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Original Article

Predictors of explosive leg power in elite football players

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Abstract
Problem statement: The assessment of players' physical attributes such as explosive power has been relevant for players' selection and talent identification in youth football. Among individual features, the literature describes a high positive correlation between explosive leg power (countermovement – CMJ, and squat jump – SJ) and superior levels of sports performance. Purpose: The aims of this study were twofold: 1) to investigate the effects of chronological age, body composition, and functional capacities on the CMJ and SJ performance; and (2) to develop a r*egression equation using easy-field tests to estimate* CMJ and SJ performance. Approach: The sample was composed of 161 male football players (age = 15.8 ± 1.7 years, height = 170.7 ± 8.5 cm, body mass = 63.6 ± 10.1 kg). The calf skinfold thickness was measured as a specific body composition indicator. Strength tests included sit-ups, handgrip, CMJ and SJ heights. Linear speed and agility (T-test) were also measured. Results: Calf skinfold, handgrip, linear speed (35 m) and change of direction speeds in CMJ and SJ performance, and sit-ups only in SJ, were all statistically significant predictors after controlling for the effect of chronological age. Specific *regression equation using calf skinfold* (X^1)*, handgrip* (X^2)*, sit-ups*(X^3)*,* linear speed (35 m) (X^4)*, and T-test* (X^5) *to estimate the CMJ* [$Y = 64.69 + (-.17) (X^1) + .10 (X^2) + .04 (X^3) + (-3.03) (X^4) + (-2.32) (X^5)$] *and SJ* [$Y = 64.82 + (-.32) (X^1) + .09 (X^2) + .05 (X^3) + (-2.97) (X^4) + (-2.28) (X^5)$] *are presented.* Conclusions: After controlling chronological age, *calf skinfold, strength, l*inear speed, and agility *are important predictors* **of explosive leg power**. *All these predictors should be considered in the monitoring training process to improve* **leg explosive power performance.**
Keywords: correlates; countermovement jump; squat jump; youth athletes; body composition; physical fitness

Introduction

In youth football, sports agents and coaches have relied on assessing body composition and functional capacities as part of the players' selection and talent identification processes (Bennett et al., 2019; Gil et al., 2007). Several performance tests have been proposed in the literature and applied by coaches and technical staff in the sports context. Particularly in the early stages of long-term sports development, monitoring the athletic development is a valuable tool to track the players' improvements and design and evaluate training interventions (Bennett et al., 2019; Bourdon et al., 2017).

Football is characterized by its high demands of intense and intermittent exercise (Ferley et al., 2020; Turner & Stewart, 2014), where explosive leg power plays a significant role in game performance (Aksović et al., 2020; Andersen et al., 2018; Padulo et al., 2017; Peñailillo et al., 2016). According to literature, successful sports performance is associated with the players' capacity to accelerate the body mass as fast as possible through the lower limb ballistic movements (Padulo et al., 2017). Indeed, explosive leg power is manifested in the game through variants of jumps, accelerations, decelerations, sudden changes of direction or stops, and speed (Aksović et al., 2020; Andersen et al., 2018).

Meanwhile, previous investigations have explored the relationships between explosive strength and several predictors of athletic performance in football players. Hammani et al. (2018) reported that maximal strength, measured by the one-repetition maximum of the back squat, was significantly related to improvements

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in speed, changes of direction, and vertical jumping in adolescent male football players aged 16.2 ± 0.6 years. In professional football players aged 18.3 ± 1.2 years, the changes in the maximal squat strength were positively reflected in the short sprint times (Styles et al., 2016). In other studies, authors have positively related the explosive leg power to speed (Aksović et al., 2020; Andersen et al., 2018; Križaj, 2020), changes of direction (Keller et al., 2020; Negra et al., 2017), and the players' selection status according to the number of minutes played (Deprez et al., 2015; Gil et al., 2007).

There is a consensus in the literature that chronological age (CA) is a longitudinal predictor of explosive leg power from childhood to young adulthood (Deprez et al., 2015). It is assumed that jumping performance increase linearly from 5 to 18 years of age in boys (Malina et al., 2004). However, especially in homogeneous groups, such as elite football players, few studies have considered the effect of CA in leg explosive power after controlling for critical predictors such as body composition and other physical fitness components. This information reinforces the importance of integrating a multicomponent training approach to improve explosive leg power, including general strength, linear speed, change of direction speed, and specific leg body composition monitoring.

