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Original Article

Gender differences in muscle activation patterns during squat and countermovement jumps in soccer players

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Abstract
Assessing muscle activation during squat and countermovement jumps is crucial for soccer players because these exercises replicate the explosive movements often required in competition, such as jumping for a header. Objective: The objective of this study is to examine the activation patterns of the rectus abdominis, lumbar erector spinae, rectus femoris, and biceps femoris on both the left and right sides in male and female soccer players during squat jumps (SJs) and countermovement jumps (CMJ). Methodology: This cross-sectional study included 30 healthy university-level players (15 males and 15 females). Surface electromyography (Noraxon-USA, MR3 3.8.30) was used to assess the activation patterns of the rectus abdominis, lumbar erector spinae, rectus femoris, and biceps femoris on both sides during SJs and CMJs. Results: The Pearson correlation coefficient was used to determine the relationship between left and right muscle activation patterns in male and female players during both types of jumps, revealing a significant correlation ($p < 0.05$). Discussion: Females exhibited more consistent left-right synchronization in muscle activation, especially in the core and leg muscles, compared to males, who showed more complex muscle interactions and asymmetries. These findings align with previous research indicating that men and women differ in their neuromuscular activation patterns, co-contraction ratios, and responses to dynamic movements such as jumping. Understanding these gender-specific patterns is important for developing targeted training and injury prevention strategies. Conclusion: The findings indicated that different jump types and genders displayed distinct muscle activation patterns. Females, in particular, demonstrated a significantly stronger correlation between the left and right muscle activation during both jumps compared to males.

Keywords: erector spinae; electromyography; hamstring; quadriceps; rectus abdominis

Introduction

The vertical jump is a complex movement that requires the coordination of multiple muscles in the trunk and legs.It is a critical performance indicator in football because it measures leg power and can be used to assess a player's anaerobic capacity. There are two main types of vertical jumps: the squat jump (SJ) and the countermovement jump (CMJ). Both are closely related to a player's explosive strength and power, making them essential performance metrics in football. The SJ begins from a fixed, semi squatting position without an arm swing, while the CMJ starts from an erect stance, involving a downward movement before pushing off (Charoenpanicha et al., 2013).

Muscle function is essential in generating the upward force required to lift the trunk, despite the coordination of multiple systems to enhance jumping performance (Charoenpanicha et al., 2013; Chappell et al., 2007). The kinetic chain describes the continuous, interconnected process of human movement. Stability during vigorous or rapid motions relies on strong core muscles, particularly the rectus abdominis (RA) and erector spinae (ES). The RA is especially important in football, providing power and stability during various movements, such as twisting, kicking, and running. The RA also helps to maintain excellent posture and core stability, both of which are essential for injury prevention and balance. Previous research has shown that the RA muscle is activated during dynamic resistance training, contributing to overall core muscle engagement (Willardson et al., 2009). Furthermore, the RA and ES play a vital role in athletic performance by ensuring spine stability during whole-body exercises in conjunction with other core muscles (Khaiyat & Norris, 2018). Additionally, studies have demonstrated that RA and ES exhibit increased muscular activation during squats (van den Tillaar & Saeterbakken, 2018).

Training sessions and activities that have been shown to influence the electromyography (EMG) activity of the rectus femoris (RF) muscle include sprinting on various surfaces, abdominal exercises, eccentric knee extension training, and kicking (Jokela et al., 2023; Begum et al., 2020). Additionally, the RF muscle is particularly prone to injuries among football players (Lempainen et al., 2018). On the other hand, the lateral head of the biceps femoris (BF) is crucial for football players because it plays a key role in both sprinting and jumping performance. Vertical propulsion during jumping actions is primarily generated by this powerful antigravity muscle (Padulo et al., 2013). Moreover, the long head of the BF is frequently involved in hamstring strain

Corresponding Author: AMRINDER SINGH, E-mail: amrindersinghpt@gmail.com injuries, which are common during high-speed running activities such as football (Marušič et al., 2020). The BF also plays a key role in knee flexion and external rotation, contributing to knee stabilization. Additionally, the BF tendon, with its multiple attachment points, provides dynamic stability to the posterolateral corner of the knee (Matar & Farrar, 2018).

