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RELATIONSHIP OF LEG STIFFNESS AND ISOKINETIC STRENGTH ON SQUAT AND COUNTER MOVEMENT JUMP IN ADOLESCENT SOCCER PLAYERS

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Abstract: Vertical jump is an important indicator for lower-limb muscular power in soccer players. The squat jump (SJ) indicates concentric strength, whereas the countermovement jump (CMJ) reflects the capacity of the stretch-shortening cycle (SSC). Although factors such as knee isokinetic strength and/or leg stiffness are known to affect jump performance, predictive roles of these factors during adolescence period remain unclear. This research was aimed to develop a regression model to predict SJ and CMJ performance in adolescent male soccer players, using isokinetic knee strength at different angular velocities (60°/s and 180°/s) and leg stiffness values. Thirty-four adolescent male soccer players participated in this study. SJ, CMJ, leg stiffness, and isokinetic knee flexor and extensor strength measurements were performed. After statistical assumptions tested, stepwise-forward regression analysis was performed to detect predictors of jump height. For CMJ, knee extension strength at 180°/s significantly reflected 15.9% of the variance in performance ($\beta = 0.399$, $p = 0.019$), while leg stiffness contributed minimally (%19,5). For SJ, knee extension strength at 60°/s was the strongest predictor, reflected 12.5% of the variance ($\beta = 0.354$, $p = 0.040$). The last model including 60°/s and 180°/s flexion/extension and, leg stiffness explained 23.0% and 22.8% of the variance for CMJ and SJ, with no significant effects from leg stiffness or knee flexion strength. High-velocity knee extension strength (180°/s) was more predictive for CMJ performance, whereas low-velocity strength (60°/s) better predicted SJ performance. It was observed that leg stiffness was not a significant predictor compared to isokinetic knee variables. These findings suggested that training programs for adolescent soccer players should emphasize velocity-specific strength development. Future studies could incorporate additional biomechanical and performance-related factors to increase prediction accuracy of the parameters.

Anahtar Kelimeler: Skuat, karşı hareketli sıçrama, futbol, izokinetik.

GENÇ FUTBOLCULARDA BACAK SERTLİĞİ İLE İZOKİNETİK KUVVETİN SKUAT VE KARŞI HAREKETLİ SİÇRAMAYLA İLİŞKİSİ

Öz: Dikey sıçrama performansı, futbolcularda alt ekstremita kas gücünün önemli bir göstergesidir. Skuat sıçrama (SJ), konsantrik kuvveti yansıtırken, karşı hareketli sıçrama (CMJ) esneme-kısalma döngüsünün (SSC) verimliliğini değerlendirir. Diz izokinetik kuvveti ve bacak sertliği gibi biyomekanik faktörlerin sıçrama performansını etkilediği bilinse de adolesan dönemindeki yordayıcı rolleri belirsizliğini korumaktadır. Bu çalışma, adolesan erkek futbolcularda farklı açılal hızlardaki (60°/s ve 180°/s) izokinetik diz kuvveti ve bacak sertliği değerlerini kullanarak SJ ve CMJ performansını tahmin etmek için regresyon modelleri geliştirmeyi amaçlamıştır. Otuz dört erkek adolesan futbolcu; SJ, CMJ, bacak sertliği ve izokinetik diz fleksör ve ekstansör kuvvet testine tabi tutuldu. İstatistiksel varsayımlar doğrulandıktan sonra, sıçrama yüksekliğinin yordayıcılarını belirlemek için ileri yönlü kademeli regresyon analizi uygulanmıştır. CMJ için, 180°/s hızdaki diz ekstansiyon kuvveti, performans varyansının %15,9'unu anlamlı bir şekilde açıklamıştır ($\beta = 0,399$, $p = 0,019$); bacak sertliği ise varyansı açıklamada minimal düzeyde katkıda bulunmuştur (%19,5). SJ için, 60°/s hızdaki diz ekstansiyon kuvveti en güçlü yordayıcı olmuş ve varyansın %12,5'ini açıklamıştır ($\beta = 0,354$, $p = 0,040$). Bacak sertliği veya diz fleksiyon/ekstansiyon kuvvetinin anlamlı bir etkisi olmaksızın, 60°/s ve 180°/s fleksiyon/ekstansiyon ile bacak sertliğinin bulunduğu son modeller CMJ için varyansın %23'ünü ve SJ için %22,8'ini açıklamıştır. Yüksek hızlı diz ekstansiyon kuvveti (180°/s) CMJ performansını daha iyi yordarken, düşük hızlı kuvvet (60°/s) SJ performansını daha iyi yordamaktadır. Bacak sertliğinin izokinetik diz değişkenlerine göre önemli bir yordayıcı olmadığı görülmüştür. Bu bulgular, ergen futbolculara yönelik antrenman programlarının hızla özgü kuvvet gelişimini vurgulaması gerektiğini göstermektedir. Gelecek çalışmalar, ek biyomekanik faktörler ve performansa ilişkin başka faktörler dahil ederek parametrelerin tahmin gücünü artırabilirler.

