HUMAN MOVEMENT (ISSN 1899-1955)
2023; 24(2): 94–100

Associations between muscular strength and vertical jumping performance in adolescent male football players

original paper
DOI: https://doi.org/10.5114/hm.2023.117778

CÍNTIA FRANÇA[1,2], ADILSON MARQUES[3,4], ANDREAS IHLE[5,6,7], JOÃO NUNO[1,8], PEDRO CAMPOS[2,9], FREDERICA GONÇALVES[2,10], JOÃO MARTINS[3,4], ÉLVIO R. GOUVEIA[1,2,5]

[1] Department of Physical Education and Sport, University of Madeira, Funchal, Portugal
[2] LARSyS, Interactive Technologies Institute, Funchal, Portugal
[3] Faculty of Human Kinetics, University of Lisbon, Lisbon, Portugal
[4] Institute of Environmental Health, University of Lisbon, Lisbon, Portugal
[5] Centre for the Interdisciplinary Study of Gerontology and Vulnerability, University of Geneva, Geneva, Switzerland
[6] Swiss National Centre of Competence in Research LIVES – Overcoming Vulnerability: Life Course Perspectives, Geneva, Switzerland
[7] Department of Psychology, University of Geneva, Geneva, Switzerland
[8] Marítimo da Madeira – Futebol, SAD, Funchal, Portugal
[9] Department of Informatics Engineering and Interactive Media Design, University of Madeira, Funchal, Portugal
[10] Polytechnic School of Technologies and Management, University of Madeira, Funchal, Portugal

ABSTRACT
Purpose. This study aimed to investigate the associations between muscular strength tests and vertical jumping performance (countermovement jump [CMJ] and squat jump [SJ]) in adolescent male football players, while controlling for important predictors such as chronological age and body composition.
Methods. The sample involved 161 male footballers (mean age: 15.8 ± 1.7 years) from the under-19, under-17, and under-15 age groups. Body fat percentage (BF%) was calculated with Slaughter equations. Muscular strength assessment included handgrip strength and push-up and sit-up tests. Vertical jumping was examined through CMJ and SJ. Pearson correlations and hierarchical regression analyses were run to analyse the data.
Results. All muscular strength tests showed significant correlations with CMJ and SJ. Handgrip strength was the most substantial predictor for CMJ (r = 0.43, p < 0.01) and SJ (r = 0.44, p < 0.01). However, regression models identified sit-ups (CMJ: β = 0.15, p < 0.01, R^2 = 0.23; SJ: β = 0.16, p < 0.01, R^2 = 0.27) and push-ups (CMJ: β = 0.13, p < 0.01; SJ: β = 0.15, p < 0.01) as significant predictors after controlling for chronological age, body mass, and BF%. In contrast, BF% remained a significant predictor of jumping performance (CMJ: β = –0.43, p < 0.01, R^2 = –0.39; SJ: β = –0.52, p < 0.01, R^2 = –0.52) in the whole hierarchical regression model.
Conclusions. This study reinforces the importance of players' overall physical development, including healthy diet habits, to enhance jumping performance.
Key words: explosive strength, countermovement jump, squat jump, youth, body composition

Introduction

Worldwide, football sports agents and coaches have relied on assessing players' physical attributes in the process of selection and talent identification [1, 2]. From those attributes, lower-body explosive strength has stood out by its strong relationship with sprints and change of direction actions [1, 3].

In the past years, 2 tests have been frequently used to assess lower-body explosive strength: the squat jump (SJ) and the countermovement jump (CMJ). In detail, SJ assesses the ability to rapidly develop force exclu-

Correspondence address: Cíntia França, Universidade da Madeira, 9020-105 Funchal, Portugal,
e-mail: cintia.franca@staff.uma.pt, https://orcid.org/0000-0001-8364-6832

Received: February 9, 2022
Accepted for publication: July 4, 2022

Citation: França C, Marques A, Ihle A, Nuno J, Campos P, Gonçalves F, Martins J, Gouveia ER. Associations between muscular strength and vertical jumping performance in adolescent male football players. Hum Mov. 2023;24(2):94–100; doi: https://doi.org/10.5114/hm.2023.117778.

sively during the concentric movement. In turn, CMJ focuses on the capacity to quickly produce force in stretch-shortening cycle movements [4]. Additionally, both SJ and CMJ can indicate muscular asymmetries or deficits in lower limbs [5]. Thus, these tests have emerged as a reliable and feasible tool in the process of players' monitoring.