Additionally, surface EMG has been used to evaluate the ES, BF, RF, external oblique, and RA muscles in both stable and unstable conditions on aquatic platforms. Significant differences in muscle activation, particularly in peak and maximum levels of RF and BF activation, support these findings. (Conceição et al., 2022). Moreover, the RA muscle has been observed to exhibit high levels of activity during reflexes associated with increased intrathoracic pressures (Bolser et al., 2000).

However, some studies suggest that there is no significant difference in the contraction patterns of the RA or RF muscles during specific jump tasks (Jung et al., 2015). Additionally, research on muscle contractions during leg raises found that the RA and RF muscles activated in a similar manner (Lee, 2015). These findings suggest that muscle activation patterns may be influenced by the specific exercise or movement being performed, highlighting the need to explore muscle function during dynamic movements. However, there is a gap in research on how core and leg muscle activation varies during different types of jumps between genders. Thus, the aim of the study is to identify the relationship between jump types, such as SJ and CMJ, and the activation patterns of core and leg muscles—specifically the RA, ES, RF, and BF—across genders, with a focus on Indian soccer players. Therefore, we hypothesize that there is a significant relationship between the activation patterns of the left and right side muscles during SJs and CMJs in both male and female players.

Methodology

This cross-sectional study was designed using G*Power version 3.1.9.4 developed by Franz Faul, Universität Kiel, Kiel, Schleswig-Holstein, (Germany) with a total sample size of 30, an effect size of 0.5, and a power of 0.86 at a significance level of 0.05. The inclusion criteria comprised male and female soccer players aged 18–23 years who had participated in the National Games twice and played at the university level. Participants were recruited from the MYAS-GNDU Department of Sports Sciences and Medicine and Khalsa College, Amritsar, Punjab, (India). The players were divided into two groups: Group A (males, n = 15) with an average age of 21.06 ± 1.43 years, body height of 173.36 ± 3.82 cm, weight of 61.96 ± 5.52 kg, and body mass index (BMI) of 20.60 ± 1.59 kg/m^2, and Group B (females, n = 15) with an average age of 19.5 ± 1.04 years, body height of 169.91 ± 4.45, weight of 63.25 ± 4.45 kg, and BMI of 21.93 ± 1.41 kg/m^2. Exclusion criteria included players with a history of pathological or traumatic injuries to the upper or lower limbs or those who had undergone spinal or knee surgery in the past two years. All subjects provided written informed consent before the testing procedures. Participants were instructed to avoid vigorous activity for 24 h before testing. The study adhered to the principles of the Declaration of Helsinki and was approved by the Institutional Ethics Committee of Guru Nanak Dev University, Amritsar, Punjab, India, under approval number 1096/HG dated 22/11/22.

Measurement tools

The research used a quantitative approach, employing Surface EMG (Noraxon-USA, MR3 3.8.30) to evaluate muscle activity. Surface EMG, recognized as the most valid and reliable tool for measuring muscle activity, was used to assess muscle function, as shown in Figure 1. Surface electrodes were placed on the muscles with a 2 cm spacing between electrodes, following the surface EMG recommendations for non-invasive muscle assessment (SENIAM). The sampling frequency was set at 2000 Hz. Before electrode placement, the skin was cleaned to ensure optimal contact. All participants, both male and female, were right-dominant, as indicated by their preferred foot for kicking the ball (Karadenizli et al., 2014). Electrodes were placed on both the left and right sides of the RA, lumbar ES, RF, and BF muscles. The EMG electrodes were placed following the SNIMEN guidelines, as shown in Figures 1 and 2 (Lazaridis et al., 2018).

