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THE RELATIONSHIP BETWEEN SQUAT AND COUNTERMOVEMENT JUMPS IN FUTSAL PLAYERS IS INFLUENCED BY PUBERTAL STAGE

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ABSTRACT

Squat jumps (SJ) and countermovement jumps (CMJ) are widely used in the assessment and training of lower limb muscle strength in futsal athletes and other sports disciplines. Although they share similarities, these jumps have specific characteristics. The objective of this study was to investigate the common variance explained between SJ and CMJ in young futsal athletes at different pubertal stages. The sample consisted of 76 futsal male athletes, aged 9 to 17 years, divided according to pubertal stage (26 pre-pubertal, 25 pubertal, and 25 post-pubertal). The peak height velocity (PHV) calculation was used to assess the pubertal stage. Standardized SJ and CMJ were evaluated. Pearson correlation analysis was used to verify the relationship between the jumps, with a significance level of $p \leq 0.05$. The results revealed strong and significant correlations between SJ and CMJ for pre-pubertal individuals ($r = 0.89$; $p<0.01$; $R^2 = 0.79$) and post-pubertal individuals ($r = 0.60$; $p \leq 0.01$; $R^2 = 0.36$), and a moderate correlation for pubertal individuals ($r = 0.35$; $p=0.09$; $R^2 = 0.13$). These findings demonstrate that the common variance explained between performance in SJ and CMJ is influenced by the pubertal stage in futsal athletes.

Key words: Squat and Countermovement Jump. Puberty. Muscle Strength. Somatic Maturation.

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RESUMO

A relação entre os saltos agachado e com contramovimento em jogadores de futsal é influenciada pelo estágio puberal

Os saltos, agachado (SA) e com contramovimento (SCM), são amplamente utilizados na avaliação e treinamento da força muscular dos membros inferiores de atletas de futsal e outras modalidades esportivas. Embora existam similaridades, esses saltos possuem características específicas. O objetivo deste estudo foi investigar a variância comum explicada entre o SA e o SCM em jovens atletas de futsal em diferentes estágios puberais. Participaram da amostra 76 atletas de futsal do sexo masculino, com idade entre 9 e 17 anos, divididos conforme o estágio puberal (26 pré-púberes, 25 púberes e 25 pós-púberes). Para a avaliação do estágio puberal foi utilizado o cálculo do pico de velocidade de crescimento (PVC). Foram avaliados os saltos padronizados SA e SCM. Para verificar a relação entre os saltos foi utilizada a análise de correlação de Pearson, com um nível de significância de $p \leq 0,05$. Os resultados revelaram correlações fortes e significativas entre o SA e SCM para os indivíduos pré-púberes ($r = 0,89$; $p =< 0,01$; $R^2 = 0,79$) e pós-púberes ($r = 0,60$; $p \leq 0,01$; $R^2 = 0,36$), e uma correlação moderada para os púberes ($r = 0,35$; $p=0,09$; $R^2 = 0,13$). Estes resultados demonstram que a variância comum explicada entre os desempenhos no SA e no SCM é influenciada pelo estágio puberal em atletas de futsal.

Palavras-chave: Salto Agachado e Contramovimento. Puberdade. Força Muscular. Maturação Somática.

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INTRODUCTION

The evaluation of lower limb muscle strength is essential for the appropriate prescription and control of training load in sports, including futsal, as it involves actions such as running, jumping, and kicking (Markovic, 2007; Claudino et al., 2017; Alvares et al., 2024).

For this purpose, the squat jump (SJ) and the countermovement jump (CMJ) are widely used due to their practicality, low cost, and high reliability (Bosco et al., 1983; Claudino et al., 2017; Petrigna et al., 2019).

Although both jumps (SJ and CMJ) assess lower limb strength (Markovic, 2007; Santos et al., 2024), the higher performance in the CMJ, due to the use of the stretch-shortening cycle (SSC), introduces additional mechanisms in this jump (Komi, 2000; Santos et al., 2024).

In the SJ, starting from a semi-squat position, a concentric action is performed, involving an upward movement of the center of mass (Komi, Bosco, 1978).

Thus, performance is fundamentally determined by the ability to produce concentric muscle force, without the use of the SSC (Komi, Bosco, 1978; Santos et al., 2024). In this jump, performance is mainly influenced by the ability to recruit high-threshold motor units, the Rate of Force Development (RFD), the contractile potential, and the stiffness of the muscle-tendon unit (MTU), which significantly contributes to the efficiency in transferring the tension generated in the cross-bridges to the bone (Folland e Williams, 2007; Isaacs, Myburgh, e Macaluso, 2022; Kubo, Kawakami e Fukunaga, 1999; Van Hooren; Zolotarjova, 2017; Ramírez-delaCruz et al., 2022).