Keywords: Squat, counter-movement, football, isokinetic.



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INTRODUCTION

Vertical jump is an important factor as athletic assessment tool and plays a critical role in various sports, especially soccer (Arvidsson & Haglund, 2019). Explosive power for lower extremities is crucial for movements like heading, tackling, and shooting. The squat jump (SJ) and counter movement jump (CMJ) are utilized and valid tests to evaluate vertical force production (Markovic et al., 2004). Vertical jump height is evaluating widely with both methods, but they are targeting different neuromuscular properties. While the SJ reflects isolated concentric force, the CMJ indicated capacity of stretch-shortening cycle (SSC) (van Hooren & Zolotarjova, 2017).

The SJ starts while knees in flexed static position, for isolating the concentric contraction phase, and depends on the ability to produce rapid concentric force via the knee extensor muscles (Bulgan, 2016; Kipp & Kim, 2022). SJ provides a direct assessment of capacity to generate explosive force (Earp et al., 2010). In contrast to this, the CMJ involves a rapid eccentric action which occurred immediately after the concentric propulsion phase. This indicates the SSC, which related with rapid force production by benefit from stored elastic energy and responses of neural reflexes (Bosco et al., 1982; Trimble et al., 2000). Following the concentric extension, eccentric flexion during CMJ results with higher force production and a rate of force development (RFD). Generally, this leading to reach higher jump height compared to SJ (Bobbert et al., 1996; Floría et al., 2016). The difference in height between CMJ and SJ enables to evaluate the eccentric contraction ratio or pre-stretch capacity as indexes efficiency of SSC (Dantas et al., 2020; McGuigan et al., 2006). Especially during adolescence, this difference becomes relevant indicator for assessment, as the improvement of SSC capacity takes places with physical maturation (Dantas et al., 2020).

For the efficiency of the SSC, leg stiffness plays a considerable role. Leg stiffness described as the ratio between surface reaction force and compression of leg during dynamic type of activities (Struzik, 2019), which representing the elastic capacity of the lower extremity with the capacity to resist deformation under a stress of load. This capability is enabling a quick and effective shift between the concentric and eccentric contraction phases in the activity like CMJ (Arampatzis et al., 2001). It supports the effective storage of elastic energy potential during the downward motion and upward propulsion, thus enhancing vertical force generation. This becoming it a crucial factor in producing explosive power during the movements related to SSC (Satkunskiene et al., 2021).

Isokinetic dynamometry is the well-established gold standard method for measuring the dynamic strength capacities that support key biomechanical functions like mentioned above. It gives opportunity to measure peak muscle torque at determined angular velocities, while isolating any specific muscle groups such as the quadriceps and hamstrings (Bulgan, 2016). Evaluating the power or torque production with varying angular velocities provides comprehensive views; angular velocity like 60°/s reflect an athlete's ability to produce maximal force, while higher angular velocity of 180°/s or 300°/s provide the more rapid contractions form of explosive actions such as sprinting and jumping/hopping (Lehnert et al., 2013; Rouis et al., 2015).

Despite the previous research reported that leg stiffness and isokinetic strength are highly related to jump efforts (Si et al., 2025), the specific interaction of these variables in adolescent populations remains understudied. Si et al. (2025) demonstrated that lower limb vertical stiffness increases significantly with higher knee flexion-extension strength ratios, suggesting

