Brief Report

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Correlation Analysis between Core Stability Levels and Sports Performance in the Aerial Phase of Taekwondo Wing Kicks

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Posted Date: 11 January 2024

doi: 10.20944/preprints202401.0854.v1

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Article

Correlation analysis between core stability levels and sports performance in 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. The wing kick is an offensive and defensive maneuver. Core stability appears to be important for improving athletic performance, but the specific relationship and effect of core stability on athletic performance in the aerial phase of taekwondo is unclear. The aim of this study was to investigate the relationship between core stability and athletic performance in taekwondo in order to provide appropriate theoretical support for training and to help coaches and athletes to improve athletic performance. A total of 16 subjects (height: 167.34±9.2 cm; weight: 61±8.96 kg; age: 24.7±3.25 years) were studied. Data were captured using 13 infrared cameras at 120Hz, kinematic and kinetic data were captured using a motivated motion capture system, and the data were exported to Visual3D in order to calculate the execution time of the aerial phase, the angular momentum of the left lower extremity, and MVC analysis of the EMG using EMG works. The core stability level of the subjects were measured using the Sahrmann Core Stability Test (SCST) to correlate with the other data, and then the subjects were grouped according to their core stability levels and the data from both groups were analyzed with t-tests. Results During the double fly lifting of aerial segments, SCST levels showed a very strong negative correlation with execution time (r= -0.739) and there was a statistically significant difference in execution time between high and low SCST levels ($p < 0.001$), and the desired negative correlation was also seen in lower limb angular momentum X-axis (thigh r= -0.6294, shank r= -0.536, foot r= -0.6175), especially in the X-axis. The left rectus femoris (LRF) data had greater activation in the low SCST group(p=0.0019*). Through this experiment, we found that athletes with high core stability had faster execution times, lower angular momentum, and higher core muscle activation. Therefore, we conclude that incorporating core stability training into taekwondo training has the potential to improve kicking performance.

Keywords: taekwondo; Sahrmann Core Stability Test; execution time ; angular momentum ; muscle activation; kicking performance

1. Introduction

Taekwondo, a traditional Korean martial arts discipline with a rich history, has gained global popularity. It encompasses three main types, with competitive Taekwondo being the most widely embraced and practiced by the largest audience worldwide[1]Taekwondo competition is an intense full-contact combat sport where winning requires obtaining more points than the opponent within a specified. Research indicates that kicking actions are often the most effective in scoring points[2] . It is important to note that the impact on scoring results depends on sports performance[3].

It is well-known that various factors influence the sports performance [4, 5]. Execution time appears to be an important factor affecting sports performance[6]. In Taekwondo, kicking actions typically involve a sequence from proximal segment to distal segment [7] . This movement necessitates a stronger emphasis on proximal fixation. Simultaneously, the activity 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. The functions of the core muscle group can be subdivided into core strength, core endurance, and core stability [9] , with core stability playing a crucial role in promoting stability in proximal body segments. The rectus abdominis (RA) and erector spinae (ES) muscles, representing key muscles in the core muscle group, were extensively studied. [10, 11], Additional research has indicated that core stability plays a crucial role in facilitating force transfer and controlling movement. This is because proximal stability is essential for effective distal movement. The effectiveness of superficial muscles in force transfer is contingent upon the strength of the deep muscles responsible for stability [12]. Muscle activation can directly affect angular momentum[13]. A correlation between angular momentum and distal velocity was found in previous tennis research [14].

In Taekwondo movements, the wing kick is one of the few actions that combines offense and defense, with the second kick in the air being considered the most crucial phase of the entire movement[15]. As this action is executed in the air, it imposes higher demands on a stable proximal, i.e., core stability. A more stable core provides a firmer proximal support for the rectus femoris（RF）, enabling it to more effectively leverage distal velocity to improve sports performance[16, 17].