On the other hand, in the CMJ, an eccentric action (downward movement) is immediately followed by a concentric action (upward movement), ending with a loss of contact with the ground (Komi, Bosco, 1978).

The presence of the concentric action in this jump means that the aforementioned mechanisms are also present in the CMJ. However, in this jump, the rapid transition between the eccentric and concentric phases enables the use of the SSC (Baker, 1996; Donahue et al., 2021; Santos et al., 2024), resulting in greater force production and, consequently, increased jump height (Asmussen, Bonde-Peter, 1974; Kozinc et al., 2022).

This improved performance can be primarily explained by three mechanisms (Santos et al., 2024); 1) the use of elastic potential energy (EPE) in the series and parallel elastic tissues of the MTU (Asmussen, Bonde-Peter, 1974; Cavagna, 1977); 2) the activation of muscle spindles resulting in the stretch reflex (myotatic reflex) (Komi, 2000; Van Hooren; Zolotarjova, 2017); 3) the increased time available for force production in the CMJ (500 to 1,000 ms) compared to the SJ (300 to 430 ms), which would reduce muscle slack and increase MTU stiffness (Van Hooren, Bosch, 2016).

Despite the robust literature indicating that these are the main mechanisms that help explain the superior performance in the CMJ (Santos et al., 2024), the percentage contribution of each mechanism has not been established.

Davies, Riemann, Manske (2007), indicate that the contribution of series elastic components to force production using the SSC is between 70 to 75%. However, this information is drawn from a textbook (Albert, 1991) and we did not find empirical support for it. Conversely, experimentally, Kubo et al. (2007) they found approximately 18% of explained common variance ($r = 0.42$; $p<0.05$; $R^2 = 0.18$) between tendon stiffness and jump height in the SJ, which is much lower than previously proposed by Davies, Riemann, Manske (2007).

On the other hand, there was no significant correlation between this variable and performance in the CMJ ($r = 0.25$; $p>0.05$). Additionally, a negative and significant correlation was demonstrated ($r = -0.47$; $p<0.05$) between tendon stiffness and the use of the SSC in the CMJ, showing that this variable contributes approximately 22% of the explained variance for increased jump height in the CMJ, albeit inversely proportional (Kubo et al., 2007).

These results reinforce the proposition that tendon stiffness is a common variable for explaining performances in both the SJ and CMJ, although the use of EPE may not be the primary mechanism contributing to SSC utilization (Van Ingen Schenau, Bobbert, Haan, 1997), highlighting the need for further studies to allow a deeper understanding of the mechanisms responsible for the greater jump height achieved in the CMJ compared to the SJ. In this sense, correlating the results between the SJ and CMJ would allow for identifying the explained common variance (R^2) between both jumps and demonstrate the percentage of similar factors capable of explaining performance.

Despite the additional mechanisms in the CMJ due to the presence of the SSC, factors influencing the SJ would also be present in the CMJ, so that performances could be explained, at least partially, by common mechanisms (muscle activation, contractile capacity, rate of force development, and MTU stiffness) (Kubo, Kawakami e Fukunaga, 1999; Van Hooren, Zolotarjova, 2017; Mackala et al., 2013).

Such information would enable coaches and physical trainers to understand how different training strategies could enhance the CMJ (present in futsal motor actions). For example, a high R^2 would support the recommendation that training aimed at improving key factors in the SJ could also improve the CMJ (Kaabi, Mabrouk e Passelergue, 2022). It would also support the possibility of using only the CMJ in the process of evaluating and monitoring training load (Markovic, 2007; Claudino et al., 2017; Petrigna et al., 2019).

On the other hand, a low R^2 would demonstrate the specificities of each motor task and emphasize the need to use both in the evaluation and monitoring of training load when aiming to measure distinct attributes of muscular force production capacity.

Within this context, pubertal stage is an essential factor to consider in the evaluation and training of young athletes (Malina et al., 2004; Alvares et al., 2020; Alvares et al., 2024).

During puberty, significant changes occur in muscle strength, MTU stiffness, and neuromuscular performance, which can directly impact jump performance (Rogol et al., 2000; Radnor et al., 2018; Alvares et al., 2020; Amatori et al., 2024).

These changes include increased sex hormones, bone growth, and gains in muscle mass and strength (Malina et al., 2004; Radnor et al., 2018), influencing physical performance in various tasks in different ways (Alvares et al., 2024).