Literature has described muscular strength as a critical motor capacity that underpins motor performance [6]. Besides its significant relationship with the individual overall health status regardless of age and clinical condition [7, 8], muscular strength is associated with enhanced force-time characteristics, which influences the performance across a wide range of both general and sport-specific skills [6]. Indeed, research has correlated greater muscular strength with improvement in players' ability to jump, sprint, and change direction [9, 10].

In the literature, sit-up and push-up tests have been broadly used as overall indicators of muscular strength and endurance [11, 12]. Handgrip strength has also been described as a strong predictor of absolute muscular strength and endurance [13]. Globally, sit-ups, push-ups, and handgrip strength are simple, reliable, and low-cost field tests that allow essential insights into the players' physical attributes.

The relationship between muscular strength and vertical jumping has already attracted empirical research. In children, authors reported a significant association between the standing long jump, push-ups, and isometric strength [12]. In a study among college-aged students, a strong correlation was described between handgrip strength and one-repetition maximum leg extension performance [13]. Moreover, previous studies have indicated that muscular strength and jumping ability can discriminate between elite volleyball players and their subelite counterparts [14]. However, data on this topic concerning youth footballers are lacking and may be of importance for the training process regarding the players' overall physical development.

Therefore, this study evaluated the associations between muscular strength tests (push-ups, handgrip, and sit-ups) and vertical jumping performance while controlling for chronological age (CA) and body composition among adolescent male football players.

Material and methods

Participants

A total of 161 male football players from the under-19 (U19), under-17 (U17), and under-15 (U15) age groups participated in this study. Overall, 49 players were U19 (age: 17.8 ± 1.1 years, height: 175.0 ± 6.1 cm, body mass: 68.9 ± 6.6 kg), 61 players were U17 (age: 15.9 ± 0.6 years, height: 172.0 ± 7.3 cm, body mass: 64.4 ± 9.1 kg), and 51 players were U15 (age: 14.0 ± 0.6 years, height: 165.5 ± 9.3 cm, body mass: 56.9 ± 10.5 kg). All participants had more than 5 years of football experience. The U19 group performed 5–6 football practices per week and 2 weekly conditioning training sessions, in accordance with the competition schedule. The U17 and U15 groups took part in 4 football practices and 1 conditioning training session per week. All groups had 1 match per week during the season (from the beginning of October to mid-June). All athletes were competing at the regional level.

The testing occurred in the pre-season during 2 consecutive weeks in the late afternoon. Anthropometric measurements and fitness assessments were performed in a gym. All testing was conducted by the research staff with previous experience in all protocols.

Anthropometric characteristics

For the anthropometric measurements, the participants were barefoot and only wearing shorts. Height was determined to the nearest 0.01 cm with a stadiometer (SECA 213, Hamburg, Germany). Body mass was evaluated to the nearest 0.1 kg with portable scales (SECA 760, Hamburg, Germany). Skinfold thickness was measured to the nearest 0.1 mm at 7 sites (biceps, triceps, subscapular, suprailiac, abdominal, thigh, and calf) by using a skinfold calliper (Harpenden Skinfold Caliper, West Sussex, England). All measurements followed the International Society for the Advancement of Kinanthropometry guidelines. Body fat percentage (BF%) was calculated with Slaughter equations [15].

Muscular strength

Three functional tests were applied to evaluate muscular strength, with a 5-minute recovery time between the assessments. The handgrip protocol consisted of 3 alternated data collection trials for each arm performed with a hand dynamometer (Jamar Plus+, Illinois, USA). The participants were instructed to hold the dynamometer in one hand, laterally to the trunk, with the elbow in a 90° position [16]. From this position, they were to progressively and continuously squeeze the hand dynamometer as hard as possible for about 2 seconds. At no time could the dynamometer contact the subject's body. The recovery time between trials was set at 45 seconds.