In disciplines such as Muay Thai（Lee & McGill, 2017）, boxing[18], mixed martial arts[19] , and other combat sports, it has been demonstrated that core stability significantly enhances sports performance. However, there remains a lack of clarity regarding how core stability affects performance in Taekwondo. This study employed the Sahrmann Core Stability Test [20], an essential test that has gained prominence in recent years in the fields of medical rehabilitation diagnostics [21] and biomechanical research[20]. Serving as an effective tool for assessing core muscle stability, this test provides us with reliable scientific metrics.

Therefore, the purpose of this study was to investigate the correlation in sports performance between taekwondo athletes with a core stability levels and to identify the factors contributing to these results: 1. A negative correlation was found between the core stability levels and the execution time of the aerial phase of the wing kick. 2. A negative correlation was found between the core stability levels and the angular momentum of the lower limb. 3. A negative correlation was found between the core stability levels and the MVC of LRF peak was negatively correlated. 4. The core muscle activation of the high SCST group was higher than that of the low SCST group. Through this study, we aimed to gain a clearer understanding of how core stability influences the relationship between core stability and sports performance in Taekwondo, so as to provide appropriate theoretical support for training and help coaches and athletes improve their sports performance.

2. Materials and Methods

2.1. Subjects

A total of 16 Taekwondo athletes participated in the study. 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 a sufficient sample size. With the α level set at 0.05, using a large target effect size (ES) of 0.65, a power of 0.8 and two tails, it was determined that 13 subjects would be needed for the analysis. And were categorized into a high core stability group (SCST score ≥ 3.5) and a low core stability group (SCST score ≤ 3) based on the SCST results, with 8 participants in each group. There were no statistically significant differences between the two groups for the variables studied ($p > 0.1$).

Table 1. Basic information about the subjects participating in the experiment.

	Subjects（n=16）	High level group（n=8）	Low level group（n=8）
Age（year）	24.7±3.25	23.75±1.98	25.38±2.6

Height（cm）	167.34±9.2	164.36±6.85	168.94±5.97
Weight（kg）	61±8.96	60.55±8.24	63.13±7.96

2.2. Prepare for Testing

Thirteen infrared high-speed video cameras (Prime 17W, OptiTrack, Natural Point Corporation, Corvallis, Oregon, USA) were employed to acquire experimental data, capturing the subjects' 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 × 2.7 cm), was utilized to record EMG signals. All EMG sensors (Trigno Avanti sensors) exhibited 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 left rectus abdominis (LRA), left erector spinae (LES), and left rectus femoris (LRF). For the experiment, 14 mm spherical reflective markers served as matching markers, with a total of 57 markers affixed to each subject to establish a comprehensive whole-body mechanical model [22]Academic data synchronization was achieved through Motive (OptiTrack, Natural Point Corporation, Corvallis, Oregon, USA). Subsequently, the acquired experimental data were imported into visual3D software (Professional 6.0, C-Motion Inc., Corvallis, OR, USA).

The EMG signal collection involves the following muscle regions: Left Rectus Abdominis (LRA), which starts at the level of the xiphoid process on the left, terminates at the level of the anterior superior iliac spine, 90% along a line parallel to the midclavicular line. Left Erector Spinae (LES) is located at the spinous process of the fifth lumbar vertebrae, extending 1 centimeter to the left. Left Rectus Femoris (LRF) is defined by a line running from the superior aspect of the patella to the 50% position between the anterior superior iliac spines. Before placing the EMG electrodes on the subject'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[23].

2.3. Test Procedure

Prior to the main experiment, participants were introduced to the testing procedure and objectives. Essential personal information, such as age, weight, and height (see Figure 1), was gathered. Preceding the wing kick experiment, participants underwent the Sahrmann Core Stability Test (SCST) while lying supine. The Stabilizer Pressure Bio-Feedback device (A&B physiotherapy, CHINA) was used beneath the lumbar spine, with the test involving abdominal wall gutting at a pressure of 40 mm Hg. 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)[24]. To progress through these levels, participants needed to maintain core stability, ensuring the pressure did not fluctuate by more than 10 mm Hg. During the prone test, participants completed the procedure five times, and the highest level achieved was recorded. Failing to execute the first step with a pressure increase exceeding 10 mm Hg resulted in a score of 0 [25].

