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The Role of Lower Extremity Neuromuscular Control and Stability in Predicting Biomotor Skills in Soccer Players[*]

Selim ASAN[1], Elanur ÖZDEMİR[1], Cebrail GENÇOĞLU[1†]
[1]Erzurum Technical University, Faculty of Sport Sciences, Erzurum, Turkey

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Abstract

Soccer is a complex sport that requires the utilization of multiple motor skills. The effective use of these skills enables players to make accurate and quick decisions. The kinetic chain in sports is a mechanism that activates neuromuscular coordination of the body segments to perform sport-specific tasks. In this context, this study aims to examine the role of lower extremity neuromuscular control and stability in predicting biomotor skills in soccer players. This study was designed with descriptive and relational survey models from quantitative research methods. A total of 53 male soccer players voluntarily participated in the study. The data collection tools included the "Personal Information Form," "20 Meter Sprint Test," "Standing Long Jump," "505 Agility Test," and the "Closed Kinetic Chain Lower Extremity Stability Test (CKCLEST)." The data were analyzed using the Pearson Correlation Test and regression analysis. According to the analysis, no significant relationship was found between the biomotor skills of the athletes and the CKCLEST points (for all variables; $p>0.212$; $r<0.130$). However, a significant positive correlation was found between agility and sprint performance ($r = 0.349$, $p = 0.010$), and a significant negative correlation was identified between agility and long jump performance ($r = -0.575$, $p < 0.001$). Regression analysis showed that the long jump explained 0.0002% of the CKCLEST variance ($R^2 = 0.000002$, $\beta = -0.019$), agility explained 1.7% ($R^2 = 0.017$, $\beta = 1.54$), and sprint explained 3.0% ($R^2 = 0.030$, $\beta = -2.87$). The findings showed no significant correlation between biomotor performance and the neuromuscular control and stability test points. However, significant positive relationships were observed between agility and sprint, and a significant negative relationship between long jump and agility. In conclusion, the findings suggest that multiple tests should be used simultaneously to differentiate athletes with similar biomotor performance levels.
Keywords: Agility, Soccer, Closed kinetic chain, Strength, Sprint

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[†] **Corresponding Author:** Dr. Cebrail GENÇOĞLU, **E-mail:** cebrail.gencoglu@erzurum.edu.tr

INTRODUCTION

Speed, one of the most important physical attributes in sports, is the ability to move quickly or change position rapidly. In mechanics, speed is expressed as the ratio of distance to time (Paul et al., 2016). Achieving the desired performance level in sports disciplines requires using scientific tools and methods effectively. It is crucial to apply scientifically grounded and modern training methods alongside sport-specific exercises to enhance an athlete's essential motor skills, such as endurance, strength, agility, agility, sprint and flexibility, and success in their specific discipline (Kızılet et al., 2010). Speed has a direct impact on the success of a football player. Footballers must be fast when running, competing, and defending during a match. The ability to move the body at high speed depends on strength while covering the maximum possible distance in the shortest time is related to speed (Günay and Yüce, 2008). Like in all other sports, muscle strength is also essential in football. This is because core and functional muscle strength are necessary during sports activities to achieve optimal performance and prevent potential injuries.

To optimize performance and prevent injuries, it is particularly essential to maintain a balance between core muscle strength and functional strength levels in the lower limbs. The hamstring and quadriceps muscle groups, which are part of the lower extremity musculature, play a pivotal role in activities such as acceleration, deceleration, jumping, landing, and other sport-specific movements (Hoshikawa et al., 2009; Ulupinar et al., 2021). In this context, lower limb stability, strength, and neuromuscular control are paramount in football (Tortu et al., 2024). Neuromuscular adaptation enables athletes to execute various movements during competitions with the utmost precision. Neuromuscular control refers to the body's dynamic response to internal and external sensory stimuli and irregularities (Asan, 2023; Kaya, 2017). This control facilitates motor responses by ensuring regulated muscle activity during voluntary movements, unexpected circumstances, and in response to both internal and external stimuli (Asan, 2023; Silfies et al., 2015). Neuromuscular control is typically evaluated using closed kinetic chain tests.