Placement of surface EMG electrodes

Figure 1: Anterior view

Figure 2: Posterior view

Procedure

Players were selected based on the inclusion and exclusion criteria. Subsequently, their body dimensions—such as height, weight, shoulder width, shoulder height, hip height, knee height, ankle height, and foot length—were assessed for both groups. Height was measured using a stadiometer, and body weight was recorded with a Quattro Jump, Kistler model 9290DD, Winterthur, Switzerland. During these measurements, players were instructed to remove their shoes, stand with their backs straight, and keep their heads in a neutral position. Then, a 5–10-min warm-up session was performed, which included hopping, toe touches, squatting exercises, and practice jumps (Lazaridis et al., 2018).

Muscle activation was assessed using maximum voluntary isometric contractions (MVIC). The manual muscle testing locations for the RA, ES, RF, and BF were established. A mobilization belt was used to apply resistance and prevent changes in muscle activity owing to variable resistance. Three-second MVIC trials for each muscle group were performed in a randomized order, with a one-min rest between each trial. For the RA muscle, the MVIC was measured with the players in a supine position, their feet supported, hips and knees flexed to the maximum, and their trunk flexed at 30°. Resistance was applied by the tester in different positions for each muscle group: for the RA, resistance was applied at the shoulders by pushing in the direction of trunk extension (Escamilla et al., 2010; Halaki & Ginn, 2012); for the lumbar ES, stretching upward against resistance while the participant hung over the edge of the test table in a prone position; for the RF, the participant was seated with the knee flexed to 90° and the hip flexed to 80–90° and was asked to perform knee extension against maximum resistance; for the BF, the participant lay prone and flexed each leg individually to a 45° angle at the knee (Halaki & Ginn, 2012)

After completing the MVIC, players were instructed to perform the SJs and CMJs on a Kistler force plate, with data recorded simultaneously from both the force plate and EMG. For the SJs, players began with their feet parallel and stepped onto the force plate. They then assumed the "ready position," which involved a squat with a 90° knee angle. From this position, they were to jump as high as possible while minimizing arm movement. A countdown of "1, 2, 3, Jump" was given to signal the start of the jump. After completing the SJ trials, participants were given a 5-min rest before beginning the CMJ trials. For the CMJ, players were instructed to jump as high as possible, descend quickly, and then stand upright upon landing. While there was no control over the depth of the CMJ, players were asked to squat to approximately 90°. To minimize the impact of upper body movements on the center of mass (COM), players were instructed to keep their hands on their hips during the jump to limit arm swing. This approach allowed for a greater focus on the force generated by the lower extremities (Singh A et al., 2024). Two maximal trials were performed, with a 2-min interval between each.

Data analysis

For surface EMG data, the Lancosh band-pass filter was applied to remove motion artifacts in the frequency range of 20–500 Hz. The signals were processed using the root mean square (RMS) method with a 100-ms moving window. The processed EMG data were then exported and transferred to an Excel spreadsheet (Microsoft, Redmond, WA). The mean RMS value from the two trials for each muscle was normalized to its corresponding MVIC value and expressed as a percentage of MVIC (Halaki & Ginn, 2012; Konard, 2005; Noh et al., 2021). Statistical analysis was performed using SPSS v26.0, and the Shapiro–Wilk test was used to assess the normality of the data distribution. The Pearson correlation coefficient was used to assess the relationship between left and right muscle activation patterns during SJs and CMJs in both groups.

Results:

Table 1 presents the descriptive characteristics of the players. Table 2 shows the mean ± standard deviation of muscle activity for all muscles and sides during SJs and CMJs for both male and female players.

Table 1: Descriptive characteristics of the players

Variables	Group A (Males) Mean ± SD	Group B (Females) Mean ± SD
Age (years)	21.06 ± 1.43	21.53 ± 1.06
Height (cm)	173.36 ± 3.82	158.34 ± 3.90
Weight (kg)	61.96 ± 5.52	53.02 ± 3.11
BMI (kg/m^2)	20.60 ± 1.59	21.17 ± 1.49
Shoulder height (cm)	143.24 ± 3.32	130.86 ± 4.37
Shoulder width (cm)	42.74 ± 25.96	31.49 ± 1.32
Hip height (cm)	92.80 ± 2.55	86.34 ± 5.01
Knee height (cm)	48.64 ± 2.90	42.38 ± 1.52
Ankle height (cm)	7.10 ± .50	6.72 ± .55
Foot length (cm)	26.42 ± .95	23.73 ± .86
Thigh circumference on the left side (cm)	48.92 ± 4.52	50.43 ± 4.14
Thigh circumference on the right side (cm)	48.06 ± 4.45	50.86 ± 4.49