Thus, different mechanisms may be more relevant to performance at each pubertal stage, which could alter the correlation between SJ and CMJ performances.

Therefore, the present study aims to investigate the correlation between SJ and CMJ in futsal players at different pubertal stages.

MATERIALS AND METHODS

This cross-sectional and correlational study involved procedures with adolescent athletes and was approved by the local Human Ethics Committee (Approval: 6.904.028).

Participation of the adolescents in the study was authorized by their guardians, who signed an Informed Consent Form (ICF), while the athletes who agreed to participate signed an Assent Form (AF). In a preliminary visit with the sports teams, the risks and benefits of participating in the research were presented.

The sample of the present study consisted of 76 male athletes from the U-11, U-13, U-15, and U-17 youth categories, aged between 9 and 17 years, from various futsal schools in the city of São Luís-MA.

The participants were grouped according to pubertal stage, with 26 pre-pubertal, 25 pubertal, and 25 post-pubertal athletes.

The sample characteristics are presented in Table 1 and were previously published in another study conducted by our research group, which utilized the same sample (Alvares et al., 2024).

As inclusion criteria, participants were required to have more than two years of experience in the sport, train at least three times per week, and be part of the main group of players in competition.

Athletes who had any injury preventing maximum effort during the established tests, as well as those who were unable to complete the evaluations, were excluded from the study (Alvares et al., 2024).

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Table 1 - Sample characteristics previously published in another study by our research group that used the same sample (Alvares et al., 2024).

Variables	Pre-PHV (n=26)	PHV (n=25)	Post-PHV (n=25)
Age (years)	11.03 ±1.18	14.52 ±1.08	15.84 ±0.85
Height (cm)	145.15 ±1.08	164.00 ±5.51	174.28 ±6.28
LL (cm)	75.02 ±5.80	84.36 ±4.54	90.60 ±4.86
BW (kg)	37.20 ±6.95	52.92 ±7.14	62.65 ±7.39
SJ (cm)	21.48 ±4.55	30.04 ±4.21	29.70 ±4.40
CMJ (cm)	21.57 ±4.83	30.08 ±4.30	31.09 ±4.78

Legend: pré-PHV = pré-pubertal; PHV= pubertal; post-PHV= post-pubertal; LL= lower limb length; BW= body weight; SJ= squat jump; CMJ= countermovement jump. Source: Adapted from Alvares et al., (2024).

Evaluation Procedure

Two phases of evaluations were conducted with a minimum interval of 48 hours and a maximum of 72 hours between them, with one day dedicated to familiarization and another day for experimental data collection of the jump tests.

The procedures were carried out at the beginning of the athletes' training sessions, with the familiarization session including anamnesis, measurement of anthropometric variables to characterize the participants, and learning the jump techniques (Alvares et al., 2024).

The individuals were instructed not to engage in high-intensity training for at least 48 hours prior to each experimental session. All were advised to arrive fed and hydrated for the evaluations and dressed in their training uniforms, with water intake allowed freely during the tests.

Height was measured using a stadiometer (Personal Caprice Sanny; accuracy of 0.1 cm), with the athletes standing barefoot in an upright position, arms extended alongside the body, and head in a horizontal position. o measure body mass (kg), a balance scale (Filizola®, accuracy of 0.1 kg) was used.

During the assessment, the athletes stood barefoot, with their head in a horizontal position and breathing normally. Lower limb length (cm) was assessed using a metal tape measure (0–150 cm), measuring the distance from the greater trochanter of the femur to the plantar region. Sitting Height (cm): Measurement was taken with the athlete seated against a wall where a measuring tape was fixed.

The knees were facing forward, forming a 90º angle at the hips, with the glutes, scapular waist, and occipital region in contact with the wall. The measurement was recorded from the bench surface to the vertex (Charro et al., 2010; Alvares et al., 2024).

Maturational Age

The pubertal stage of the athletes was assessed based on somatic maturation using the calculation of peak height velocity (PHV). The values for age (A), lower limb length (LL), sitting height (SH), body mass (BM), and height (H) were entered into the equation [PHV= – 9,236 + 0,0002708 (LL x SH) – 0,001663 (A x LL)+0,007216 (A x SH) + 0,02292 (BM/H)] (Malina et al., 2015).

The classification of somatic maturation stage reflected the chronological position in relation to PHV and was categorized as: pre-pubertal (PHV<-1), pubertal (-1> PHV +1) and post-pubertal (PHV >+1) (Malina et al., 2015; Alvares et al., 2024).