Regarding the influence of lower-body strength on the game performance, the countermovement jump (CMJ) and the squat jump (SJ) have been widely used by sports professionals as valid tests to assess power and strength (Andersen et al., 2018; Campos-Vazquez et al., 2015; Dietze-Hermosa et al., 2020; Goranovic et al., 2021). An example of the popularism of these tests in the football context is the data available for the CMJ and the SJ performance values according to players' position on the field (Turner & Stewart, 2014). However, the CMJ and SJ performance evaluation demands access to specific measurements instruments such as a force platform or a photocell system (Contreras-Diaz et al., 2018), as well as high time-consuming protocols. It would be beneficial to have a procedure to assess and monitor explosive leg power changes that are less costly and accurate. To our knowledge, few studies have proposed regression equations to estimate CMJ and SJ using easy and specific correlates of body composition and functional capacities.

In addition, although explosive leg power has been correlated with body composition variables and other athletic performance indicators (Caia et al., 2016; Keller et al., 2020; Peñailillo et al., 2016), few is known on the interrelationship between those variables as predictors of explosive power. Therefore, the aims of this study are twofold: (1) to investigate the contribution of essential predictors such as specific body composition indicators and functional capacities, on the CMJ and SJ performance, after controlling by the effect of CA; and (2) to develop a *regression equation using easy-field tests (c*alf skinfold, handgrip, sit-ups, linear speed, and agility test) to estimate the CMJ and SJ performances.

Materials & Methods

Participants

One hundred and sixty-one adolescent male football players (age = 15.8 ± 1.7 years, height = 170.7 ± 8.5 cm, body mass = 63.6 ± 10.1 kg) have participated in this study. All procedures applied were approved by the Ethics Committee of the Faculty of Human Kinetics, CEIFMH N. º 34/2021. The investigation was conducted following the Declaration of Helsinki, and informed consent was obtained from the underage participants' legal guardians.

Procedures

Anthropometric characteristics

For the anthropometric measurements, participants were barefoot and only using shorts. Height was measured to the nearest 0.01 cm using a stadiometer (SECA 213, Hamburg, Germany). Body mass was measured to the nearest 0.1 kg using a portable scale (SECA 760, Hamburg, Germany). Skinfold thickness was measured to the nearest 0.1 mm at seven sites (biceps, triceps, subscapular, suprailiac, abdominal, thigh, and calf) using a skinfold calliper (Harpenden Skinfold Caliper, West Sussex, England). All measurements were taken following the ISAK (International Society for the Advancement of Kinanthropometry) guidelines.

Strength assessment

Two functional tests were applied to assess upper-body strength, with a five-minute recovery time between each test assessment. The handgrip protocol consisted of three alternated data collection trials for each arm performed using a hand dynamometer (Jamar Plus+, Illinois, USA). Participants were instructed to hold a dynamometer in one hand, laterally to the trunk with the elbow on a 90º position (Gerodimos, 2012). From this position, participants were instructed to squeeze as hardest as possible and progressively and continuously the hand dynamometer for about two seconds. At no time, the dynamometer could contact the participant's body. The recovery time between trials was set at 45 seconds.

A sit-ups protocol performed the most significant number of repetitions for 30 seconds (Conseil, 1990). Participants were instructed to start in a sitting position, torso vertical, hands behind their neck, bent knees (90-degree), and feet on the floor. From this position, participants were instructed to stretch out on their back, shoulders in contact with the floor, then straighten up to the sitting position bringing the elbows forward in contact with their knees and/or passing them through the knees. Counting took place the moment the elbows touched or passed the knees. The absence of counting meant that the repetition had not been correctly performed.

Vertical jumping

Two tests were applied to assess lower limb explosive strength and power: (1) countermovement jump (CMJ) and (2) squat jump (SJ) (Bosco et al., 1983). Both protocols included four data collection trials and were performed in the Optojump Next (Microgate, Bolzano, Italy) system of analysis and measurement. Participants rest 45 seconds between each trial and five minutes between each test. In both tests, participants were encouraged to jump for maximum height.

In the CMJ protocol, participants were directed to perform the CMJ "as they usually would" with a quick countermovement to a comfortable depth emphasized before exploding upwards to gain maximum height. Hands remained on the hips for the entire movement to eliminate any influence of arm swing (Bosco et al., 1983). The SJ protocol testing began with the participant in a squat position at a self-selected depth of approximately 90º of knee flexion, holding this position for researchers' count of three before jumping. If a dipping movement of the hips was evident, then the trial was repeated (Bosco et al., 1983).