The push-up protocol consisted of performing the maximal number of push-ups within 60 seconds [11]. The participants were instructed to start in a plank position, with the elbows in extension and feet slightly apart. The hands should be placed under or slightly to the side of the shoulders, with the fingers facing forward (starting position). The subjects should keep the plank position, bend the elbow slowly, and control forming an approximately 90° angle between the upper arm and forearm (final position). The return to the starting position should also be slow and controlled, until the elbow was fully extended. Any push-up that did not respect this standard was not counted.

Finally, the sit-up protocol consisted of performing the maximal number of repetitions within 30 seconds [17]. The participants were instructed to start in a sitting position, torso vertical, hands behind their neck, knees bent (90°), and feet on the floor. From this position, the subjects were 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 at the moment when 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-body explosive strength and power: CMJ and SJ [5]. Both protocols included 4 data collection trials and were performed in the Optojump Next (Microgate, Bolzano, Italy) system of analysis and measurement. In both tests, the participants were encouraged to jump for maximum height.

In the CMJ protocol, the subjects were directed to perform the CMJ 'as they usually would,' with a quick countermovement to a comfortable depth before exploding upwards to gain maximum height. Hands remained on the hips for the entire movement to eliminate any influence of arm swing [5].

The SJ protocol testing began with the participant in a squat position at a self-selected depth, with approximately 90° of knee flexion, holding this position for researchers' count of 3 before jumping. If a dipping movement of the hips was evident, the trial was repeated [5].

Statistics

Descriptive statistics are presented as means ± standard deviations. The Pearson product-moment correlation coefficients were used to determine the relationship between CA, BF%, body mass, muscular strength, and vertical jumping. The strength of the correlation was evaluated by using Cohen's guidelines as small ($0.1 < r < 0.3$), moderate ($0.3 < r < 0.5$), or large ($0.5 < r < 1.0$) [18]. Hierarchical multiple regression analyses were conducted to investigate the amount of variance in the CMJ and SJ performance that was explained by muscular strength tests (entered in step 3), after controlling for CA (entered in step 1) and body composition (entered in step 2). All analyses were performed with the IBM SPSS Statistics software 26.0 (SPSS Inc., Chicago, USA). Statistical significance of the results was accepted at $p < 0.05$.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Ethics Committee of the Faculty of Human Kinetics, University of Lisbon (approval No.: 34/2021).

Informed consent

Informed consent has been obtained from the legal guardians of all individuals included in this study.

Results

The descriptive statistics of the participants are presented in Table 1 by age group.

The significant results of Pearson product-moment correlation coefficients are presented in Table 2. CA was a significant positive predictor of vertical jumping ($r = 0.44$, $p < 0.01$), and body mass showed the greatest correlation with handgrip strength ($r = 0.60$, $p < 0.01$). BF% displayed the most powerful negative relationship with vertical jumping (CMJ: $r = -0.47$, $p < 0.01$; SJ: $r = -0.57$, $p < 0.01$). All muscular strength tests exhibited significant correlations with CMJ and SJ. Handgrip strength was the most substantial predictor of CMJ height ($r = 0.43$, $p < 0.01$) and SJ height ($r = 0.44$, $p < 0.01$).

Table 3 describes the results of hierarchical multiple regression analyses conducted to investigate the relationships of vertical jumping and muscular strength tests (push-ups, handgrip strength, and sit-ups), after controlling for CA and body composition (body mass and BF%). The model as a whole was able to explain 45% and 52% of the variance observed in CMJ and SJ, respectively. In both CMJ and SJ performance, sit-ups and push-ups remained significant predictors from the

Table 1. Descriptive statistics of male adolescent football players' anthropometry, muscular strength, and vertical jumping tests in accordance with their age groups (n = 161)