Abbreviations: kg - kilogram; cm - centimeter

Table 2: Descriptive data for all muscles and sides for SJs and CMJs among both male and female players (expressed as mean ± standard deviation)

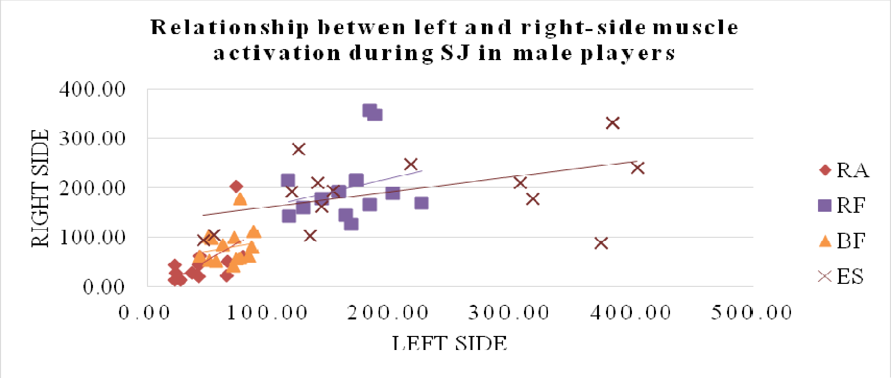
Muscles	Sides	SJ (Male) Mean ± SD	SJ (Female) Mean ± SD	CMJ (Male) Mean ± SD	CMJ (Female) Mean ± SD
RA	**LT**	45.48 ± 4.76	22.04 ± 1.59	40.24 ± 4.38	28.04 ± 3.72
	RT	47.16 ± 11.86	24 ± 2.83	45.36 ± 12.03	37.09 ± 5.11
RF	**LT**	166.02 ± 7.89	206 ± 22	153.69 ± 10.25	137.44 ± 10.92
	RT	200.81 ± 17.45	209.06 ± 31.32	154.39 ± 18.03	212.45 ± 27.20
BF	**LT**	69.31 ± 3.79	78.70 ± 10	68.97 ± 3.80	76.82 ± 10.43
	RT	80.07 ± 8.98	80.26 ± 5.19	77.79 ± 10.71	73.51 ± 8.22
ES	**LT**	220.95 ± 33.01	167.18 ± 17.05	180.36 ± 26.98	123.55 ± 12.82
	RT	197.90 ± 20.61	168 ± 17.20	166.52 ± 19.81	138.04 ± 15.30

Abbreviations: RA - rectus abdominis; RF - rectus femoris: BF - biceps femoris; ES - erector spinae; LT - left; RT - right

GRAPHS:

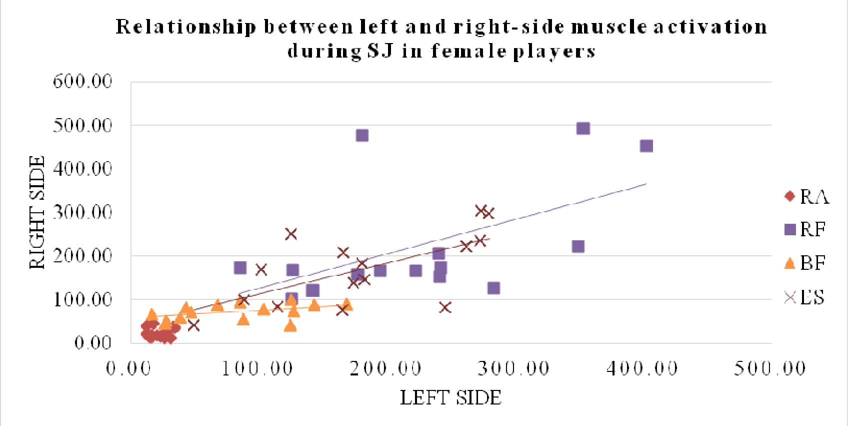
Graphical representations of the activation patterns of left and right side muscles in males and females during SJs (Graphs 1 and 2) and CMJs (Graphs 3 and 4):

