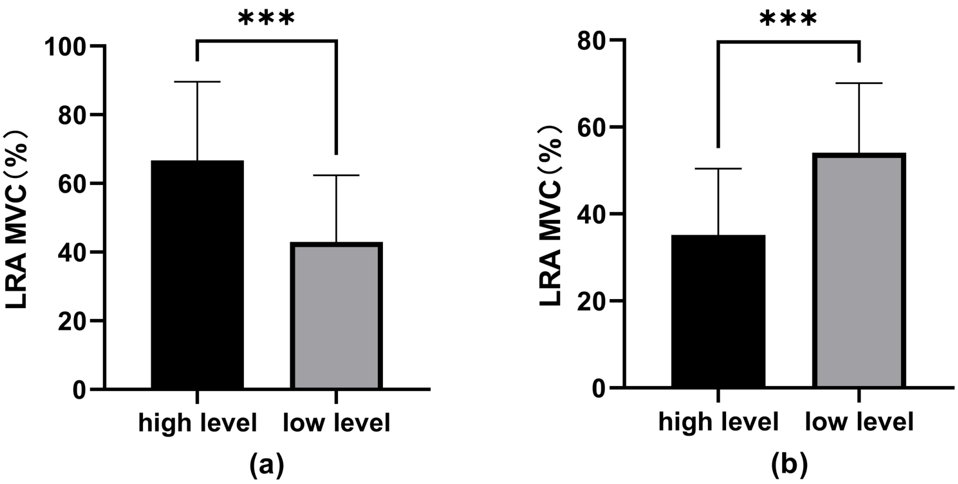

FIGURE 6. Comparison of left rectus abdominis (LRA) muscle activation levels between high level SCST group and low level SCST group. (a) Peak MVC of LRA during the LTO-LKMF phase. (b) Peak MVC of LRA during the LKMF-LKME phase. MVC: maximum voluntary contraction. (***: $p < 0.001$).

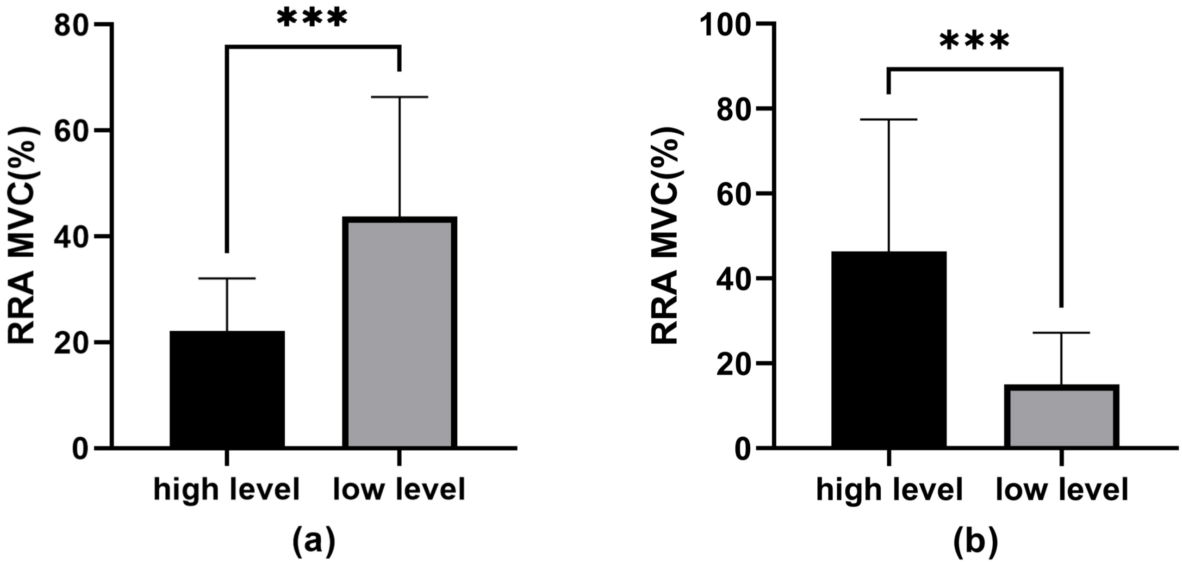

FIGURE 7. Comparison of right rectus abdominis (RRA) muscle activation levels between high level SCST group and low level SCST group. (a) Peak MVC of RRA during the LTO-LKMF phase. (b) Peak MVC of RRA during the LKMF-LKME phase. MVC: maximum voluntary contraction. (***: $p < 0.001$).