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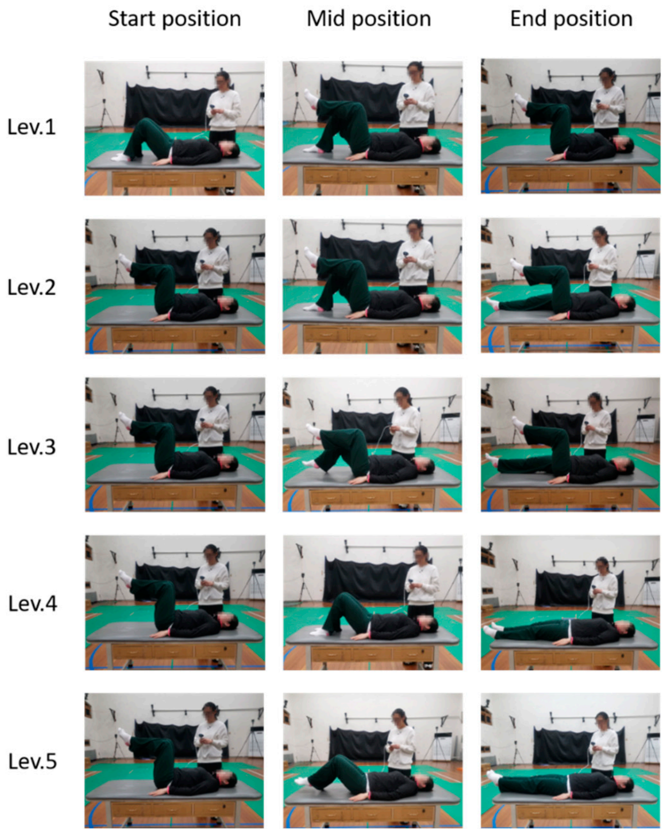

Figure 1. Sahrmann core stability test. [26].

Following a 5-minute interlude following the SCST, participants engaged in a kicking experiment (depicted in Figure 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.

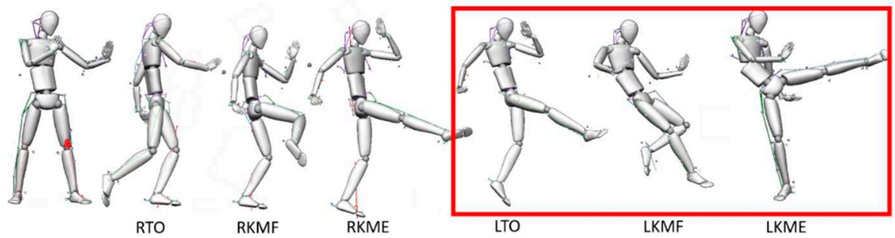

Figure 2. wing kick movement phase division [27], Red boxes indicate the phase of analysis in this study.

2.4. Data processing and Statistical analysis

Correlations between SCST scores and kinetics variables were meticulously examined using GraphPad PRISM 8.0 (GraphPad Inc., San Diego, CA, USA). 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 left rectus abdominis muscle, left rectus femoris, and left erector spinae. To provide a robust quantitative description, a 95% confidence interval (CI) was applied. For correlation analysis, non-parametric test underwent scrutiny using the Spearman rank correlation coefficient (r), while parametric test were assessed using the Pearson correlation coefficient (r). 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[28]. Subsequent to the correlation analyses, t-tests were conducted on both kinetics and muscular data, comparing the high and low-level SCST groups. This comparison was undertaken due to the potential impact of these variables on sports performance in Taekwondo.

For digital filtering, a Butterworth 4th-order zero phase-lag low-pass filter with a cutoff frequency of 10 Hz was employed[29].EMG data analysis was carried out using EMG Works, involving an initial application of a band-pass filter within the 10-400 Hz range[30]. 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.

3. Results

SCST levels showed a very strong negative correlation with the execution time of the wing kick and a statistically significant difference was found when comparing high and low level groups.