A closed kinetic chain refers to an activity where the distal segment of the lower limb is fixed and supports body weight, allowing the proximal segment to move over the stable distal segment (Fu et al., 1992). The closed kinetic chain lower extremity dynamic stability test is a novel method that examines functional performance and evaluates the antigravity posterolateral hip muscle system (Lee et al., 2020). Closed kinetic chain exercises can enhance lower limb strength, stability, and neuromuscular adaptation. CKCLEST assesses endurance, strength, whole-body stability, functional lower limb stability, core stability, and static/dynamic control of the lower limbs, alongside simultaneous coactivation of the quadriceps and hamstring muscles. CKCLEST is a valid and reliable objective measurement tool that evaluates the function of the closed kinetic chain (Arikan et al., 2022). Unlike plyometric tests, CKCLEST places no pressure on the joints.

Studies have shown that closed kinetic chain exercises in rehabilitation programs significantly increase muscle strength through eccentric, concentric, and isometric contractions. These exercises contribute to the strength and power required for daily activities such as walking, running, and stair climbing (Girgin et al., 2020; Pamboris et al., 2024). Additionally, closed kinetic chain exercises enhance proprioception and neuromuscular control by improving joint stability, thereby accelerating functional recovery (Abbas and Daher, 2017). As a result, valid tests have been developed to measure the outcomes of closed kinetic chain exercises. These tests can symmetrically assess differences between the two lower limbs. The CKCLEST has been designed to measure the strength, power, and stability of the lower limbs, torso, and whole body. Furthermore, it can be used to evaluate the functional stability of the lower limbs and the static or dynamic control of the lower extremities (knees/hips) or the torso (Arikan et al., 2022). Closed kinetic chain (CKC) exercises have been widely recognized for their effectiveness in improving neuromuscular control and joint stability. Girgin et al. (2020) demonstrated that CKC exercises significantly enhanced physical function and reduced pain in patients with knee osteoarthritis, emphasizing their importance in lower extremity rehabilitation. Similarly, Ubinger et al. (1999) found that a 4-week CKC training program improved neuromuscular control in the upper extremity, highlighting the versatility of CKC exercises across different body regions. These findings suggest that incorporating CKC exercises into rehabilitation programs can enhance joint stability and functional performance for various populations. In light of this information, the CKCLEST not only provides insight into the performance of athletes in football but also highlights that incorporating exercises appropriate for the test into training programs can enhance athlete performance.

Football is played at a much faster pace today compared to the past, and physical power has not only retained its importance. However, it has also become one of the most crucial components of the sport, highlighting the significance of children's early development in youth academies. Therefore, athletes' sporting success or readiness typically depends on their physical fitness, coordination abilities (strength, speed, balance, agility, endurance, mobility), and technical and tactical skills (Ulupınar et al., 2021). The motor learning process, which serves as a transition to the application of understanding, refining, and reinforcing motor skills, manifests through the acquisition and development of coordination and synchronization abilities (Bayazıt, 2007). The number of activities supporting motor development is increasing day by day. Maximizing children's motor skills is directly related to the continuity of activities and skills acquisition. When considering individual differences, the timing and correct execution of movements are very important (Sayın, 2011). Proper evaluation of sports performance and adapting training programs to individual needs contribute to optimizing performance in the specific discipline. In this context, this study aims to investigate the impact of lower extremity neuromuscular control and stability on predicting biomotor skills in football players.

Therefore, our hypotheses for this research:

H1: There is a significant positive relationship between lower extremity neuromuscular control and stability, as measured by CKCLEST, and biomotor skills such as sprint speed, agility, and standing long jump performance in soccer players.

H2: Athletes with higher agility performance will demonstrate stronger correlations with sprint speed and lower correlations with standing long jump distance due to the differing motor and biomechanical demands of these skills.

METHOD

Research Model

In this study, descriptive and relational survey models from quantitative research methods were used. The descriptive model examines the current state of a phenomenon without manipulation, while the correlational survey model examines the relationship between two or more variables and its direction (Karasar, 2014).

Research Group

The study group consisted of licensed male athletes aged between 15 and 18, actively playing football with at least two years of team experience. The following exclusion criteria were applied in selecting participants: a) history of limb injuries, b) cardiovascular or respiratory system diseases, c) ongoing chronic pain, and d) significant differences between limbs. Based on the G*Power analysis, with a 95% confidence interval, 95% test power, and 5% effect size, the sample size was determined to be 34. However, to enhance the study's validity and prevent potential participant attrition, 53 participants were included in the research.