Evaluation of SJ and CMJ

The jump assessments were conducted after a warm-up protocol that included a five-minute run at 7 km/h, with sprints and jumps added every minute of the total warm-up time (Dal Pupo et al., 2017; Alvares et al., 2024).

In the SJ (Figure 1), the participant begins from a semi-squat position, with knee and hip angles close to 90° flexion and the torso held in a vertical position. After holding this position for approximately three to four seconds, the jump is executed (Komi e Bosco, 1978; Santos et al., 2024).

In the CMJ (Figure 2), the individual starts standing, then performs a countermovement (downward phase), immediately followed by a rapid transition with the extension of the lower limb joints (upward phase), culminating in the jump (Komi e Bosco, 1978; Santos et al., 2024).

For both types of jumps, participants are instructed to keep their hands on their waist throughout the execution to prevent assistance from arm-swing movements (Gillen et al., 2020; Bogataj et al., 2020).

Each athlete performed five attempts with a one-minute interval between them, and the average was considered for statistical analysis.

The jumps were performed on a contact mat (Cefise, São Paulo, Brazil), and the data were analyzed using Jump System 1.0 software. Additionally, the intraclass correlation coefficient (ICC) was calculated for the different pubertal stages (pre-PHV, PHV, and post-PHV) for the SJ (ICC = 0.98, ICC = 0.92, and ICC = 0.94, respectively) and CMJ (ICC = 0.96, ICC = 0.93, and ICC = 0.92, respectively).

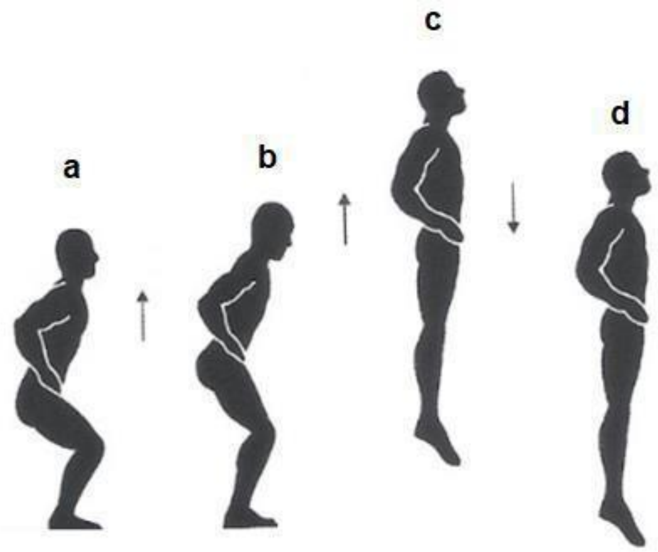

Figure 1 - Phases of Movement in the Squat Jump (SJ): a - initial position; b - upward phase; c - flight phase; d - landing phase.
Source: (Chaves et al., 2020).

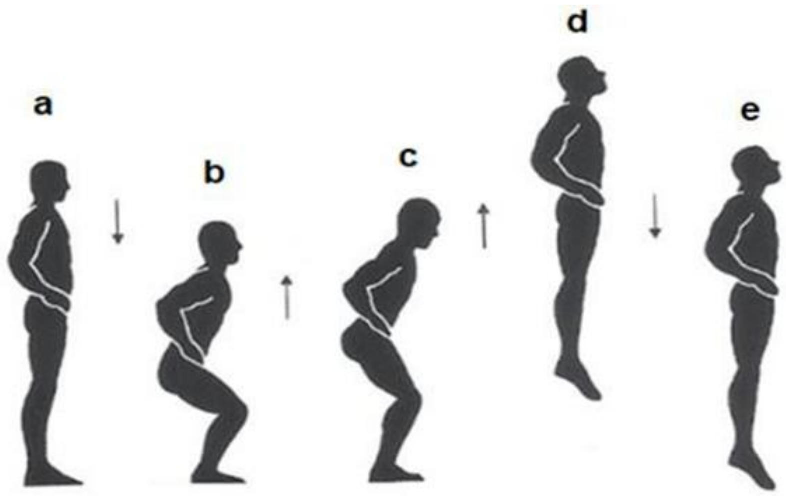

Figure 2 - Phases of Movement in the Countermovement Jump (CMJ): a - initial position; b - downward phase; c - upward phase; d - flight phase; e - landing phase. Source: (Chaves et al., 2020).

Statistical Analysis

Initially, the Shapiro-Wilk normality test was conducted to verify the normality of the data distribution. Given that the distribution was normal, Pearson's correlation was calculated. The correlation level was classified as weak if r ≥ 0.10, moderate if r ≥ 0.30, and strong if r ≥ 0.50 (Nikolaidis, 2016). The analyses were performed using the SPSS 18.0 statistical software (Statistical Package for Social Science, SPSS Inc., Chicago, USA). The significance level adopted was $p < 0.05$.