Linear speed

Participants performed maximal sprints at 5-, 10- and 35-m. Sprint time was recorded in seconds using Witty-Gate photocells (Microgate, Bolzano, Italy), and the best of two trials was retained for analysis. Participants recovered between each sprint by walking back to the start-line with a total of 2 minutes between each trial.

Agility

Agility was evaluated through the t-test. The t-test is a 4-directional agility and body control test that assesses the ability to change direction rapidly while maintaining balance and without losing speed (Semenick, 1990). Participants sprinted 9.14 m straight, then shuffled 4.75 m to the left side. Next, participants shuffled to the right side 9.14 m and immediately after shuffled 4.75 m back. Finally, participants run backward until they pass the starting point. Test time was recorded in seconds using Witty-Gate photocells (Microgate, Bolzano, Italy), and the best of two trials was retained for analysis.

Statistical analyses

First, descriptive characteristics of participants were reported as means, standard deviation, and confidence intervals. Second, hierarchical multiple regression analyses were conducted to investigate the amount of variance in CMJ and SJ heigh that was explained by CA, body composition (calf skinfold), strength measures (handgrip and sit-ups), and speed/agility (linear speed and T-test). Preliminary analyses were performed to ensure no violation of normality, linearity, multicollinearity, and homoscedasticity assumptions. Finally, to estimate CMJ and SJ heigh, a multiple regression analysis was performed, with calf skinfold, handgrip, sit-ups, linear speed, and T-test as main predictors. The level of significance was set at $p < .05$. Data analysis was performed using IBM SPSS Statistics version 26 (SPSS Inc., an IBM Company, Chicago, Illinois, U.S.A.).

Results

Descriptive statistics for analyzed variables are presented in Table 1.

Table I. Descriptive statistics for analyzed variables.

	Mean	Std. Deviation	95% Confidence Interval for Mean	
			Lower Bound	Upper Bound
CA (years)	15.8	1.7	15.6	16.1
CMJ Height (cm)	29.2	5.4	28.4	30.0
SJ Height (cm)	28.6	5.6	27.8	29.5
Calf skinfold (mm)	10.2	4.9	9.2	10.6
Sit-ups (n)	36.0	12.4	34.6	38.5
Handgrip (kg)	33.3	7.3	32.2	34.5
Speed 35 m (s)	5.1	0.4	5.0	5.1
Agility T-test (s)	10.0	0.7	9.9	10.1

CA (chronological age).

The hierarchical multiple regression analyses for CMJ height are displayed in Table 2 and SJ height in Table 3. In step 1, CA predicted 18% and 17% of CMJ and SJ height variance in these analyses, respectively. In step 2, calf skinfold significantly increased explained variance by 13% in CMJ height and 22% in SJ height. Strength measures (sit-ups and handgrip) entered in step 3 significantly increased explained variance in CMJ height (9.6%) and SJ height (10.3%). Linear speed (35m) and T-test (agility) entered in step 4 increased the explained variance by 12.8% in CMJ height and 12.1% in SJ height. Finally, the total variance explained by the model (as a whole) was 53.1% and 61.2% in CMJ and SJ height, respectively. Concerning CMJ height, in the final model four variables were statistically significant: calf skinfold ($\beta = -.14$, $p = 0.040$), handgrip ($\beta = .14$, $p = .042$), linear speed (35m) ($\beta = -.26$, $p = .003$), and T-test ($\beta = .30$, $p < 0.001$). Similar results were found for the SJ height in the final model, with five variables being statistically significant: calf skinfold ($\beta = -.25$, $p < 0.001$), handgrip ($\beta = .14$, $p = .023$), sit ups ($\beta = .12$, p = .035), linear speed (35m) ($\beta = -.27$, $p = .001$), and T-test ($\beta = .28$, $p < 0.001$).

Table II. Summary of hierarchical regression analyses with CA, calf skinfold, strength measures (sit-ups and handgrip), speed, and agility (T-test) predicting CMJ height.

	I	II	III	IV
	β	β	β	β
CA (years)	.42***	.29***	.10	.01
Calf skinfold (mm)		-.38***	-.32***	-.14***
Handgrip (kg)			.29***	.14*
Sit-ups (n)			.18**	.10
Speed 35m (s)				-.26**
Agility T-test (s)				-.30***
R^2	.18	.31	.40	.53
F for change in R^2	34.75***	29.63***	12.65***	21.13***

Model I − CA; Model II – CA and Calf skinfold; Model III - CA and Calf skinfold, Sit Ups, Handgrip; Model IV – CA and Calf skinfold, Sit Ups, Handgrip, Speed 35m, and Agility T-test.
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; CA (chronological age).