Table 1. Descriptive characteristics of the participants (n=53)

	Mean ± SD	Min	Max
Age (year)	16.49 ±1.13	15.00	18.00
Training Experience (year)	5.11 ± 1.78	2.00	8.00
Body Mass (kg)	64.94 ± 9.58	45.00	85.00
Height (cm)	1.75 ± 0.06	1.62	1.90
BMI (kg/m$^{2)}$	20.99 ± 2.28	16.26	24.89

Values are presented as mean (M) ± standard deviation (SD); BMI: Body Mass Index; Min: Minimum value; Max: Maximum value.

Reviewing Table 1, it was determined that the participants consisted of 53 male football players aged between 15 and 18 years (16.49 ± 1.13). Their years of sports experience ranged from 2 to 8 years (5.11 ± 1.78), body weight ranged from 45 to 85 kg (64.94 ± 9.58), height ranged from 1.62 to 1.90 m (1.75 ± 0.066), and BMI ranged from 16.26 to 24.89 kg/m^2 (20.99 ± 2.28).

Data Collection Tools

The participants were administered the following data collection tools: the "Personal Information Form" (comprising descriptive questions such as age, years of sports experience, height, and weight), the "20-Meter Sprint Test," the "Standing Long Jump Test," the "505 Agility Test," and the "Closed Kinetic Chain Lower Extremity Stability Test (CKCLEST).

Closed Kinetic Chain Lower Extremity Stability Test (CKCLEST)

CKCLEST is conducted on a solid surface to assess neuromuscular control and stability of the lower extremities. Participants begin in a plank position, supported by their forearms, with feet shoulder-width apart, toes touching the ground, and the body in a straight alignment. While maintaining this position, participants are instructed to cross one foot over to touch the outside of the opposite foot and then return to the starting position. The same movement is then repeated with the other foot. Participants perform this movement as quickly and consecutively as possible, with the number of repetitions completed within a 15-second interval recorded (Arıkan et al., 2022).

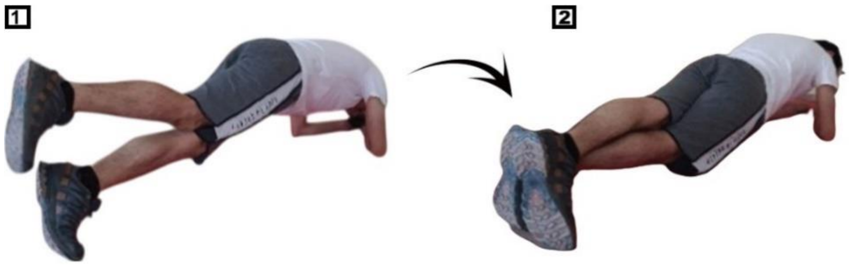

Figure 1. Closed kinetic chain lower extremity stability test - visual representation of the test procedure (Arslan et al., 2022)

Agility Test

The 505 Agility Test, utilized in this study, measures the time between the final 5 meters of a 15-meter sprint and the same 5 meters on the return leg. Participants are required to sprint towards a designated line located 15 meters from the starting point, make contact with the line using one foot, perform a 180-degree turn, and then sprint 5 meters back past the finish line. The attempt is not scored if the participant initiates the turn before reaching the designated line. Each participant completed three trials, with the best time being considered for analysis. The timing for the test was measured using a photocell system (Microgate Witty, Microgate, ITALY) to ensure accuracy (Nimphius et al., 2016; Özbay et al., 2018).

20 Meter Sprint Test

The 20-meter sprint test measures how quickly an athlete completes a 20-meter distance (Ulupınar et al., 2021). Athletes start 1 meter behind the starting line and complete the distance at maximum speed. Participants are allowed two trials, with a 3-minute rest period between each. The athlete's best time is recorded as valid for the statistical analysis (Yanci et al., 2017). Sprint times were measured using a photocell timing system (Microgate Witty, Microgate, ITALY).

The Standing Long Jump Test (SLJT)

The Standing Long Jump Test (SLJT) measures how far participants can jump from a stationary position (Castro-Piñero et al., 2010; Gençoğlu et al., 2023). Participants position themselves with their toes as close as possible to the starting line without a running start. Using maximum effort, they swing their arms backward and forward to assist with the jump. Each participant is allowed two attempts, and the best distance is recorded as the test result (Castro-Piñero et al., 2010).

Ethics Approval

The ethical process of the research was completed by Decision No. 10, made during the 04th meeting of the Erzurum Technical University Research and Publication Ethics Committee on

04.04.2024. Voluntary consent was obtained from all participants, and for individuals under 18, permission was secured from their parents or legal guardians.