Graph 1:



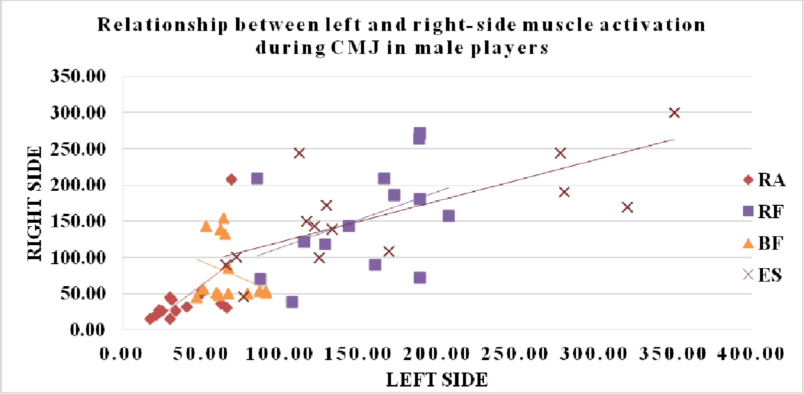
Graph 1: We observed significant relationships between the left and right side muscles during SJs among male players, listed in descending order as follows: a strong positive correlation was found between the left side of the RA and the right side of the BF (r = .749; p = .001); a moderate positive correlation was noted between the left side of the BF and the left side of the ES (r = .597; p = .019); and a moderate correlation was observed between the left and right sides of the RA (r = .560; p = .030).

Graph 2:



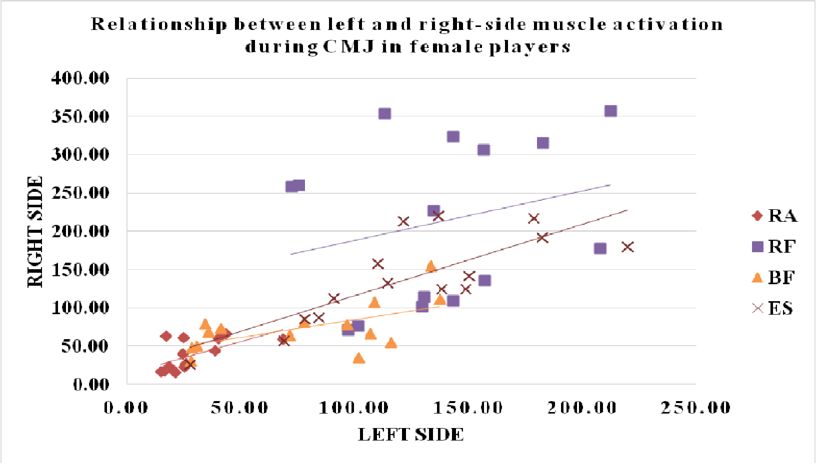
Graph 2: We observed significant relationships between the left and right side muscles during SJs among female players, listed in descending order as follows: a strong positive correlation was found between the left side of the RA and the left side of the ES (r = .774; p = .001) as well as between the left side of the RA and the right side of the ES (r = .754; p = .001). Additionally, moderate positive correlations were observed between the left side of the ES and the right side of the ES (r = .638; p = .011), the left side of the RF and the left side of the ES (r = .636; p = .011), the left side of the RA and the left side of the RF (r = .629; p = .012), the left side of the RF and the right side of the RF (r = .547; p = .035), and the left side of the RF and the right side of the ES (r = .533; p = .041), and vice versa.