Table III. Summary of hierarchical regression analyses with CA, calf skinfold, strength measures (sit-ups and handgrip), speed, and agility (T-test) predicting SJ height.

	I	II	III	IV
	β	β	β	β
CA (years)	.41***	.24***	.04	-.06
Calf skinfold (mm)		-.50***	-.43***	-.25***
Handgrip (kg)			.29***	.14*
Sit-ups (n)			.20**	.12*
Speed 35m (s)				-.27**
Agility T-test (s)				-.28***
R^2	.17	.39	.49	.61
F for change in R^2	32.32***	57.15***	15.90***	24.05***

Model I − CA; Model II – CA and Calf skinfold; Model III – CA and Calf skinfold, Sit-ups, Handgrip; Model IV - CA and Calf skinfold, Sit-ups, Handgrip, Speed 35 m, and Agility T-test.
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; CA (chronological age).

Regression Equation Using calf skinfold, handgrip, sit-ups, linear speed, and T-test to estimate the CMJ height and SJ height

CMJ Height

$Y = 64.69 + (-.17)(X1) + .10(X2) + .04(X3) + (-3.03)(X4) + (-2.32)(X5)$

(X1), = calf skinfold; (X2) = handgrip; (X3) = sit ups; (X4) = linear speed (35 m); (X2) = T-test; R2 = .52; SEE = 3.65; Durbin-Watson = 1.92. The calf skinfold (β = -.14; p = .040), handgrip (β = .14; p = .034), linear speed (35 m) (β = -.26; p = .002), T-test (β = -.30; p < 0.001), were significant predictors.

SJ Height

$Y = 64.82 + (-.32)(X1) + .09(X2) + .05(X3) + (-2.97)(X4) + (-2.28)(X5)$

(X1), = calf skinfold; (X2) = handgrip; (X3) = sit ups; (X4) = linear speed (35 m); (X2) = T-test; R2 = .61; SEE = 3.46; Durbin-Watson = 1.97. The calf skinfold (β = -.25; p < 0.001), handgrip (β = .12; p = .038), sit ups (β = .11; p = .046), linear speed (35m) (β = -.24; p = 0.002) and T-test (β = -.28; p < 0.001) were significant predictors.

Discussion

This study in elite male football players aged between 12.9 and 21.7 years showed that CA, individually, strongly predicts the variance observed in the CMJ and SJ height. However, after considering other measures of general strength (e.g., handgrip and sit-ups) and speed variation tests, CA loses its ability to explain the variance observed in CMJ and SJ performances. Calf skinfold, handgrip, linear speed (35 m) and change of direction speeds in CMJ and SJ performance, and sit-ups only in SJ, were all statistically significant predictors after controlling for the effect of CA and all variables in the model. This study proposes specific-regression equations for this population to estimate CMJ and SJ performances using calf skinfold, handgrip, sit-ups, linear speed (35 m), and change of direction speeds, considered accessible and simple physical fitness measures.

There is a consensus in the literature that CA is a significant predictor of explosive leg power from childhood to young adulthood (Deprez et al., 2015; Joksimović et al., 2019; Malina et al., 2004). There is a positive correlation between CA and explosive leg power among youngsters. Our study partly corroborates this relationship between CA and explosive leg power. In the first step of our model, CA, individually, was a significant positive predictor for the variance observed in the CMJ (42%) and SJ (41%). However, after considering handgrip, sit-ups, and linear and change of direction speeds in the model, CA lost its ability to explain the variance observed in CMJ and SJ performances. These results suggest that besides CA and calf skinfold, the players' physical fitness attributes are essential variables to consider to improve explosive leg power. As practical implications, during the training with the young football players, the conditional coaches should focus on developing this multifaceted nature of explosive leg power development.

In this study, the calf skinfold remained a significant negative predictor for CMJ and SJ after controlling CA and physical fitness components. Indeed, the skinfolds are used as indicators of fat mass percentage (FM%), which justifies its negative influence on vertical jumping. Previous studies have described the adverse effects of FM% in tasks requiring projection (jumps), rapid movement (dashes, shuttle runs), and lifting (Malina et al., 2004). However, note that CA and the calf skinfold could explain 31 and 39% of the variance observed in the CMJ and SJ, respectively. This reinforces the need to monitor FM% and promote multidisciplinary approaches based on specific training and a healthy diet among youth football players, to improve explosive power. On the other hand, an accessible and simple measure such as calf skinfold could be used to predict explosive leg power by researchers, coaches, and sporting professionals.

