



HAL
open science

Acceleration Capacity and Vertical Jump Performance Relationship in Prepubertal Children

Baptiste Chanel, Nicolas Babault, Carole Cometti

► **To cite this version:**

Baptiste Chanel, Nicolas Babault, Carole Cometti. Acceleration Capacity and Vertical Jump Performance Relationship in Prepubertal Children. Applied Sciences, 2024, 14 (8), pp.3535. 10.3390/app14083535 . hal-04612811

HAL Id: hal-04612811

<https://hal.science/hal-04612811v1>

Submitted on 14 Jun 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

Article

Acceleration Capacity and Vertical Jump Performance Relationship in Prepubertal Children

Baptiste Chanel ^{1,2,*} , Nicolas Babault ^{1,2,*}  and Carole Cometti ^{1,2}

¹ Center for Performance Expertise, Faculty of Sports Sciences, University of Burgundy, F-21000 Dijon, France; carole.cometti@u-bourgogne.fr

² NSERM UMR1093-CAPS, Faculty of Sports Sciences, University of Burgundy, F-21000 Dijon, France

* Correspondence: baptiste.chanel@u-bourgogne.fr (B.C.); nicolas.babault@u-bourgogne.fr (N.B.)

Abstract: Sprint and jump abilities are considered basic skills that are regularly evaluated in training and school contexts. The correlations between these two skills have previously been established in adults and adolescents, but they have not been fully assessed in children. The present study aimed to explore sprinting and jumping ability in prepubertal boys and girls. Thirty-one prepubertal individuals (aged 8–11 years) were assessed during sprinting for different distances (5, 10, and 20 m) and using different vertical and horizontal jump modalities (squat jump, countermovement jump, broad jump, and hop test). Correlations between the different results were tested. Strong correlations were found between vertical jump and sprint performances, especially over short distances. These results suggested that vertical jump tests are more sensitive than horizontal jumps to reveal acceleration capacity in children.

Keywords: youth athlete; training; stretch-shortening cycle

1. Introduction

Physical testing is necessary to identify strengths or weaknesses to build an efficient training periodization. It is also used to monitor training efficiency and to assess fatigue and over-reaching [1,2]. In this way, physical tests are commonly used during childhood in the context of training. Moreover, tests are used in a recreational context, for instance in school physical education programs, to provide information about general fitness levels [3]. Thus, it is still an actual concern to establish normative values for children [4] and to propose test batteries appropriated to this population [5].

These tests should be easy to administer under time constraints. For this reason, most test batteries apply jump and sprint assessments. These two abilities are considered fundamental and determinant in several activities [6,7]. Moreover, jump and sprint performances are used in many federations and institutions for talent identification.

The development of jumping and sprinting performance during growth is well documented. A rapid increase is generally observed from 5 to 14 years of age [8], with a slower increase between 9 and 12 years of age [9] due to the stabilization of central nervous system development [10]. The second rapid increase after 12 years of age is generally attributed to gains in strength and power associated with hypertrophy, observable by an increase in the cross-sectional area [11]. This hypertrophy can be associated with changes in the muscle architecture including lengthening of the fascicle and modifications of the pennation angle. Moreover, an increase in the proportion of fast-twitch fibers is observed during adolescence [11]. It has also been shown that prepubertal children have a reduced efficiency during exercises involving the stretch-shortening cycle [12,13]. Other authors have explained this low efficiency by neural aspects such as inefficient muscle preactivation [14] or a lower stretch reflex control [15]. These deficits in neural capacities induce a suboptimal regulation of the muscle–tendon stiffness during jumps [14]. Moreover, children have a more compliant muscle–tendon system than adults, which may reduce their ability to recoil



Citation: Chanel, B.; Babault, N.; Cometti, C. Acceleration Capacity and Vertical Jump Performance Relationship in Prepubertal Children. *Appl. Sci.* **2024**, *14*, 3535. <https://doi.org/10.3390/app14083535>

Academic Editor: Mark King

Received: 18 March 2024

Revised: 16 April 2024

Accepted: 19 April 2024

Published: 22 April 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

elastic energy [16,17]. It could be principally explained by the greater compliance of the tendons [16], which could imply a lower efficiency in force transmission.