Variable	U19 (n = 49)	U17 (n = 61)	U15 (n = 51)
CA (years)	17.8 ± 1.1*	15.9 ± 0.6	14.1 ± 0.6**
Body mass (kg)	68.6 ± 6.6	64.5 ± 9.1**	57.8 ± 10.9
Stature (cm)	175.0 ± 6.0	172.0 ± 7.3	165.6 ± 9.2*
BMI (kg/m^2)	22.4 ± 1.7*	21.8 ± 2.1	21.0 ± 2.9**
Waist circumference (cm)	77.8 ± 4.2*	76.0 ± 5.3	75.3 ± 8.2**
Triceps skinfold (mm)	10.0 ± 3.5*	10.6 ± 3.5**	12.1 ± 5.0
Biceps skinfold (mm)	4.6 ± 1.5**	5.3 ± 2.0**	6.3 ± 3.1**
Subscapular skinfold (mm)	9.9 ± 2.4	9.4 ± 2.7**	9.6 ± 4.3**
Suprailiac skinfold (mm)	10.7 ± 4.0	11.4 ± 5.4**	12.1 ± 6.6**
Abdominal skinfold (mm)	12.0 ± 4.4*	12.6 ± 5.0**	14.7 ± 7.1*
Calf skinfold (mm)	7.9 ± 3.3**	9.9 ± 3.4	12.4 ± 6.1**
BF%	14.1 ± 4.6**	16.0 ± 4.5	19.0 ± 8.0*
CMJ height (cm)	32.5 ± 5.1	29.5 ± 4.1	25.9 ± 5.0
SJ height (cm)	31.8 ± 5.0	29.2 ± 3.9	25.2 ± 5.7
Push-ups (n)	41.4 ± 13.9*	37.2 ± 8.4**	30.0 ± 12.1
Handgrip strength (kg)	37.2 ± 6.6	34.3 ± 6.2	28.6 ± 6.6
Sit-ups (n)	22.8 ± 3.1	22.6 ± 3.4**	22.2 ± 4.7

All values reported as means ± standard deviations.
CA – chronological age, BMI – body mass index, BF% – body fat percentage, CMJ – countermovement jump, SJ – squat jump
* $p < 0.05$, ** $p < 0.01$ according to Kolmogorov-Smirnov normality test

Table 2. Significant correlation coefficients for chronological age, body composition, muscular strength, and vertical jumping in male adolescent football players (n = 161)

Variable	1	2	3	4	5	6	7	8
1. CA		0.47**	–0.27**	0.38**	0.51**		0.44**	0.44**
2. Body mass			0.31**		0.60**		0.25**	0.19*
3. BF%				–0.36**	–0.13**	–0.20**	–0.47**	–0.57**
4. Push-ups					0.29**	0.25**	0.39**	0.44**
5. Handgrip strength						0.19*	0.43**	0.44**
6. Sit-ups							0.30**	0.33**
7. CMJ height								0.92**
8. SJ height								

CA – chronological age, BF% – body fat percentage, CMJ – countermovement jump, SJ – squat jump
* correlation significant at $p < 0.05$, ** correlation significant at $p < 0.01$

Table 3. Summary of hierarchical regression analyses with body composition and muscular strength predicting vertical jump performance among adolescent male football players (n = 161)

Variable	CMJ height			SJ height		
	Model I β	Model II β	Model III β	Model I β	Model II β	Model III β
CA	0.44**	0.12	0.07	0.43**	0.10	0.04
Body mass		0.36**	0.29**		0.34**	0.25**
BF%		–0.53**	–0.43**		–0.64**	–0.52**
Sit-ups			0.15**			0.16**
Handgrip strength			0.09			0.11
Push-ups			0.13*			0.15**
R^2	0.19	0.39	0.45	0.19	0.46	0.52
F for change in R^2	39.727**	27.445**	4.941**	38.631**	43.998**	7.371**

CMJ – countermovement jump, SJ – squat jump, model I – CA, model II – body mass and BF%, model III – sit-ups, handgrip strength, and push-ups, β – standardized beta coefficient, CA – chronological age, BF% – body fat percentage
* $p < 0.05$, ** $p < 0.01$

whole model. Sit-ups were the most significant predictor among the muscular strength tests (CMJ: $\beta = 0.15$, $p < 0.01$, $R^2 = 0.23$; SJ: $\beta = 0.16$, $p < 0.01$, $R^2 = 0.27$). With regard to body composition, BF% was the most powerful predictor of vertical jumping performance (CMJ: $\beta = -0.43$, $p < 0.01$, $R^2 = -0.39$; SJ: $\beta = -0.52$, $p < 0.01$, $R^2 = -0.52$). After introducing body composition and muscular strength tests in the model, CA was no longer a significant predictor of CMJ and SJ height.