Graph 3:



Graph 3: We observed significant relationships between the left and right side muscles during CMJs among male players, listed in descending order as follows: a strong positive correlation was found between the left side of the BF and the right side of the ES (r = .805; p = .000); a moderate positive correlation was noted between the left side of the RA and the right side of the RA (r = .589; p = .021) and between the left side of the RF and the left side of the BF (r = .559; p = .030). Additionally, moderate negative correlations were observed between the right side of the BF and the right side of the ES (r = −.601; p = .018) and between the right side of the BF and the left side of the ES (r = −.582; p = .023), and vice versa.

Graph 4:



Graph 4: We observed significant relationships in muscle activation patterns between the left and right sides during CMJs among female players, listed in descending order as follows: a strong positive relationship was found between the left side of the ES and the right side of the ES (r = .781; p = .001). Moderate positive correlations were observed between the left side of the RA and the left side of the RF (r = .664; p = .007), the left side of the RF and the right side of the BF (r = .638; p = .011), the left side of the RA and the right side of the RA (r = .622; p = .013), the left side of the RA and the right side of the BF (r = .594; p = .020), and the left side of the BF and the right side of the BF (r = .583; p = .022), and vice versa.

Discussion

This study investigated the relationship between the activation patterns of core and leg muscles—specifically the RA, ES, RF, and BF—on the left and right sides during SJs and CMJs. We hypothesized that there would be a significant relationship between the activation patterns of the left and right sides of these muscles during both SJs and CMJs for both male and female players.

During dynamic motions such as jumping and walking, muscular co-contraction provides stability and control by involving the simultaneous activation of agonist and antagonist muscles around a joint (Maeo et al., 2013). In this study, as shown in Graph 1, a strong positive relationship in muscle activation was observed between the left side of the RA and the right side of the BF, and vice versa. This indicates that changes in the activity of the left RA were synchronously linked with changes in the activity of the right BF during SJ in male soccer players. Additionally, a moderate positive relationship was noted between the left side of the BF and the right side of the ES, as well as between both the left and right sides of the RA during SJs. As shown in Graph 2, females exhibited a stronger muscle activation relationship between the left and right sides compared to males. A particularly strong positive relationship was observed between the left side of the RA and the left side of the ES.

Additionally, moderate positive correlations were found between the left side of the RA and the right side of the ES, the left side of the ES and the right side of the ES, the left side of the RF and the left side of the ES, the left side of the RA and the left side of the RF, the left side of the RF and the right side of the RF, and the left side of the RF and the right side of the ES, and vice versa. These findings suggest that men and women use their muscles differently during jumping activities. Similar patterns have been observed in other studies. For example, Chappell et al. (2007) found that during the take-off phase of vertical and backward stop-jump tasks, males exhibited greater anterior shear forces on the proximal tibia compared to females. Additionally, during the take-off phase of a CMJ, men demonstrated greater muscle thickness and pennation angles than women (Rubio-Arias et al., 2017). These findings indicate statistically significant differences in kinetic jump variables between genders. Moreover, Ortíz et al. (2014) observed that during single-leg drop jumps, females had higher quadriceps-to-hamstring EMG co-contraction ratios, increased activation of the gluteal and RF muscles, and similar hamstring activity, suggesting distinct patterns of muscle activation in females during jumping tasks.