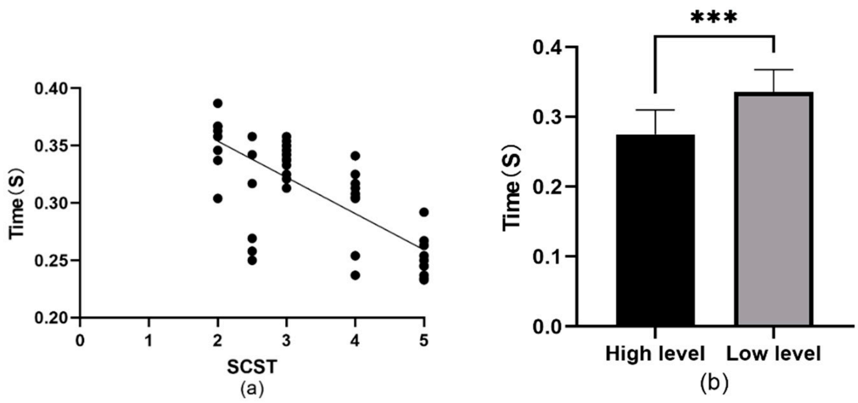

Figure 3. Correlation and comparison analysis of SCST with execution time. (a) Correlation analysis between SCST and execution time of the aerial phase of the wing kick ($r = -0.739$, $N = 16$, $p < 0.001$). (b) Comparative analysis of execution time of the aerial phase of the wing kick at high and low levels of SCST ($p < 0.001$***).

In the aerial phase of the wing kick, in the correlation analysis between SCST and peak angular momentum of the lower limb segments we found that only the data for shank Y and Foot Y were weakly correlated, while all other variables showed moderate to strong correlations.

Table 2. Descriptive data and correlation coefficient (r) between the SCST levels and the peak angular momentum of the lower limb segments (n=16) .X-axis flexion and extension, Y-axis adduction and abduction, Z-axis internal and external rotation (p=0.12ns,=0.033*,=0.002**,<0.001***).

			SCST	
Varible	Axis	r	p	CI
Thigh	X	-0.6294	<0.001***	-0.785- -0.399
	Y	-0.3753	0.014*	-0.6097- 0.08055
	Z	-0.5189	<0.001***	-0.7107- -0.2552
Shank	X	-0.5360	<0.001***	-0.7223- -0.2772
	Y	0.06555	0.68	-0.2432- 0.3623
	Z	-0.5035	<0.001***	-0.7003- -0.2356
Foot	X	-0.6175	<0.001***	-0.7809- -0.3751
	Y	0.1641	0.3181	-0.1597- 0.456

	Z	-0.4694	0.003**	-0.6837- -0.1806

There was a statistically significant difference in most of the results in the high level SCST group compared to the low level SCST group and a significant difference in the thigh X comparisons.

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=8; Low level group n=8).X-axis flexion and extension, Y-axis adduction and abduction, Z-axis internal and external rotation. Unit=$kg \cdot m^2 \cdot s^{-1}$ (p=0.12ns,=0.033*,=0.002**,<0.001***).

		SCST		
Varible	Axis	High level group	Low level group	p
Thigh	X	6.19±2.28	9.16±2.52	<0.001***
	Y	5.51±1.37	7.09±2.59	0.023*
	Z	-0.26±0.7	0.93±2.64	0.06
Shank	X	6.88±2.62	9.48±3.33	0.009**
	Y	6.53±1.67	6.14±2.14	0.526
	Z	4.06±2.1	6.5±3.91	0.018*
Foot	X	6.88±2.78	9.86±3.03	0.003**
	Y	6.18±2.07	5.56±0.9	0.33
	Z	3.08±2.66	5.74±5.17	0.52

In the correlation analysis between SCST levels and lower limb peak muscle activation, we found that LRF presented a strong correlation, LRA presented a moderate correlation, and LES showed a moderate correlation in the first half of the aerial maneuver.