Discussion

The purpose of this study was to examine the associations between muscular strength indicators (sit-ups, handgrip strength, and push-ups) and vertical jumping performance (CMJ and SJ), after controlling for significant predictors such as CA and body composition. Our results indicate strong correlations between muscular strength tests and jumping ability. Additionally, the sit-up and push-up tests remained significant predictors of the variance observed in vertical jumping performance after controlling for CA and body composition.

In our study, the correlations showed a significant negative relationship between BF% and vertical jumping tasks. These results are in line with previous research on this topic since BF% has been consistently related with lower performance levels in jumping ability [19, 20]. According to the literature, the detrimental effect of BF% is apparent in tasks requiring projection (jumps), rapid movement (dashes, shuttle runs), and lifting [21]. Indeed, the results of hierarchical regression analyses presented BF% as the most powerful predictor from the final model, explaining 43% and 52% of the variance observed in the CMJ and SJ performance, respectively. These results reinforce the importance of monitoring BF% in youth football, mainly to improve lower-body explosive strength. Thus, multidisciplinary approaches, including healthy nutritional habits, should be promoted by sports agents and coaches as part of the training process.

All muscular strength tests presented significant positive relationships with vertical jumping tests. Handgrip strength displayed the most significant correlation with CMJ and SJ. Overall, the literature advocates a strong linear relationship between handgrip strength and lower-body strength in competitive sports [22]. However, studies have pointed out positive correlations between handgrip strength, BF%, and body mass, reflecting a larger body size [21]. This trend was noticed in this study. Although the handgrip strength showed the most significant linear correlation with vertical jumping tasks, that was not observed after controlling for CA and body composition. Specifically, handgrip strength was not a significant predictor of the whole model in the hierarchical regression analyses, accounting for 9% and 11% of the variance observed in CMJ and SJ, respectively. Previous research on this topic has provided controversial results. Milliken et al. [23] reported significant associations between lower-body explosive strength (one-repetition maximum leg press) and the handgrip test in children. In contrast, minor correlations were found between handgrip strength and jumping performance (CMJ and SJ) among adolescent female handball players [24]. Therefore, although handgrip strength seems to be an important attribute of elite players [22], future research is still needed on its relationship with jumping ability.

Sit-ups and push-ups have been widely used to assess muscular strength and endurance [11]. In this study, both tests presented substantial linear correlations with vertical jumping tasks. In a previous study that aimed to compare the short-term effects of on-field combined core strength and small-sided game training vs. only small-sided game training in football players, the authors reported greater improvements in CMJ and SJ performance in the group that was submitted to the core strength training [25].

After controlling for CA and body composition, both sit-ups and push-ups remained powerful predictors of the hierarchical regression model, particularly the sit-up tests. Indeed, literature has mentioned that a strong central body area may decrease the risk of injury and enhance explosive strength [26]. The results suggest that it is crucial to consider the players' overall physical development, even if the main focus is to improve lower-body explosive strength.

Finally, CA showed a positive linear relationship with vertical jumping, which is in line with previous research on the issue [27]. Growth and biological maturation indicators were not considered in this study. Thus, these results should be interpreted with caution, particularly since there is a dramatic improvement of strength and power in boys aged 14–16 years [2], a range covered in our sample. For that reason, CA was controlled for in the hierarchical regression analyses. Ultimately, after introducing body composition and muscular strength tests in the model, CA lost its strength as a predictor of the CMJ and SJ performance. Therefore, our results underline the trivial contribution of CA as compared with players' body composition and physical attributes, which is in line with previous studies [28–30].