that optimal stiffness facilitates greater force production especially during the push-off phase. Similarly, in preadolescence populations, Pentidis et al. (2020) identified that while muscle strength is a primary predictor of jump height in non-athletes, tendon stiffness becomes the significant predictor in trained preadolescence athletes, highlighting the crucial role of tissue mechanical properties in developmental age. Furthermore, recent studies on young adults have established moderate to strong positive correlations ($r = 0.59 - 0.75$) between maximal eccentric strength and vertical jump metrics, such as jump height and reactive strength index (Park et al., 2024), with systematic reviews confirming that eccentric force variables are critical determinants of CMJ performance (Nishiumi et al., 2023). Despite these findings, there are limited number of studies employing a predictive model that integrates the vertical jump performance, isokinetic strength and leg stiffness specifically in adolescent athletes (Nishiumi et al., 2023). Since jumping performance depends on a combination of maximal strength, angular velocity, and effective SSC function, it is important to understand how these elements work together to impact vertical jump outcomes. Therefore, this study aimed to establish a predictive model for SJ and CMJ performance in adolescent soccer players by comparing isokinetic knee extension and flexion torque at angular velocities of $60^\circ/s$ and $180^\circ/s$, along with leg stiffness as predictor variables.

METHODS

Research Design

The present study conducted on a cross-sectional design in male adolescent soccer players. Ethics Committee of Trabzon University approved the study procedures (Approval No: 2025-8/2.2), and all the measurements were implemented in accordance with the Declaration of Helsinki. Participants visited the laboratory on two separate occasions: the first visit was for familiarization with the procedures, and the second visit was for the testing. Under their coach's supervision, participants were informed in detail about the purpose and procedures of the research. Parental permissions were obtained with written informed consent from all participants. All tests were performed at the Trabzon Sports Performance Measurement and Ability Center. To standardize the testing conditions, participants were instructed to refrain from any vigorous exercise for 24 hours and to avoid caffeinated beverages for 12 hours before the testing day. Prior to jump testing, all participants subjected to a standardized warm-up consisted of 5 minutes of light running, 5-min stretching for lower-limb muscle groups, and 3 submaximal jump trials. Jump protocols including continuous hopping for leg stiffness were separated by 3-min recovery periods. Participants then rested for 20 min before subjected to the isokinetic test protocols. Prior to the isokinetic test, each participant performed a warm-up on a cycle ergometer at a cadence of 50–70 RPM for 5 min. Following the warm-up, participants were subjected to the isokinetic knee test, first at $60^\circ/s$ and then at $180^\circ/s$. Before the actual test at each angular velocity, participants performed three submaximal warm-up trials. A 30-second rest period was provided between the warm-up trials and the actual test, while a 3-minute recovery period was given between the two angular velocity protocols. All tests were conducted between 08:00 and 10:00 AM.