Collection of Data

The study was conducted in a single session. An anthropometric assessment was initially performed to determine the participants' height, weight, and body mass index. The participants completed a 15-minute general warm-up protocol and a 5-minute stretching protocol. After the warm-up, the participants were randomly assigned to perform the tests randomly. First, they completed CKCLEST, followed by the standing long jump, agility, and 20-meter sprint tests. All participants were thoroughly informed about the protocol process and any associated experimental risks.

To ensure standardization, participants were instructed to refrain from consuming caffeine or carbonated drinks and engaging in intense physical activity 24 hours prior to the test session. Additionally, all participants were asked to maintain their regular sleep routines, achieving at least 8 hours of sleep before the session. The testing took approximately 90 minutes per participant, with breaks of 3-5 minutes between trials and 10 minutes between different tests to minimize fatigue. The testing process was supervised by three experienced researchers to ensure accurate data collection and participant safety. Standardized verbal encouragement was provided during the tests to motivate participants.

Analysis of Data

The statistical analysis of the data collected in this study was performed using SPSS 27 software (IBM Corp., Armonk, NY, USA). The normality of the data was assessed through the Shapiro-Wilk test, which confirmed that the variables were normally distributed ($p > 0.05$). Given that the assumption of normality was satisfied, parametric tests were deemed appropriate for the analysis. Pearson's correlation coefficient (r) was utilized to explore the relationships between variables. At the same time, regression analysis (R^2) was conducted to assess the influence of the CKCLEST on performance in the sprint, agility, and standing long jump tests. A threshold for statistical significance was set at $p < 0.05$ for all analyses.

FINDINGS

The presented findings encompass a detailed analysis of the participants' neuromuscular control, stability, and biomotor abilities, alongside their interrelations and predictive factors. This comprehensive evaluation provides a robust foundation for understanding performance outcomes and their underlying mechanisms, as demonstrated in the subsequent tables and discussions.

Table 2. Findings regarding the neuromuscular control, stability, and biomotor abilities of the participants

Variables	Mean ± SD	Min.	Max.
CKCLEST (rep number)	24.96 ± 3.73	17.00	33.00
SLJT (cm)	1.95 ± 0.27	1.30	2.80
Agility (sec)	2.86 ± 0.31	2.42	3.54
Sprint (sec)	3.38 ± 0.22	2.96	3.90

Values are presented as mean ± standard deviation (SD); SLJT: Standing Long Jump Test; Min: Minimum value; Max: Maximum value; CKCLEST: Closed Kinetic Chain Lower Extremity Stability Test.

As indicated in Table 2, the results of the CKCLEST ranged from 17 to 33 repetitions (24.96 ± 3.73), the Standing Long Jump distances ranged from 1.30 to 2.80 meters (1.95 ± 0.27), the Agility Test times ranged from 2.42 to 3.54 seconds (2.86 ± 0.31), and the 20-meter Sprint Test times ranged from 2.96 to 3.90 seconds (3.38 ± 0.22).

Table 3. Findings regarding the relationship between participants' neuromuscular control, stability, and biomotor skills

Variables (r)	Mean ± SD	CKCLEST	SLJT	Agility	Sprint
CKCLEST (rep number)	24.96 ± 3.73	—			
SLJT (cm)	1.95 ± 0.27	-0.001	—		
Agility (sec)	2.86 ± 0.31	0.130	-0.575**	—	
Sprint (sec)	3.38 ± 0.22	-0.174	-0.154	0.349*	—

*The relationship between the variables is presented as the correlation coefficient (r); CKCLEST: Closed Kinetic Chain Lower Extremity Stability Test; SLJT: Standing Long Jump Test; *: p < 0.05; **: p < 0.01.*

As shown in Table 3, no significant correlations were found between CKCLEST scores and performance in the Standing Long Jump Test ($r = -0.001$, $p = 0.992$), Agility Test ($r = -0.130$, $p = 0.355$), or Sprint Test ($r = -0.174$, $p = 0.212$) ($p > 0.05$). However, there was a significant relationship between agility and standing long jump performance ($r = -0.575$, $p < 0.001$), as well as between agility and sprint performance ($r = -0.349$, $p = 0.010$) ($p < 0.05$).