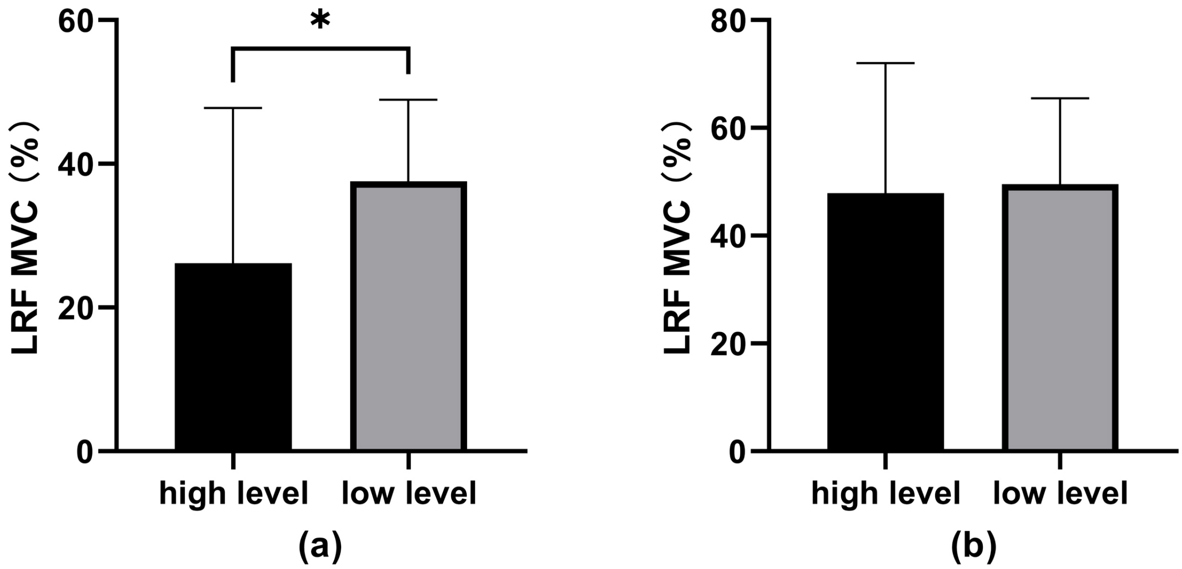

FIGURE 8. Comparison of left rectus femoris (LRF) muscle activation levels between the high level SCST group and the low level SCST group. (a) Peak MVC of LRF during LTO-LKMF phase. (b) Peak MVC of LRF during LKMF-LKME phase. MVC: maximum voluntary contraction. (*: $p < 0.01$).

rest of the results were significantly different. This suggests that a stable core allows the body to be more balanced during movement, thereby decreasing the generation of angular momentum in the lower limbs. Furthermore, it indicates that core stability may reduce unwanted rotation and oscillation during movement, facilitating more efficient motor performance. Increased core stability might allow athletes to control their bodies more accurately, thus reducing unnecessary changes in angular momentum. Stability is the foundation of all body movement, and core stability is a prerequisite for achieving whole body stability and maintaining posture [29]. Individuals with low core stability are unable to coordinate the kinetic chain during exercise [30], hindering the efficient transmission and utilization of forces within the body [31]. In this case, the body needs to compensate for the loss of stability by increasing angular momentum [32], providing sufficient force to maintain balance and greater angular momentum.

We found some interesting findings in the muscle activity results: firstly, in the correlation results, we found a strong relationship between the activation of both LRA and RRA throughout the movement phase. In the comparative analyses, there was a significant differentiation between these muscles groups, reflecting a coupling and alternation between the left and right side muscles due to phase differences. In the activation of LRF, we found a negative correlation in the accumulation phase during LTO-LKMF. This suggests that individuals in the high-level group exhibit the reduced LRF activation with shorter execution times, indicating that higher core stability aids in enhancing execution times and reducing muscle energy consumption [33]. Athletes with higher levels of stability were more flexible in the way their muscles functioned during segmental transitions of the movement. Secondly, we found a strong negative correlation between core stability levels and rectus femoris activation. Athletes with heightened core stability exhibit greater adaptability in adjusting their body posture during the movement execution through core stability. This compensatory mechanism is observed when activation of the rectus femoris muscle is required to perform a motor task in the presence of core instability [31]. This can be interpreted as strong core activation ensuring pelvic stability during movement and providing a stable stress point for the proximal rectus femoris [13, 34]. In contrast, the low level SCST group was unable to provide adequate pelvic stability during exercise due to insufficient core stability. As a result, they may need to activate the rectus femoris muscle more to accelerate movement of the distal segment. This set of results highlights the importance of core stability in rectus femoris activation and distal velocity control. This provides important insights into the relationship between core stability and athletic performance, particularly in taekwondo.