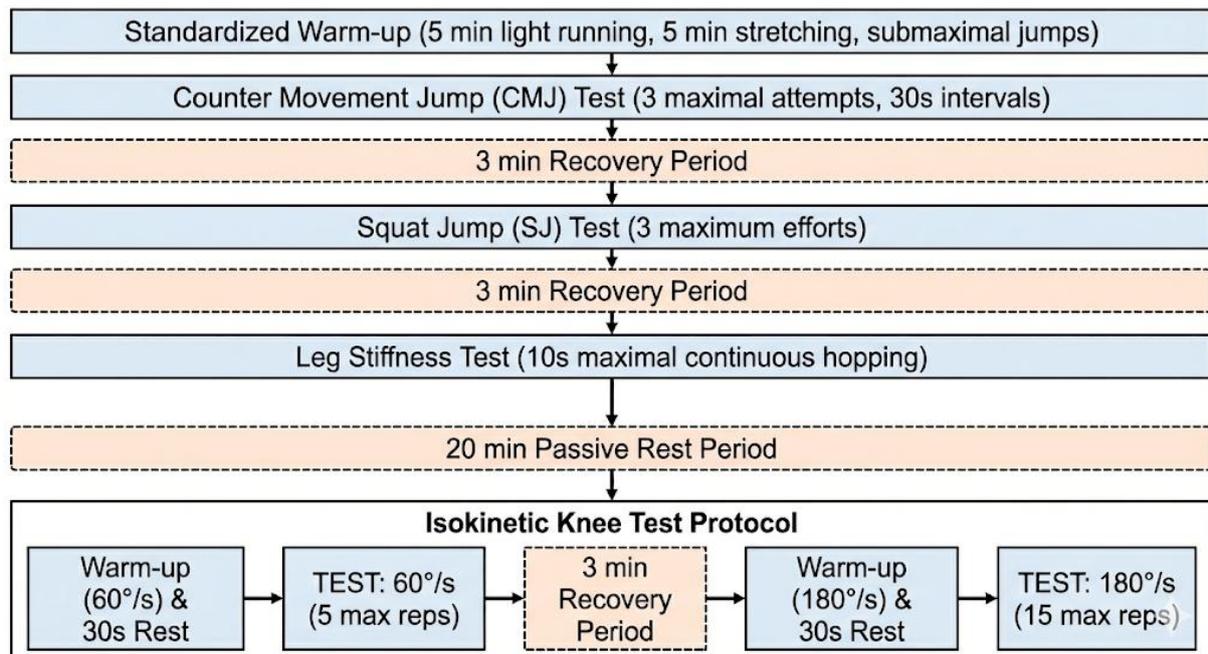


Figure 1. Procedural flowchart

Participants

This study conducted with 40 male amateur soccer players aged between 15 and 17 years (age: 15.97 ± 0.62 years; stature: 170.8 ± 5.34 cm; body mass, 63.7 ± 7.44 kg). To be eligible, participants needed at least three years of soccer experience, no musculoskeletal injuries within the previous six months, no history of acute or chronic illness, and not being goalkeeper. Six players withdrawn from the study of their own accord, remaining of 34 participants completed the tests.

Data Collection Tools

Counter Movement Jump

The CMJ were evaluated by OptoJump system (Microgate, Bolzano, Italy). For the test protocol, participants stood on feet with align their shoulder width and hands on their iliac crests. They were instructed to perform a rapid CMJ by flexing the knees with a self-selected depth and jump for maximal height. Total of three maximal CMJ attempts were performed with 30-s rest periods between the trials. The highest jump height value amongst the three attempts was included in the analysis (McHugh et al., 2024).

Squat Jump

Vertical jump performance was also evaluated using the SJ protocol, which isolates lower-extremity concentric power generation by excluding the impact of the SSC. Each participant performed three maximum efforts of SJ attempts. For each jump, they were instructed to lower into a static squat while their hands placed iliac crests. Upon reaching a knee angle of 90° , they held the position for 2-3 sec to eliminate any pre-loading force of eccentric contraction. From this static position, they jumped vertically with their maximum effort, while avoiding any downward motion before takeoff. The highest value was used for analysis (Glatthorn et al., 2011).

Leg Stiffness

Standardized bilateral hopping protocol was utilized for leg stiffness. Following a 3-minute rest period after squat jump test, participants completed maximal (with possible minimum contact time) continuous repeated hops for 10 seconds (Dalleau et al., 2004).

Isokinetic Knee Test

Measurement of isokinetic knee strength was performed via IsoMed 2000 dynamometer (D&R Ferstl GmbH, Germany). Participants' hip joint positioned at 75° flexion to ensure full knee extension capability while seating. The popliteal fossa fitted precisely at the seat's anterior margin for the tested leg. Adjustable pads and straps secured the femur, pelvis, thorax, and shoulders to prevent compensatory movements during the testing. The lever arm of the dynamometer was adjusted at 90° with the knee's range of motion, aligned with the lateral femoral epicondyle and carefully aligned with the rotational axis (Birol and Tortu, 2025). Knee joint muscles were tested at the angular velocities of 60°/s and 180°/s. Participants fulfilled three reps of submaximal movements for familiarization with the angular velocity before each angular velocity. During the test, participants were asked to perform five reps of maximal knee flexion and extension movements for 60°/s and 15 reps for 180°/s to evaluate isokinetic knee muscle strength. After the warm-ups 30 second rest period was given before the main phase of the test. A 3 min recovery period provided between the two angular velocity protocols.

Statistical Analysis

To determine the required sample size for the study, an a priori power analysis was conducted using G*Power software (version 3.1), based on the correlation coefficients reported by Park et al. (2024). By utilizing the correlation coefficient ($r = 0.75$) from the previous study, the squared multiple correlation (p^2) was calculated as 0.56. With an effect size (f^2) of 1.27, an alpha level (α) of 0.05, and a statistical power ($1-\beta$) of 0.95, it was determined that a minimum of 22 participants was required for a model consisted of 5 predictors. Stepwise-forward linear regression analyses were conducted following the confirmation of required statistical assumptions. Durbin-Watson statistics was evaluated for the independence of observations which indicating the absence of residual autocorrelation (1.838 for SJ, $p = 0.633$ and 1.875 for CMJ, $p = 0.713$). Through partial regression plots linearity was checked, which exhibited no systematic deviations. The homoscedasticity was demonstrated by the random dispersion of standardized residuals (CMJ: ± 1.89 ; SJ: ± 2.05). No influential outliers detected with evaluation of Cook's distance values (< 1 for all cases). Multicollinearity observed on acceptable levels via diagnostics yielded variance inflation factor (VIF) values below 5 and tolerance values above 0.2 (maximum VIF = 4.527 for SJ and 4.341 for CMJ). Q-Q plots and residual histograms displayed normal distribution. The predictor factors were sequentially entered via stepwise-forward model based on their bivariate correlations with CMJ and SJ outcomes, and their explained variances of relative contribution (ΔR^2). JASP (Amsterdam, Netherlands) was used for statistical analysis and significance level set at $p < 0.05$.