RESULTS

The correlation coefficient between SJ and CMJ for pre-pubertal individuals was classified as strong and significant (r = 0.89; p<0.01), with an explained common variance of 79% ($R^2 = 0.79$) (Figure 3).

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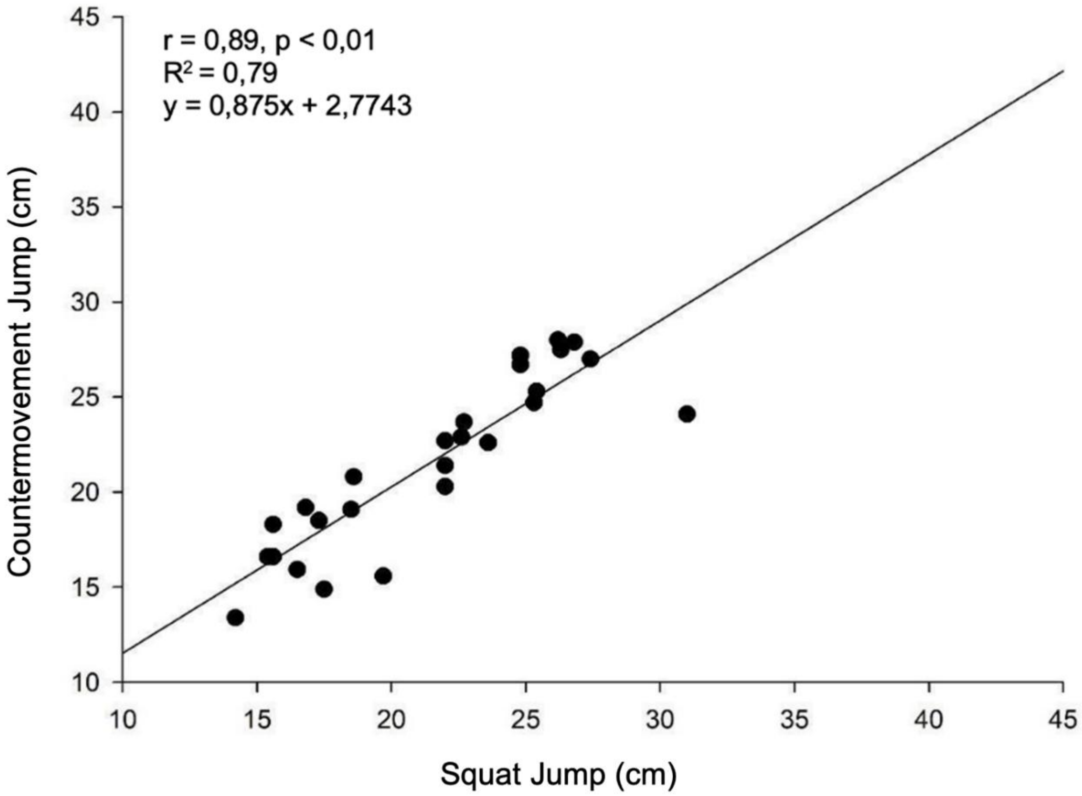

Figure 3 - Correlation between Squat Jump and Countermovement Jump in Pre-Pubertal Individuals.

The correlation coefficient between SJ and CMJ in pubertal individuals was classified as moderate and not significant (r=0.35; p=0.09), with an explained common variance of 13% (R^2 = 0.13) (Figure 4).