Table 4. Correlation analysis between SCST grade and peak MVC in lower limb muscles (n=16).X-axis flexion and extension, Y-axis adduction and abduction, Z-axis internal and external rotation (p=0.12ns,=0.033*,=0.002**,<0.001***).

		SCST		
Muscle	Phase	r	p	CI
LRF	LTO-LKMF	-0.5413	<0.001***	-0.7259- -0.2842
	LKMF-LKME	-0.5852	<0.001***	-0.7532- -0.3456
LES	LTO-LKMF	0.3018	0.196	-0.1634- 0.6566
	LKMF-LKME	-0.0029	0.988	-0.3405- 0.3358
LRA	LTO-LKMF	0.4469	0.005**	0.1485- 0.6708
	LKMF-LKME	-0.4615	0.004**	-0.6808- -0.1664

In the comparative assessment of peak MVC, noteworthy statistical distinctions were evident in the activation of the left rectus abdominis between the two groups throughout the airborne phase. Specifically, during the LTO-LKMF phase, the high stability group demonstrated greater activation than the low stability group, whereas in the LKMF-LKME phase, the low stability group displayed higher activation compared to the high stability group.

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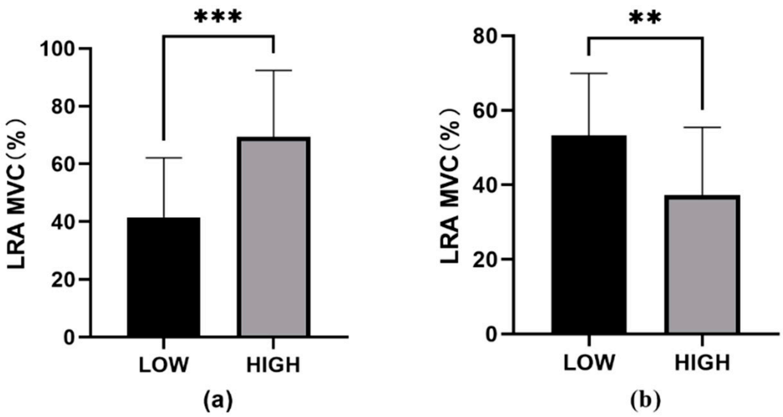

Figure 4. Comparison of Left Rectus Abdominis (LRA) Muscle Activation Levels between High-level SCST Group and Low-level SCST Group: (a) Peak MVC of LRA during the LTO-LKMF phase. (b) Peak MVC of LRA during the LKMF-LKME phase (LTO-LKMF phase p<0.001 ***, LKMF-LKME phase p=0.007 **).

Activation patterns for the Left External Oblique (LES) mirror those of the Left Rectus Abdominis (LRA), yet no statistically significant difference was observed between the two groups peak MVC during the LKMF-LKME phase.

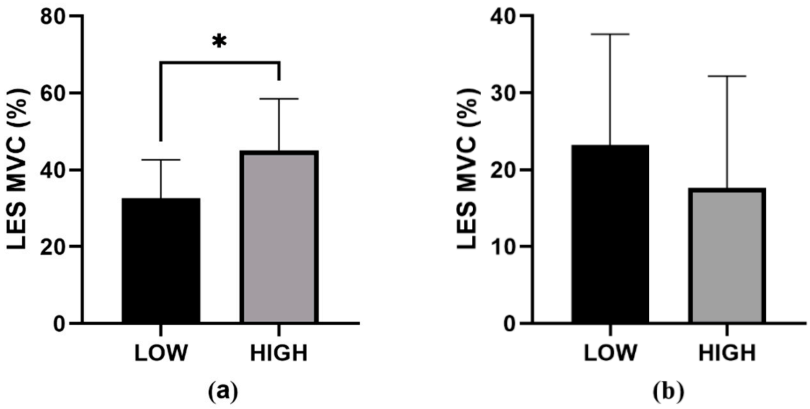

Figure 5. Comparison of LES muscle activation levels between the High-level SCST Group and the Low-level SCST Group: (a) Peak MVC of LES during LTO-LKMF phase. (b) Peak MVC of LES during LKMF-LKME phase (LTO-LKMF p=0.03*, LKMF-LKME p=0.275).