RESULTS

For CMJ, 180°/s knee extension strength (ex180) was statistically significant in Model 1 ($\beta = 0.399$, $p = 0.019$), explaining 15.9% of the variance ($\Delta R^2 = 0.159$, $F(1,32) = 6.05$). Model 2, which added leg stiffness (STF), increased the variance to 19.5% ($\Delta R^2 = 0.036$, $F(2,31) = 3.74$, $p = 0.035$), though stiffness was not significant ($\beta = -0.189$, $p = 0.251$). Inclusion of 60°/s knee flexion (ex60) strength (Model 3) and 60°/s knee extension (ex60) (Model 4) provided negligible improvements ($\Delta R^2 \leq 0.023$, $p > 0.05$). The last model (Model 5) explained 23.0% of the variance ($R^2 = 0.230$), with no additional statistical significance ($p > 0.45$) (Table 1).

Table 1. Stepwise-forward linear regression results for counter movement jump

Model	R ²	ΔR ²	F(df)	p	β (95% CI)
M1	.159	.159	6.05(1,32)	.019	Ex180: 0.399* (1.06, 11.30)
M2	.195	.	3.74(2,31)	.035	Ex180: 0.379* (0.76, 11.00), STF: -0.189 (-0.36, 0.10)
M3	.218	.023	2.79(3,30)	.058	Ex180: 0.284 (-1.64, 10.45), STF: -0.239 (-0.40, 0.08), Flex60: 0.184 (-4.50, 12.32)
M4	.227	.009	2.13(4,29)	.102	Ex180: 0.155 (-6.81, 11.63), STF: -0.271 (-0.44, 0.07), Flex60: 0.149 (-5.77, 12.06), Ex60: 0.180 (-5.38, 9.76)
M5	.230	.002	1.67(5,28)	.174	Ex180: 0.209 (-7.73, 14.21), STF: -0.274 (-0.45, 0.07), Flex60: 0.190 (-6.85, 14.89), Ex60: 0.129 (-7.21, 10.36), Flex180: -0.071 (-12.78, 9.53)

Abbreviations; M: model; Ex60: 60°/s extension; STF: leg stiffness; Ex180: 180°/s extension; Flex180: 180°/s flexion; CI: Confidence Interval; for coefficients: *p < .05

The regression analysis for SJ revealed that ex60 knee extension strength was statistically significant predictor in Model 1 ($\beta = 0.354$, $p = 0.040$), explaining 12.5% of the variance ($\Delta R^2 = 0.125$, $F(1,32) = 4.58$). STF in Model 2 improved the explained variance with 20.2% ($\Delta R^2 = 0.076$, $F(2,31) = 3.91$, $p = 0.031$), however STF was not showed statistically significant association ($\beta = -0.280$, $p = 0.095$). Other models (3-5) exhibited; ex180, flex180, and flex60 variables did not significantly enhance the models (all $\Delta R^2 \leq 0.023$, $p > 0.05$). The last model (Model 5) reached for 22.8% of the variance ($R^2 = 0.228$), with no significant contributions by the added variables ($p > 0.70$) (Table 2).