Table 4. Findings of the regression analysis regarding the relationship between participants' neuromuscular control, stability, and biomotor skills

CKCLEST	R^2	β	Constant	Standard Error
SLJT	0.000002	-0.019	24.99	1.91
Agility	0.017	1.54	20.54	1.65
Sprint	0.030	-2.87	34.69	2.27

*The regression values between the variables are presented as R^2; CKCLEST: Closed Kinetic Chain Lower Extremity Stability Test; SLJT: Standing Long Jump Test; β: regression coefficient; *: $p < 0.05$; **: $p < 0.01$.*

According to the results in Table 4, no significant effect was found between CKCLEST scores and the relationships with SLJT, agility, and sprint ($p > 0.05$ for all variables). The impact of SLJT performance on CKCLEST scores was minimal ($R^2 = 0.000002$, $\beta = -0.019$), and the regression equation is expressed as CKCLEST = 24.99 - 0.019 * SLJT. Agility exhibited a slight positive effect on CKCLEST scores, though it did not contribute significantly ($R^2 = 0.017$, $\beta = 1.54$), with the regression equation being CKCLEST = 20.54 + 1.54 * Agility. Sprint, likewise, did not show a significant impact on CKCLEST scores ($R^2 = 0.030$, $\beta = -2.87$), with the regression equation expressed as CKCLEST = 34.69 - 2.87 * Sprint.

DISCUSSION and CONCLUSION

This research examined the effects of lower extremity neuromuscular control and stability on biomotor skills in football players. The findings demonstrated no significant correlation between biomotor performance, neuromuscular control, and stability scores. However, a significant positive relationship was identified between agility and sprint performance, while a significant negative relationship was observed between SLJT and agility. These results indicate that lower extremity stability and neuromuscular control alone cannot fully explain biomotor skills. Furthermore, simultaneously evaluating multiple performance parameters is crucial for distinguishing athletes with similar performance levels. It is suggested that moving beyond individual tests to incorporate multiple assessments provides a more accurate prediction of an athlete’s overall performance level.

The lack of a significant relationship between neuromuscular control and biomotor skills observed in this study may be attributed to the specific characteristics of the CKCLEST. As Stapleton et al. (2021) demonstrated, functional and dynamic movement tests provide a better prediction of athletic performance than static assessments, particularly in sports requiring rapid and coordinated movements. Moreover, Behm and Colado (2012) emphasized the principle of task specificity, highlighting that test outcomes may vary depending on the degree to which the assessment mirrors the physical demands of the sport.

In the study conducted by Martin et al. (2014) on neuromuscular control, the impact of energy transfer on performance and injury during tennis serves was examined in detail. The research demonstrated that efficient energy flow was associated with higher ball speeds in athletes, which, in turn, led to reduced joint stress and a potential decrease in injury risk. Both studies highlighted the potential of neuromuscular control, particularly in sport-specific movements, to enhance performance (Martin et al., 2014). In their study on plyometric training, the effects of neuromuscular control on improving sports performance are further supported by Chelly et al. (2010). Chelly et al. (2010) found that plyometric exercises improved football players' leg strength, jump height, and sprint performance. This improvement may be linked to the development of neuromuscular control, as plyometric exercises engage the stretch-shortening cycle (SSC), which enhances muscle force production and coordination. Similarly, Martin et al. (2014) found that effective energy transfer and muscle control in tennis players were associated with a lower risk of injury, indicating that proper energy transmission and muscle control can both reduce injury risk and enhance performance.

Closed kinetic chain exercises have been widely supported in the literature for their effectiveness in enhancing sports performance and reducing injury risk (Almansoof et al., 2023). Specifically, closed kinetic chain exercises have been highlighted for improving joint stability and force transmission, positively impacting the musculoskeletal system by reducing the risk of injuries caused by overloading and compensatory movements (Myer et al., 2010). As noted in the study by Almansoof et al. (2023) the coordination of the kinetic chain ensures that body segments move with optimal speed and timing, with energy transfer between these segments playing a critical role. When this energy transfer is disrupted, the risk of injury in athletes may increase. In particular, imbalances between the quadriceps and hamstring muscles are significant in anterior cruciate ligament (ACL) injuries (Hewett et al., 2006). These findings suggest that closed kinetic chain exercises promote neuromuscular adaptations, enhancing performance and significantly reducing injury risk (Almansoof et al., 2023; Chelly et al., 2010). However, our study found no significant relationship between CKCLEST and biomotor skills. This discrepancy may be attributed to differences in sample characteristics across studies and the similar performance levels of the athletes in our study.