Our study extends the evidence to youth football players (12.9 to 21.7 years) that handgrip, an isometric strength measure, also indicates overall strength since it reflects the lower limbs strength (Bohannon, 2012), as already seen in older populations. In addition, sit-ups, only for SJ performance, remained a significant positive predictor after controlling for CA and the other functional capacities in the model. The literature has highly discussed the role of strength training among youth football players (Bennett et al., 2019; Campos-Vazquez et al., 2015; Peñailillo et al., 2016). Overall, the authors described improvements in body composition and athletic performance after a strength program intervention (Campos-Vazquez et al., 2015; Di Giminiani & Visca, 2017; Peñailillo et al., 2016). Regarding lower-body strength, a study performed among 21 football players aged 18.1 ± 0.8 years reported an improvement of about 2 cm in the CMJ height after 8 weeks of strength training (Campos-Vazquez et al., 2015). The same trend was observed in 19 football players aged 13 years after a two-year program. The explosive strength (CMJ and SJ) improved between 2.5 and 3.3% in the first season, respectively. The improvements were greater at the end of the second season, corresponding to 4.9 and 7%, respectively (Di Giminiani & Visca, 2017). On the other hand, the correlations between lower-body strength, speed, and agility, have been consistently described as significant and positive (Andersen et al., 2018; Negra et al., 2017). Indeed, our results corroborate the whole-body strength training as crucial at the early stages of football's long-term development, mainly to promote explosive leg power. Therefore, coaches should contemplate the strength development in the periodization and training sessions design as part of the football player improvement.

Both linear and change of direction speeds remained negative predictors of CMJ and SJ performances. Indeed, the negative relationship observed is justified by the fact that higher levels of explosive strength are associated with lowering time spent in sprinting and change of direction (Križaj, 2020; Negra et al., 2017; Priya et al., 2021). Thus, plyometric training involving vertical jumping has been highly recommended to enhance fundamental game performance skills, such as speed and agility (Paul et al., 2016). The majority of the revised literature on the topic has been studying the contribution of explosive leg power on the speed performance. Few studies have used the linear and change direction speeds as predictors of explosive leg power inversely. Our study intends to use those speed variations as simple and accessible fitness measures to estimate CMJ and SJ performance using specific regression models.

Finally, our study presents specific regression equation to estimate the CMJ *[*Y = 64.69 + (-.17) (*calf skinfold*) + .10 (*handgrip*) + .04 (*sit-ups*) + (-3.03) (linear speed 35 m) + (-2.32) (change of direction speed)*], and SJ [*Y = 64.82 + (-.32) (*calf skinfold*) + .09 (*handgrip*) + .05 (*sit-ups*) + (-2.97) (linear speed 35 m) + (-2.28) (change of direction speed)*]*. Since an accurate assessment of the CMJ and SJ requires the use of extensive protocols and expensive equipment, the use of simple and accessible physical fitness measures, such as those mentioned above, can be easily used in the practice by coaches to estimate explosive strength in young footballers.

Although growth and maturation variables were not covered in our analysis, which represents a limitation, it is believed that our data has crucial practical implications, particularly for the ones involved in youth football. Coaches should contemplate the strength and speed development in the training sessions' periodization and design to enhance explosive power. The strength programs should target the whole body and not exclusively the lower body. Additionally, the equations displayed are a less costly and accurate procedure to evaluate and monitor changes in explosive leg power among youth football players. Therefore, teams that do not have specific instruments available, such as force platforms or photoelectric cells, can still monitor the players' long-term development concerning explosive power. Future research designed to investigate the interrelationship between CA, body composition, and upper- and lower-body strength, considering the participants' maturity status, may be more informative.

Conclusions

The present study provides evidence of a negative correlation between performance in the CMJ and SJ with the calf skinfold and linear and change of direction speeds. On the other hand, a significant and positive correlation was verified between performance in CMJ and SJ with handgrip and sit-ups only in SJ. After controlling for CA, calf skinfold, general strength, linear speed, and change of direction speeds are essential predictors of explosive leg power performance. All these predictors should be considered in the monitoring training process to improve leg explosive power performance in youth football players.

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Conflict of interest declaration

The authors declare no conflict of interest.

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