Table 2. Stepwise-forward linear regression results for squat jump

Model	R ²	ΔR ²	F(df)	p	β (95% CI)
M1	.125	.125	4.58(1,32)	.040	Ex60: 0.354* (0.20, 8.35)
M2	.202	.076	3.91(2,31)	.031	Ex60: 0.397* (0.79, 8.80), STF: -0.280 (-0.42, 0.04)
M3	.225	.023	2.90(3,30)	.051	Ex60: 0.174 (-4.97, 9.18), STF: -0.219 (-0.39, 0.10), Ex180: 0.269 (-4.82, 13.10)
M4	.228	.003	2.14(4,29)	.101	Ex60: 0.143 (-5.79, 9.26), STF: -0.214 (-0.40, 0.10), Ex180: 0.325 (-5.48, 15.50), Flex180: -0.066 (-10.61, 7.58)
M5	.228	.000	1.65(5,28)	.179	Ex60: 0.132 (-7.16, 10.34), STF: -0.217 (-0.41, 0.11), Ex180: 0.330 (-5.84, 16.01), Flex180: -0.075 (-12.83, 9.38), Flex60: 0.017 (-10.46, 11.19)

Abbreviations; M: model; Ex60: 60°/s extension; STF: leg stiffness; Ex180: 180°/s extension; Flex60: 60°/s flexion; Flex180: 180°/s flexion; CI: Confidence Interval; for coefficients: *p < .05

DISCUSSION AND CONCLUSION

Results of the regression analyses indicated that knee extension strength at 180°/s and 60°/s seen as the most effective predictors for CMJ and SJ performance, respectively. However, the explanatory power of these variables declined as additional predictors were introduced into the models. The lack of significant contributions by the leg stiffness and other variables suggests that higher angular velocity for extension strength was more relevant for CMJ, while lower

angular velocity for extension strength was more predictive for SJ. The reduction in model fit following the involving of non-significant predictors highlighted their limited explanatory value in accordance with variance in vertical jump performance.

The present study offers preliminary insights into the factors influencing vertical jump performance in adolescent soccer players, suggesting potential associations between isokinetic strength and vertical jump related outcomes. These associations align with the specific biomechanical demands between the type of jumps. While the SJ more related to concentric contraction (Bulgan, 2016), CMJ's gained rapid force production relies on SSC demands (Trimble et al., 2000). Stronger correlations between jump performance and higher-velocity strength outcomes in various athletic populations are consistent with the observed patterns in current study (Yapici et al., 2014; Górski et al., 2024). The importance of tailoring strength training programs to meet the specific force-velocity profiles of each jump type, the changes in predictive power of strength across movement velocities underscored. The results reported by Kipp and Kim (2022) demonstrated that while vertical ground reaction forces and jump heights may remain similar between tasks, the CMJ relies on significantly greater muscle forces and force-producing abilities from the vastus lateralis and gluteus maximus. This superior performance in the CMJ is primarily attributed to more favorable force-velocity behavior, as these muscles work at a higher capacity during the longer movement duration of the jumping task. Conversely, the SJ appears to be supported by more optimal force-length behavior of the hamstrings. Furthermore, muscle moment analysis reveals that the hamstring produces greater hip extension and knee flexion moments during the CMJ, effectively balancing the higher vastus lateralis forces to maintain overall jump performance parity across both jumping tasks.

Leg stiffness did not significantly contribute to either jump performance in the present study, contrary to some previous studies conducted in adult populations (Satkunskiene et al., 2021). The changes in reported results may be indicated the variations in neuromuscular function during the growth phase, as the adolescent athletes in the present study are still in maturation and had not yet fully reached their full capability to benefit from elastic energy mechanisms (Dantas et al., 2020). The limited relationship between leg stiffness and jump performance in this study for adolescent population indicates that for enhancing vertical jump height via only focusing to increase stiffness could not be the most effective approach. However, increasing stiffness plays undeniable role in developing athletic performance and reducing injury risk factors in athletes' developmental period (Perkins and Canavan, 2023). This also aligns with previous findings reported by Lloyd et al. (2014) emphasizing the need for age-related training programs during periods of rapid growth and maturation. Studies reported that the ability to utilize SSC effectively improves progressively during adolescence (Dantas et al., 2020), which could explain why leg stiffness observed with limited prediction value in the present study's findings. It's likely that the stiffness-related measures and hamstring strength parameters showed only a modest explanatory contribution because the participants were adolescent athletes. This group is undergoing neuromuscular maturation which includes development of tendon mechanical properties and the refinement of the movement coordination strategies (Michailidis et al., 2025). This perspective offers that training prescription should be carefully periodized gradually incorporate with biological maturation stages and increased training experience for optimizing adaptations (Sattler et al., 2014; Duarte et al., 2018).