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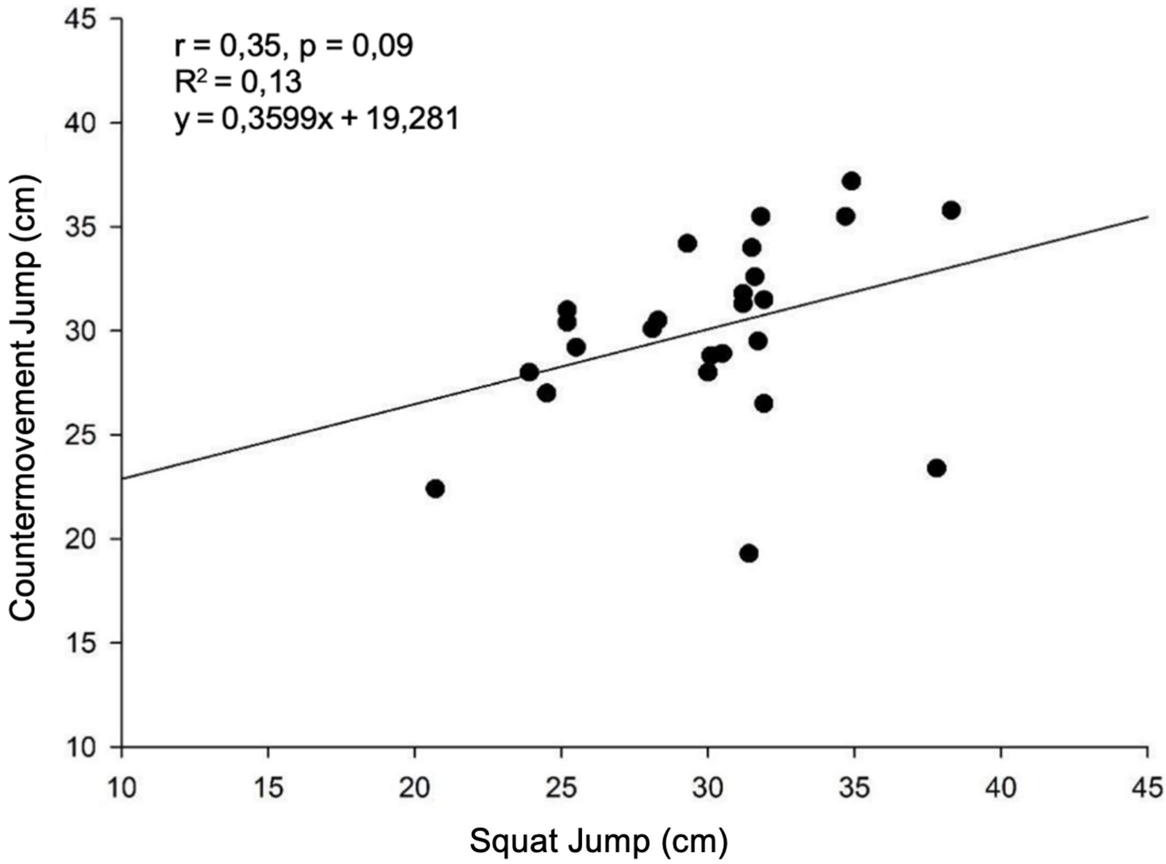

Figure 4 - Correlation between Squat Jump and Countermovement Jump in Pubertal Individuals.

The correlation coefficient between SJ and CMJ for post-pubertal individuals was classified as strong and significant ($r = 0.60$; $p<0.01$), with an explained common variance of 36% ($R^2 = 0.36$) (Figure 5).

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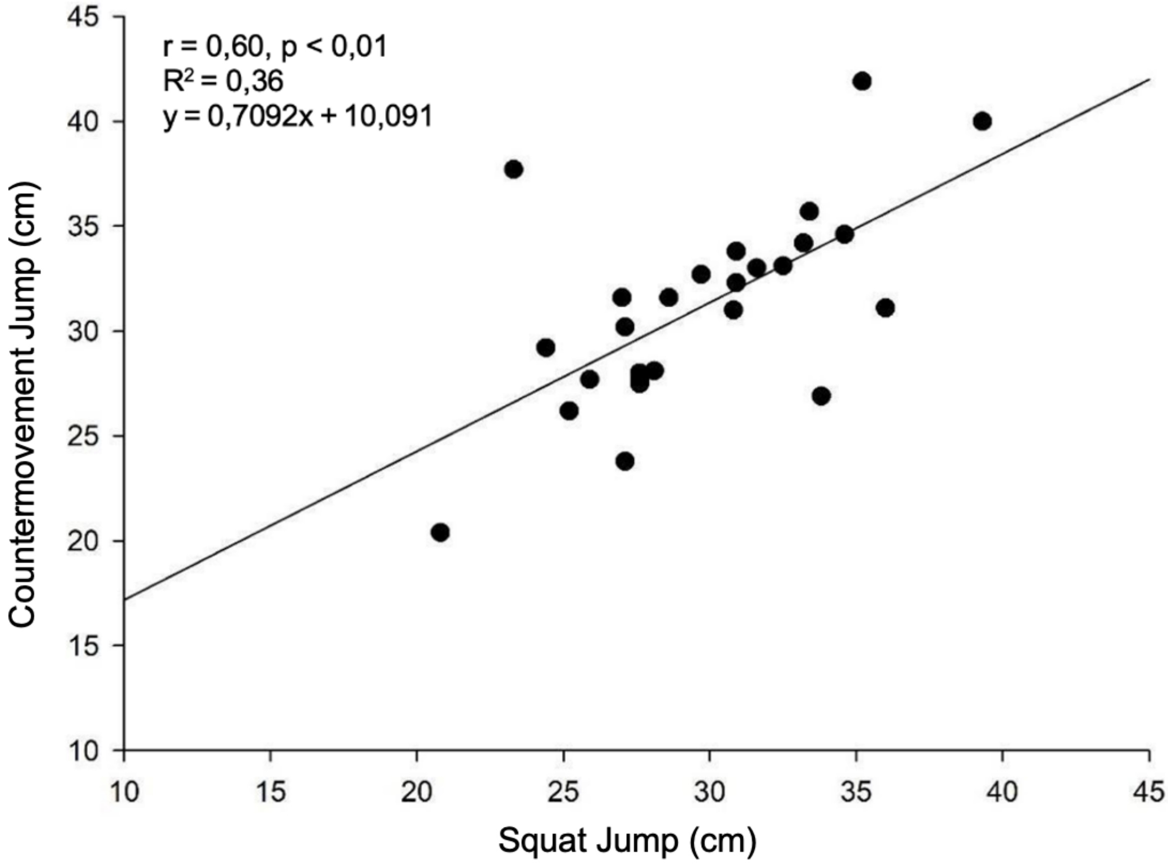