And in the comparative analysis of LES and RES activation, while no significant differences were observed, it is noteworthy that the high level group demonstrated slightly better performance in terms of muscle coupling phenomenon compared to the low level group.

In the present study, we observed correlations between SCST level and kinetics and muscle activation, which seems to help explain the phenomenon of core stability leading to changes in lower limb kinetics. However, it is worth noting that wing kicks in taekwondo are supported by synergistic dynamics between different body segments [35]. Various methods of force application may alter the level of activation of the core muscles, thereby affecting changes in stability. In addition, gender differences in muscle activity are a factor that should not be overlooked [36].

In this study, we focused on the correlation between the level of core stability and the level of muscle activation as well as lower limb kinematics and dynamics. Our findings indicate that the stronger the core stability level, the shorter the execution time, and at the same time the lower limb's angular momentum is lower, which allows for better control of the body to conserve energy while completing the movement quickly. However, changes in neuromuscular control in different segments may affect movement patterns and thus alter kick performance [31]. In addition, our experiment did not consider the effect of targets, as previous studies have shown that the presence of targets affects performance [37]. Therefore, it is recommended that future studies consider the effect of goals on changes in exercise performance. Furthermore, it is recommended that the number of participants and gender should be further increased in order to gain a more comprehensive understanding of the relationship between core stability, muscle activation, and lower extremity dynamics, as well as improving the scientific validity and reliability of the study. Apart from that, there was no strict requirement for the body fat percentage of the participants in this experiment. Abdominal fat can significantly influence the superficial EMG signals of the core muscle groups. Therefore, we recommend incorporating a requirement for body fat percentage in future Taekwondo core muscle EMG studies to enhance the scientific validity and rigor of the research.

Despite certain limitations, experimental research using the Sachmann Core Stability Test (SCST) in Taekwondo remains an underexplored area. The present study revealed the relationship between core stability and motor performance, suggesting that increasing the level of core stability appears to improve execution time and overall motor performance. The results of this study provide new directions for future research in taekwondo and provide valuable insights for coaches and athletes to design more effective training programs. Although there is still room for further research and improvement, this study provides useful insights into the importance of core stability and its potential implications on taekwondo.

5. Conclusions

The results of this study show that the level of core stability in Taekwondo athletes affects the performance of the aerial phase of the wing kick, thus supporting our hypothesis. The following main conclusions are drawn from our experiments: (1) There is a strong negative correlation between the level of SCST and execution time. At the same time, the high level group had significantly faster execution time than the low level group. (2) There is a moderate to very strong negative correlation between SCST level and most of the lower limb angular momentum. The high level group had smaller and more stable angular momentum than the low level group. (3) There is a strong correlation between SCST level and bilateral RA activation, with a strong negative correlation between LRF in the first half of the movement, and the high level group had better muscle coupling than the low level group. These findings serve as crucial elements for improving the performance of taekwondo athletes and provide valuable information for future training programs and individualised instruction. Despite certain limitations within this study, the findings provide important insights into how core stability affects athletic performance.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

LHG, KL, YK and SK—designed the research study. LHG, KL, HL and YK—performed the research. YK and SK—provided help and advice on study design, data collection, and writing the original manuscript, validated the study; interpreted the data and edited the manuscript, contributed to editorial changes in the manuscript. YK—managed the study. LHG, KL and HL—analyzed the data. LHG and KL—wrote the original manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study complies with the Declaration of Helsinki. The study protocol was explained to all participants, and they read and signed a formal informed consent form. The protocol of this study was approved by the Jeonbuk National University Institutional Review Board (JBNU2022-04-008-002) and was performed in accordance with relevant guidelines/regulations.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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