In male players performing CMJ, the interaction between different muscle groups is complex, as depicted in Graphs 3 and 4. The relationships between the left and right sides during CMJ differed between genders. Specifically, in male players, a strong positive correlation was observed between the left side of the BF and the right side of the ES. Additionally, moderate positive correlations were noted between the left and right sides of the RA and the left and right sides of the RF. Conversely, a moderate negative correlation was found between the left side of the ES and the right side of the BF and between the right and left sides of the ES. Our key findings regarding the association between the activation patterns of the left and right side muscles during CMJ in female players, presented in descending order, are as follows. As shown in Graph 4, there was a strong positive relationship between the left side of the ES and the right side of the ES. Additionally, moderate positive correlations were observed between the left side of the RA and the left side of the RF, as well as between the left side of the RA and the right side of the BF. Furthermore, a strong positive relationship was found between the left side of the RA and the right side of the ES. We observed significant relationships between the left side of the RA and the right side of the BF, between the left side of the BF and the right side of the BF, and vice versa. Studies have indicated that skeletal muscle fatigability varies by gender, with men and women exhibiting distinct neuromuscular activation patterns and changes in the EMG power spectrum during muscle contractions (Clark et al., 2003). Additionally, research has shown a positive correlation between bodybuilding experience and the level of muscle activity during maximal voluntary co-contraction, suggesting that activity level may influence co-contraction abilities (Radžiūnas et al., 2018). This study found that, compared to males, females exhibited more synchronized activation between the left and right sides of the RA, ES, RF, and BF, as shown in Graphs 1, 2, 3, and 4 .These findings align with previous research that identified differences in muscle activation patterns between genders, particularly noting asymmetries (delta) in the frequency of damped oscillations in the trapezius, BF, and gastrocnemius (both inner and outer parts) on the left and right sides of the body. The results indicated that men and women with a lower risk of trauma exhibited greater asymmetries between the left and right sides of the body (Zellar et al., 2003).

Furthermore, research has shown that during specific movements, such as isometric axial rotations and axial trunk rotations, the muscle activation patterns on the right and left sides of the body can differ significantly (Marta et al., 2016). Additionally, maintaining postural control and stability during dynamic tasks requires the activation of trunk muscles such as the RA and ES (Marta et al., 2016). These findings support the notion that asymmetrical muscle activation is a common phenomenon during dynamic activities. Furthermore, research has highlighted how factors such as age, gender, and body mass index influence the morphometric variability of abdominal wall muscles on both sides of the body, including the rectus abdominis, external oblique, internal oblique, and transversus abdominis (García-Jaén et al., 2023). Additionally, the way abdominal muscles contract during specific movements, such as leg lifting, can provide insights into the coordination of the left and right RA (Kim et al., 2014). Furthermore, evaluating trunk muscle recruitment after exercises and analyzing muscle activation during specific movements, such as the hundred and teaser, can provide insights into the relationship between the left and right RA during dynamic activities (Tayfur et al., 2022).

It is well established that a significant portion of the kinetic energy absorbed by the muscular system during landing from a jump is due to the eccentric contraction of the calf muscles (Tayfur et al., 2022). Additionally, muscles contract before landing to prepare the limbs for the impending impact, highlighting the role of anticipatory muscular co-contraction during dynamic movements (Gambelli et al., 2015). In this study, jump depth was not controlled, and there was considerable variability in jumping skill in each group, which may have influenced the results. Future research with a larger sample size, joint markers, and specific angles will provide more valuable insights into this sports population.

Practical implications

This study provides an overview of the relationship between muscle activation patterns of core and leg muscles on the left and right sides during SJs and CMJs. Understanding muscle activity during these jumps is essential for developing targeted therapies and rehabilitation strategies that optimize muscle co-contraction patterns across different populations. Additionally, accurately assessing the level of each player in a group is crucial for selecting appropriate training loads and ensuring specificity.

Conclusion

This study examined muscle activation patterns in both male and female players during SJs and CMJs. The findings revealed that muscle activation patterns varied between genders and with different types of jumps. In males, a significant correlation was observed between the left side of the RA and the right side of the BF during SJs. In contrast, females showed a higher positive relationship between the left side of the RA and both sides of the ES. During CMJs, males demonstrated a strong positive relationship between the left side of the BF and the right side of the ES, while females exhibited a strong positive correlation between the left side of the ES and the right side of the ES. Additionally, beyond the muscles previously mentioned, other leg and core muscles also exhibited interactions with one another. These findings suggest that different core and leg muscles are recruited during SJs and CMJs, with a notable connection between the activation of left and right-side muscles, indicating cocontraction. This study will assist coaches and sports practitioners in designing specific training protocols that consider the activation patterns of left and right-side muscles during various types of jumps in their target populations.

Conflict of Interest

The authors declare no conflict of interest.

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