Figure 5 - Correlation between Squat Jump and Countermovement Jump in Post-Pubertal Individuals.

DISCUSSION

The objective of this study was to investigate the correlation between SJ and CMJ performance in young futsal players at different pubertal stages.

The explained common variance revealed that puberty impacts the relationship between SJ and CMJ, indicating the extent to which the mechanisms responsible for performance in these jumps are similar but diverge throughout pubertal development.

These findings are essential for guiding various assessment and training possibilities in futsal athletes to monitor and enhance jump performance across different pubertal stages.

In pre-pubertal individuals, the strong and positive correlation (r=0.89; p<0.01) between SJ and CMJ (R^2 = 0.79) indicates that SJ performance is a strong predictor of CMJ performance.

The explained common variance of nearly 80% could result from the mechanisms present in SJ, which could also partially explain CMJ performance.

Although still underdeveloped in pre-pubertal individuals, these mechanisms may include muscle cross-sectional area, the ability to recruit motor units, antagonist muscle coactivation, nerve conduction velocity, and motor unit synchronization (Radnor et al., 2018; O'Brien et al., 2010; Lloyd et al., 2012; Croix et al., 2021).

On the other hand, during the CMJ, the presence of the SSC activates additional mechanisms, such as the storage and utilization of EPE, activation of the stretch reflex, and increased time available to generate force, reducing muscle slack (Komi, 2000; Van Hooren, Bosch, 2016; Van Hooren, Zolotarjova, 2017; Santos et al., 2024).

However, in pre-pubertal individuals, factors such as MTU stiffness, the ability to activate the stretch reflex, and the utilization of EPE are reduced (Radnor et al., 2018; O'Brien et al., 2010; Lloyd et al., 2012; Croix et al., 2021), which results in the effect of the SSC on enhancing jump height in the CMJ being low, around 1 to 5% (Lloyd et al., 2009; Radnor et al., 2018).

Thus, when correlating the height of SJ and CMJ in pre-pubertal individuals, the high explained common variance may stem from the underdeveloped factors that enhance the use of the SSC during the CMJ

On the other hand, this relationship changes significantly during puberty. In pubertal individuals, the correlation between SJ and CMJ decreases considerably (r=0.35; p 0.09; R^2=0.13).

This means that only 13% of the variation in CMJ performance is explained by SJ performance at this stage. This reduction suggests that other factors, beyond those common to both SJ and CMJ, begin to influence jump performance during puberty. Factors such as accelerated growth, hormonal changes, and increased muscle mass may contribute to this decrease in correlation (Radnor et al., 2018; O'Brien et al., 2010; Lloyd et al., 2012; Croix et al., 2021).

The accelerated growth during puberty, driven primarily by peak height velocity, leads to an abrupt increase in the length of body segments, especially the lower limbs (Malina et al., 2015; Alvares et al., 2024).

This rapid growth can result in temporary bodily awkwardness, known as "motor awkwardness," which negatively affects motor coordination (Philippaerts et al., 2006; Rommers et al., 2019) and could impact jump execution, particularly the CMJ, which requires greater neuromuscular control. Hormonal changes, with significant increases in testosterone and growth hormone levels, also influence SSC performance in complex ways (Radnor et al., 2018; O'Brien et al., 2010; Lloyd et al., 2012; Croix et al., 2021).