In another study, Almansoof et al. (2023) examined the correlation between ankle dorsiflexion range of motion (ADROM) and lower extremity kinetic chain function and its relationship with performance-based tests. The study found that closed kinetic chain activities enhance lower extremity stability, allowing muscles to engage more effectively during movement. It was also noted that closed kinetic chain exercises contribute to joint stability by reducing shear forces on the joints and promoting the coordinated function of agonist-antagonist muscle groups (Almansoof et al., 2023; Lutz et al., 1993). Additionally, the ankle dorsiflexion range of motion was closely linked to closed kinetic chain exercises, significantly contributing to success in performance tests. The kinetic chain is a system where body segments work in coordinated harmony to transfer force, optimizing athletic performance. Specifically, in the overhead throwing mechanism, the lower extremities and core muscles provide essential support by maximizing ground reaction forces during the throw (Chu et al., 2016). Research has shown that 51-55% of the kinetic energy generated by larger muscle groups is transferred to hand movements, demonstrating the direct impact of coordinated and optimally functioning muscles on performance (Chu et al., 2016). The role of closed kinetic chain exercises in enhancing lower extremity stability, reducing shear forces on the joints, and encouraging the co-contraction of agonist-antagonist muscles is vital for athletes, as it aids in both performance enhancement and injury prevention (Almansoof et al., 2023). In this context, the literature supports the critical role of closed kinetic chain exercises in improving performance and preventing injuries, particularly by enhancing joint stability and energy transfer (Chelly et al., 2010; Chu et al., 2016).

Another finding of the present study revealed a significant positive relationship between agility and sprint performance and a significant negative relationship between SLJT and agility. Studies in the literature support similar findings. Gisladottir et al. (2024) examined the relationships between agility, linear speed, and vertical jump performance among professional and U-14 athletes. A strong correlation between linear speed and agility was found in professional athletes ($r = 0.90$, $p = 0.01$), whereas no significant relationship was observed between these two parameters in U-14 athletes. These results highlight the contribution of advanced neuromuscular coordination and motor skills to physical performance in professional athletes. A similar study by Köklü et al. (2015) reported a strong correlation between 30-meter sprint time and countermovement jump (CMJ) performance ($r = -0.599$, $p = 0.02$) in young football players. Both studies emphasize the impact of integrating and developing motor skills on athletes' overall performance. Enhancing biomotor abilities such as speed, agility, and vertical jump is particularly critical for optimizing athletic performance.

In conclusion; the absence of a statistically significant correlation between the neuromuscular control and stability test scores and the biomotor performance of young athletes could be attributed to the homogeneity of the sample in this study. The similarity in biomotor performance values among athletes likely made distinguishing apparent differences between groups complex. Additionally, while a significant positive relationship was observed between sprint and agility, a negative correlation was found between SLJT and agility performance. The differences in measurement units can explain this negative correlation; in the standing long jump, a greater distance indicates better performance, whereas a shorter time in sprinting reflects better speed. These inverse relationships are natural and expected outcomes when evaluating biomotor abilities.

Limitations and Suggestions

The results indicate that tests such as the CKCLEST may lack the sensitivity to effectively discriminate biomotor skill performance among athletes with similar proficiency levels. The cross-sectional design of this study, alongside its limited sample size comprising only male football players aged 15-18 years, is a significant constraint in establishing causal inferences. The homogeneity of the sample in terms of age, gender, and sporting discipline may have further limited the generalizability of the findings. Future studies should aim to include broader and more heterogeneous populations by incorporating both male and female athletes from various age groups and diverse sports disciplines. For instance, younger athletes or adults competing in sports requiring different neuromuscular demands, such as gymnastics or track and field, may yield different outcomes, potentially providing more robust conclusions about the relationship between neuromuscular control and biomotor skills.

Additionally, the potential influence of uncontrolled variables, such as psychological factors like anxiety, motivation, or familiarity with the testing protocol, should be considered, as these may have affected participants' performance. Environmental factors, such as the testing conditions, surface type, and timing of the assessment (e.g., morning versus evening), may also have contributed to variability in the results. To address these limitations, future research should adopt longitudinal designs to observe changes over time, incorporate larger sample sizes, and ensure controlled testing environments. Such methodological improvements will help refine the sensitivity and applicability of the CKCLEST and similar assessments in evaluating neuromuscular control and biomotor performance across diverse athletic populations.

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