Similarly, knee flexion strength did not find as a significant predictor, even the theoretical association of hamstring function in vertical jump (Kipp and Kim, 2022). This aligns with findings in elite youth soccer players where correlations between isokinetic strength and jump performance were reported as low to moderate ($r > 0.30$ in only 56% of cases) and highly

dependent on the training phase. While hamstring-to-quadriceps ratios are critical in adults, these relationships fluctuate during the annual cycle in youth athletes due to ongoing neuromuscular maturation. Thus, the lack of predictive power in this study likely reflects the inconsistent contribution of hamstring strength during this specific developmental and training period (Lehnert et al., 2013).

The established models in the scope of the present study suggested that subsequently added variables to the models may decrease the contribution to predict vertical jump performance. The decrease for the prediction could be caused from biomechanical factors of the jumping, which demands highly coordinated multi-joint actions, involving the hip, ankle, and knee (Tsiokanos et al., 2002), in addition to these neuromuscular and technical aspects (Floria et al., 2016). The limited predictive power of the model, despite including multiple variables, could stem from the biomechanical difference between isolated isokinetic testing and the coordinated multi-joint nature of jumping. Tsiokanos et al. (2002) found that combined isokinetic torques explain only 38–42% of jump height variance, as they do not reflect the technical synchronization required in jump efforts. Furthermore, vertical performance relies heavily on the SSC and the ability to generate high eccentric forces to decelerate the body. As reported by Floría et al. (2016), elite performance is distinguished by the efficiency of the eccentric to concentric transition rather than produced absolute strength/power alone. Therefore, increasing strength/power-based predictors may not linearly improve the model, as unmeasured variables like neuromuscular timing and technical coordination remain unclear in the scope of the present study.

From a coaching perspective, these results highlight how training programs should be tailored based on the specific strength qualities required for different jump types in young soccer players. Maximal strength at slower speeds (around 60°/s) emerges more relevant for development of SJ, however, explosive power production at higher angular velocities (180–300°/s) indicates stronger relationships with CMJ (Gheller et al., 2014). This relationship supports implementing training methods that match with the different force production characteristics of each type of jump, consistent with the principle of velocity-specific training (Behm & Sale, 1993). The association of strength and jump performance can change by sports, disciplines, training status, playing positions (González-Ravé et al., 2014; Górski et al., 2024) and/or even measurement period of the season (Lehnert et al., 2013). Therefore, all the mentioned factors should be handled carefully throughout the season in the scope of the evaluation of the measurements.

Importantly, the nature of the strength-performance relationship differs between the jump types. SJ execution is relying exclusively on concentric muscle activation that shows greater dependence on maximal strength capacities which measuring at slower angular velocities (60°/s), while CMJ is incorporating with the SSC which exhibits stronger connections to explosive strength measuring at higher angular velocities (180°/s) (Bobbert et al., 1996; van Hooren & Zolotarjova, 2017). These variations in relationships suggest the importance of implementing movement-specific protocols during the adolescent training years, facilitating targeted development of the specific neuromuscular features for each jump type (Alves et al., 2022).

The results obtained in this study have several limitations, therefore, they should be considered carefully. Firstly, the cross-sectional design, only measurement of knee flexors/extensors and specific sample of male adolescent amateur soccer players limit the generalizability to other age groups or sport disciplines. Secondly, the absence of biological maturation assessments

may have influence the predictive power of the models, as neuromuscular and tendon properties fluctuate differentially during adolescence period. Lastly, no technical assessments were conducted via a video analysis method, which might have helped explain the variances related to movement specificity.

In conclusion of the present study, extension peak torque at 180°/s angular velocity was the significant predictor for CMJ, whereas for SJ, the significant predictor was peak torque during extension at 60°/s. It was observed that leg stiffness was not a significant predictor compared to isokinetic knee variables. However, according to the final model (M5) which all parameters were evaluated collectively, these variables demonstrated low predictive power for vertical jump performance in adolescent soccer players. Future research could employ longitudinal designs to evaluate trends in the strength-performance relationship by including hip and ankle joint muscles throughout the maturation process. On the other hand, including technical development factors (Floria et al., 2016), biomechanical assessments of jumping mechanics (Gillen et al., 2021) and variables like anthropometric characteristics, muscle morphology, and neuromuscular activation patterns (Kellis & Katis, 2007) could enhance the understanding of determinants of jump performance in youth soccer players or athletes. The most valuable next step would be examined the any mentioned determinants in longitudinal research design how the strength and vertical jump performance evolves and how different training programs might impact these relationships at various developmental stages (Sattler et al., 2014).

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