In contrast, concerning the Left Rectus Abdominis (LRA), a distinct muscle activation pattern was noted. Across the entire airborne phase of the wing kick, the activation in the Low-level SCST Group was notably higher than that in the High-level SCST Group.

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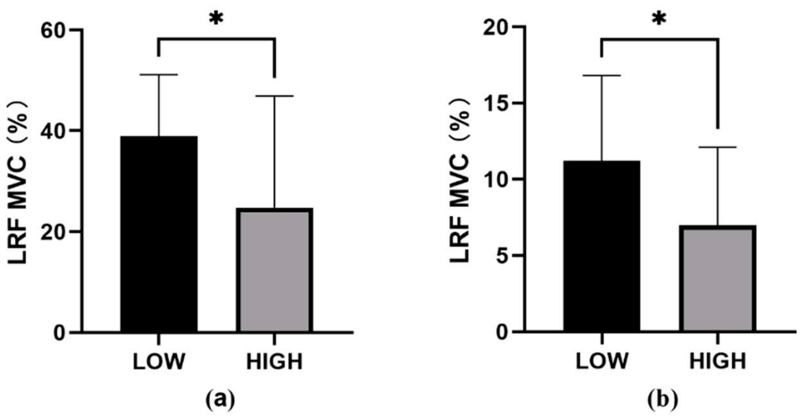

Figure 6. Comparison of LRF muscle activation levels between the High-level SCST Group and the Low-level SCST Group: (a) Peak MVC of LRF during LTO-LKMF phase. (b) Peak MVC of LRF during LKMF-LKME phase (LTO-LKMF: p=0.019*, LKMF-LKME: p=0.014*).

4. Discussion

In this study, we used the Sahrmann Core Stability Test (SCST) to assess each participant's core stability, and then correlated kinetics and muscle data with SCST ratings. Subjects were then divided into groups based on SCST scores and compared. The findings showed statistically significant differences in kinetics and muscle activation between the different SCST groups.

In our study, we found a very strong negative correlation between SCST rating and execution time of the aerial phase of the wing kick. This suggests that the higher the SCST rating, the shorter the execution time of the aerial phase of the wing kick, which is similar to findings from other programs[31]. The comparative analysis clearly showed a significant difference between the two groups, and such a difference may have been key in influencing the scores. The high SCST group had shorter movement execution times, which may reflect their greater efficiency in movement control. Core stability plays a key role in movement execution [32, 33] and helps to efficiently modulate the synergistic action of different muscle groups by providing stability and balance in the body [34]. High SCST may make athletes more able to quickly and accurately adjust their body posture at critical moments, resulting in lower execution times and improved performance. Efficient core stability may not only improve movement execution efficiency, but may also provide athletes with a more competitive advantage in competition.

The results for lower limb segmental angular momentum are generally consistent with our hypothesis, in which the correlations are largely strongly negative. In particular, a strong negative correlation was observed on the X-axis angular momentum of all segments of the lower limbs. A more stable core may allow the body to be more able to maintain balance during movement, thus reducing angular momentum in the lower limb segments. This suggests that core stability may reduce unnecessary rotation and oscillation during exercise and efficiently accomplish sports performance. The comparative analysis also showed that the angular momentum of the high SCST group was smaller than that of the low SCST group. Increased core stability may have led to more precise control of the athlete's body, thus reducing unnecessary changes in angular momentum. Subjects with low core stability are unable to ensure coordination of the kinetic chain during exercise [35], preventing the body from efficiently transmitting and utilizing power during exercise [12]. In this case, the body needs to compensate for the loss of stability by increasing angular momentum[36], providing enough force to maintain balance and greater angular momentum.