This study presents some limitations, particularly the lack of control for growth and biological maturation variables. Also, specific information regarding the participants' diet habits or drink ingestion was not collected before testing. Nevertheless, it is believed that our results bring crucial practical implications, mainly as data focused on the associations between muscular strength and vertical jumping in youth football are scarce. Both sit-ups and push-ups are reliable, low-cost field tests and constitute powerful predictors of the SJ and CMJ performance, allowing sports agents and coaches important insights into the players' physical attributes. The youth football training process should consider multidisciplinary approaches, including interventions to promote players' overall physical development and healthy diet to avoid the detrimental effect of BF% on sports performance.

Conclusions

In summary, this study concludes that muscular strength tests are significant indicators of vertical jumping performance, even after controlling for important predictors such as CA and body composition. Both sit-ups and push-ups are low-cost field tests and powerful predictors of jumping ability, allowing substantial insights into players' physical attributes. Athletes' monitoring should be part of the youth football training process to assess the efficacy of the implemented programs and identify specific needs to be addressed. Sports agents and coaches should promote strategies focused on players' overall physical development to enhance jumping performance.

Acknowledgements

The authors would like to thank all players and their legal guardians for their participation in this study.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

References

1. Ford P, De Ste Croix M, Lloyd R, Meyers R, Moosavi M, Oliver J, et al. The long-term athlete development model: physiological evidence and application. J Sports Sci. 2011; 29(4):389–402; doi: 10.1080/02640414.2010.536849.
2. Pearson DT, Naughton GA, Torode M. Predictability of physiological testing and the role of maturation in talent identification for adolescent team sports. J Sci Med Sport. 2006;9(4):277–287; doi: 10.1016/j.jsams.2006.05.020.
3. Smirniotou A, Katsikas C, Paradisis G, Argeitaki P, Zacharogiannis E, Tziortzis S. Strength-power parameters as predictors of sprinting performance. J Sports Med Phys Fitness. 2008;48(4):447–454.
4. Wisløff U, Castagna C, Helgerud J, Jones R, Hoff J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. Br J Sports Med. 2004;38(3):285–288; doi: 10.1136/bjsm.2002.002071.
5. McGuigan MR, Doyle TLA, Newton M, Edwards DJ, Nimphius S, Newton RU. Eccentric utilization ratio: effect of sport and phase of training. J Strength Cond Res. 2006;20(4):992–995; doi: 10.1519/R-19165.1.
6. Bosco C, Luhtanen P, Komi PV. A simple method for measurement of mechanical power in jumping. Eur J Appl Physiol Occup Physiol. 1983;50(2):273–282; doi: 10.1007/BF00422166.
7. Suchomel TJ, Nimphius S, Stone MH. The importance of muscular strength in athletic performance. Sports Med. 2016;46(10):1419–1449; doi: 10.1007/s40279-016-0486-0.
8. Ortega FB, Silventoinen K, Tynelius P, Rasmussen F. Muscular strength in male adolescents and premature death: cohort study of one million participants. BMJ. 2012;345:e7279; doi: 10.1136/bmj.e7279.
9. Styles WJ, Matthews MJ, Comfort P. Effects of strength training on squat and sprint performance in soccer players. J Strength Cond Res. 2016;30(6):1534–1539; doi: 10.1519/JSC.0000000000001243.
10. Thomas C, Comfort P, Chiang C-Y, Jones PA. Relationship between isometric mid-thigh pull variables and sprint and change of direction performance in collegiate athletes. J Trainology. 2015;4(1):6–10; doi: 10.17338/trainology.4.1_6.
11. Esco MR, Olson MS, Williford H. Relationship of push-ups and sit-ups tests to selected anthropometric variables and performance results: a multiple regression study. J Strength Cond Res. 2008;22(6):1862–1868; doi: 10.1519/JSC.0b013e318181fd03.
12. Castro-Piñero J, Ortega FB, Artero EG, Girela-Rejón MJ, Mora J, Sjöström M, et al. Assessing muscular strength in youth: usefulness of standing long jump as a general index of muscular fitness. J Strength Cond Res. 2010; 24(7):1810–1817; doi: 10.1519/JSC.0b013e3181ddb03d.
13. Trosclair D, Bellar D, Judge LW, Smith J, Mazerat N, Brignac A. Hand-grip strength as a predictor of muscular strength and endurance. J Strength Cond Res. 2011; 25:S99; doi: 10.1097/01.JSC.0000395736.42557.bc.
14. Gonçalves CA, Lopes TJD, Nunes C, Marinho DA, Neiva HP. Neuromuscular jumping performance and upper-body horizontal power of volleyball players. J Strength Cond Res. 2021;35(8):2236–2241; doi: 10.1519/JSC.0000000000003139.
15. Slaughter MH, Lohman TG, Boileau RA, Horswill CA, Stillman RJ, Van Loan MD, et al. Skinfold equations for estimation of body fatness in children and youth. Hum Biol. 1988;60(5):709–723.