Although these hormones are essential for the development of muscle mass and strength, increased muscle strength does not always translate into a greater ability to utilize the SSC (Radnor et al., 2018).

The lack of coordination between strength development and nervous system maturation can result in less efficient movements (Harrison e Gaffney, 2001; Rogol et al., 2000).

These factors together may explain the marked reduction in the explained common variance between SJ and CMJ (13%), indicating the presence of distinct mechanisms as responsible factors for performance in these jumps.

In post-pubertal individuals, the correlation between SJ and CMJ increases once again (r=0,60; p≤0,01; R^2=0,36). This increase to 36% of explained common variance can be attributed to the maturation of mechanisms influencing SJ performance, which are more fully developed at this pubertal stage (Radnor et al., 2018; O'Brien et al., 2010; Lloyd et al., 2012; Croix et al., 2021).

This increase could reflect the maturation of morphological and neurophysiological functions that lead to improvements in RFD, positively impacting both SJ and CMJ performances (Radnor et al., 2018).

On the other hand, the improvement of mechanisms related to the more efficient use of the SSC may explain why the common variance between SJ and CMJ, although increased, did not reach the values observed in the pre-pubertal stage (Beunen e Malina, 1988).

Laffaye et al., (2016) they observed an approximate 58% increase in SSC utilization in boys from ages 15-16. This result can be explained by the increase in MTU stiffness, neuromuscular maturation, hormonal development, improvements in intermuscular coordination, and physical growth (Laffaye et al., 2016), factors that enhance SSC utilization in the CMJ (Kubo et al., 2007; Radnor et al., 2018; Kubo, Kawakami e Fukunaga, 1999; Van Hooren, Zolotarjova, 2017; Mackala et al., 2013).

Thus, the increase in explained common variance to 36% reflects how puberty is essential in the maturational development of the various physiological mechanisms (both similar and distinct) that influence SJ and CMJ performances.

It is important to highlight that the explained common variance, while providing relevant information about the relationship between SJ and CMJ, does not represent the entirety of factors influencing performance in each type of jump.

Other factors, beyond puberty, such as training level, body composition, injury history, sport-specific demands, and movement execution technique, could also modulate this relationship (Bobbert et al., 1996; Laffaye et al., 2016; Rogol et al., 2000).

This study has important limitations, such as the exclusive use of jump height to assess SSC, due to the absence of muscle strength measurements obtained through a force platform, such as rate of force development, peak force and impulse, which could provide a more detailed and accurate analysis.

In addition, the use of a previously published sample, even from our own research group, may restrict the originality of the data. Furthermore, the analysis focused only on the correlation between SJ and CMJ, without investigating causal mechanisms or controlling factors such as training volume, injury history and external conditions, limits the understanding of the differences in performance.

Additionally, the extrapolation of this study's results should consider that only futsal athletes were evaluated; therefore, caution should be taken when applying these findings to other sports with different motor characteristics and to female athletes.

Therefore, the analysis of the explained common variance between SJ and CMJ at different pubertal stages reveals the complex interaction between biological maturation and motor performance.

Puberty, marked by hormonal, morphological, neuromuscular, and anthropometric changes, significantly impacts jump performance and the ability to utilize the SSC, affecting the relationship between these two types of jumps.

Understanding these mechanisms is crucial for developing training programs tailored to different pubertal stages, especially considering that futsal requires rapid force production often involving the SSC.

CONCLUSION

It has been demonstrated that puberty influences the relationship between squat jump and countermovement jump performance.

Thus, futsal players in the pre-pubertal stage may benefit from more generalized training strategies aimed initially at improving squat jump performance, which, due to their maturational development stage, can also positively impact motor actions utilizing the stretch-shortening cycle, such as the countermovement jump.

Conversely, pubertal athletes should engage in more specific training when the goal is to enhance performance in actions that rely on the stretch-shortening cycle.

For post-pubertal athletes, despite some common factors between squat jump and countermovement jump performance, the mechanisms explaining them are largely distinct.

This suggests that general training may be effective, but specific approaches are needed to optimize countermovement jump performance.

ACKNOWLEDGMENTS

The authors are grateful to the Laboratory of the Physical Exercise Research Group: Health and Human Performance of the Federal University of Maranhão, the Brazilian fostering agency Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) [Coordination for the Advancement of Higher Education Personnel]-Financial Code 001 and Fundação de Amparo à Pesquisa do Maranhão (FAPEMA) [Maranhão Research Assistance Foundation].

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Recebido para publicação em 15/01/2025
Aceito em 22/01/2025