Our experimental results are consistent with our third hypothesis that the higher the core stability levels, the less activation of the rectus femoris (LRF) muscle. Also compared to the high SCST group, the low SCST group had a higher level of rectus femoris activation, which further validated our hypothesis. We found a strong negative correlation between core stability levels and rectus

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femoris activation. A high core stability grade may allow athletes to be more able to adjust their body posture through core stability during the execution of a movement, a compensatory outcome that occurs when greater rectus femoris activation is required in order to accomplish a motor task in the presence of core instability[12]. This can be explained by the strong activation of the core muscles to ensure pelvic stability during movement and provide a stable force point for the proximal rectus femoris[16, 17]. 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 require greater activation of the rectus femoris muscle to accelerate movement of the distal pedicle. This set of results highlights the importance of core stability in rectus femoris activation and distal speed control. This provides important insights into the relationship between core stability and sports performance, particularly in taekwondo.

The high SCST group demonstrated greater rectus abdominis and erector spinae activation in the first half of the movement. This may reflect the ability of the high SCST group to more effectively activate the core muscles to provide stability and controlled support during the initiation of the movement. This core control may be more important at the onset of the movement to ensure that the athlete maintains good posture and stability throughout the movement sequence [7], thereby improving overall sports performance. This observation is consistent with previous findings[37]. This activation ensures that the LRA and LES allow for better force transmission[12], during which the pelvis is tilted posteriorly, with higher activation of the lumbar erector spinae (LRA) and lower activation of the rectus femoris (LRF) muscles consistent with previous findings [38]. Trunk muscles consist of two systems: a local system that ensures stability and a global system that facilitates trunk movement. The erector spinae (ES) and rectus abdominis (RA) belong to the second group of muscles[39]. They can only transmit force better if core stability is strong enough[12]. Enhanced core activation provides sufficient proximal stability for increased distal velocity to improve execution time of completed movements[40].

In this study, we observed correlations between SCST levels and kinetics and muscle activation levels and differences between high and low SCST groups, which seem 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 performed with the support of synergistic dynamics between different body segments[41]. Various force application methods may alter the activation levels of core muscles, thereby influencing changes in stability. Additionally, gender differences in muscle activity are a noteworthy factor that should not be overlooked[42].

In this study, our main focus was on the correlation between core stability levels and muscle activation levels as well as lower limb kinetics factors. On this basis, a comparative analysis was conducted between the high SCST and low SCST groups. However, changes in neuromuscular control at different segments may affect movement patterns and thus alter kicking performance [6]. Furthermore, our experiments did not consider the effect of targets because previous research has shown that the presence of targets affects performance[43]. Therefore, it is recommended that future studies take into account the impact of targets on changes in sports performance. In addition, it is recommended to further control the number and gender of participants to gain a more comprehensive understanding of the relationship between core stability, muscle activation, and lower limb kinetics and enhance the scientific rigor and reliability of the study.

Despite some limitations, to the best of our knowledge, the experimental study of Taekwondo using the Sahrmann Core Stability Test (SCST) remains an area that is not yet fully explored. This study sheds light on the impact of core stability on sports performance, showing that increasing core stability levels can improve execution time and overall sports 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. While there is still room for further research and improvement, this study provides useful insights into understanding the importance of core stability and its potential impact on Taekwondo.

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5. Conclusions

The results of this study showed that the core stability levels of Taekwondo athletes affects the performance of the aerial phase of the wing kick, supporting our hypothesis. Through experiments, we mainly discovered the following key points: 1. There is a very strong negative correlation between SCST levels and execution time. The execution time of the high SCST group is significantly faster than that of the low SCST group. 2. There is a moderate to strong negative correlation between the SCST levels and the angular momentum of most lower limbs. The angular momentum of most lower limbs in the high SCST group is significantly greater than that in the low SCST group. 3. There is a moderate negative correlation between SCST levels and LRF activation. The high SCST group has lower activation than the low SCST group in the entire movement segment. 4. There is a moderate positive correlation between SCST levels and core muscle activation in the first half of the movement (LTO-LKMF). The high SCST group has higher activation than the low SCST group in the first half of the movement (LTO-LKMF). These findings represent key factors in improving performance in Taekwondo athletes and provide valuable information for future training programs and personalized guidance. Although the study has some limitations, the results provide important insights into how core stability affects sports performance.

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