16. Gerodimos V. Reliability of handgrip strength test in basketball players. J Hum Kinet. 2012;31:25–36; doi: 10.2478/v10078-012-0003-y.
17. Conseil de l'Europe. EUROFIT physical fitness tests [in French]. Strasbourg: Conseil de l'Europe; 1990.
18. Cohen J. Statistical power analysis for the behavioral sciences. New York: Lawrence Erlbaum Associates; 1988.
19. Caruso JF, Daily JS, Mason ML, Shepherd CM, McLagan JR, Marshall MR, et al. Anthropometry as a predictor of vertical jump heights derived from an instrumented platform. J Strength Cond Res. 2012;26(1): 284–292; doi: 10.1519/JSC.0b013e31821d97c0.
20. Caia J, Weiss LW, Chiu LZF, Schilling BK, Paquette MR, Relyea GE. Do lower-body dimensions and body composition explain vertical jump ability? J Strength Cond Res. 2016;30(11):3073–3083; doi: 10.1519/JSC.0000000000001406.
21. Malina RM, Bouchard C, Bar-Or O. Growth, maturation, and physical activity. Champaign: Human Kinetics; 2004.
22. Cronin J, Lawton T, Harris N, Kilding A, McMaster DT. A brief review of handgrip strength and sport performance. J Strength Cond Res. 2017;31(11):3187–3217; doi: 10.1519/JSC.0000000000002149.
23. Milliken LA, Faigenbaum AD, Loud RL, Westcott WL. Correlates of upper and lower body muscular strength in children. J Strength Cond Res. 2008;22(4):1339–1346; doi: 10.1519/JSC.0b013e31817393b1.
24. Hammami M, Gaamouri N, Suzuki K, Shephard RJ, Chelly MS. Effects of upper and lower limb plyometric training program on components of physical performance in young female handball players. Front Physiol. 2020;11:1028; doi: 10.3389/fphys.2020.01028.
25. Arslan E, Soylu Y, Clemente FM, Hazir T, Isler AK, Kilit B. Short-term effects of on-field combined core strength and small-sided games training on physical performance in young soccer players. Biol Sport. 2021; 38(4):609–616; doi: 10.5114/biolsport.2021.102865.
26. Afyon YA. Effect of core training on 16 year-old soccer players. Educ Res Rev. 2014;9(23):1275–1279; doi: 10.5897/ERR2014.1876.
27. França C, Gouveia ER, Calderia R, Marques A, Martins J, Lopes H, et al. Predictors of explosive leg power in elite football players. J Phys Educ Sport. 2021;21(6): 3599–3605; doi: 10.7752/jpes.2021.06486.
28. Paul DJ, Gabbett TJ, Nassis GP. Agility in team sports: testing, training and factors affecting performance. Sports Med. 2016;46(3):421–442; doi: 10.1007/s40279-015-0428-2.
29. Faude O, Koch T, Meyer T. Straight sprinting is the most frequent action in goal situations in professional football. J Sports Sci. 2012;30(7):625–631; doi: 10.1080/02640414.2012.665940.
30. Negra Y, Chaabene H, Hammami M, Amara S, Sammoud S, Mkaouer B, et al. Agility in young athletes: is it a different ability from speed and power? J Strength Cond Res. 2017;31(3):727–735; doi: 10.1519/JSC.0000000000001543.