Muscle strength positively influences both sprinting and jumping performance, suggesting a strong relationship between jump and sprint abilities. Such association has already been demonstrated in adults [18,19] and adolescents [20–22]. These correlations are generally attributed to the importance of lower body strength and power output for sprint and jump performances [23]. Some studies have suggested a similar relationship in children. Indeed, several training programs have induced an improvement in both sprint and jump performance [24,25]. Recently, a study showed a correlation between 20 m sprint and horizontal jump performance [26]. Some others have identified a relationship between vertical jump and 30 m sprint performance with 7- to 10-year-old boys [27], and between CMJ and 15 m sprint performance in prepubertal boys [28]. However, to our knowledge, no study has investigated the relationship between jump and short-sprint performance. However, the ability to accelerate over a short distance is important in several activities [29,30].

In adults, some studies dealing with strength capacity and running acceleration or maximal velocity have shown different correlations. Young et al. [31] demonstrated that acceleration was strongly correlated with peak force during a squat jump, corresponding to a concentric contraction. In contrast, the maximal velocity was more strongly correlated with the stretch-shortening cycle and maximal absolute strength. This distinction between acceleration and maximal velocity remains to be explored in children.

Thus, the aim of this study was to investigate the relationship between jumping ability and short-sprint performance in children using different jump modalities. We hypothesized that acceleration would be more strongly correlated with squat jump performance than a countermovement jump, as observed in adults.

2. Materials and Methods

2.1. Participants

This study included 31 participants (10 girls and 21 boys) whose characteristics are summarized in Table 1. Their maturation development was assessed using the Mirwald formula [32]. To be included in this study, the real age of the participant had to be lower than the estimated age of peak height velocity. No participant reported lower limb injuries during the last three months. To ensure homogeneity of training levels, all participants were recruited from the same handball club, where they are engaged in twice-weekly handball training, and an additional weekly match. All are familiar with the jump and sprint exercises, which are introduced after the warm-up of a handball training session. Written consent was obtained from all participants' parents.

Table 1. Participants' characteristics (mean, SD, minimum, and maximum).

	Girls (n = 10)	Boys (n = 21)	Sex Effect <i>p</i>	Cohen's <i>d</i>
Age (years)	9.3 (±0.8) (8.1; 10.9)	9.7 (±0.9) (8.2; 10.9)	0.268	0.452
Height (cm)	136.4 (±8.3) (124.0; 151.5)	139.9 (±7.4) (129.5; 155.0)	0.263	0.457
Body mass (kg)	30.1 (±6.6) (23.5; 45.0)	32.2 (±6.6) (24.0; 49.7)	0.426	0.323
APHV (years)	12.7 (±0.4) (12.0; 13.3)	13.8 (±0.5) (12.9; 14.5)	<0.001 ***	2.578

APHV: estimated age at peak height velocity; ***: significant sex effect.

2.2. Experimental Procedure

The protocol was composed of two sessions. The first session was dedicated to anthropometric measurements and the control of inclusion criteria. The second session started with a standardized warm-up composed of concentric and eccentric submaximal contractions of the knee extensors, knee flexors, and plantar flexors, followed by some athletic drills and several horizontal and vertical jumps [33]. Jump and sprint physical tests described thereafter were then performed.

All participants began with the sprint tests using photoelectric cells (Witty, Microgate, Bolzano, Italy). Two maximal 20 m sprints were performed with intermediate measurements at 5 and 10 m. The two sprints were separated by two minutes of recovery. Volunteers were free to start the sprint when they wanted.

Then, volunteers conducted vertical and horizontal jumps in a randomized order. Vertical jumps were composed of three modalities. The squat jump (SJ) was performed starting from a static semi-squatting position (90° knee angle). The countermovement jump (CMJ) started from a standing position, bending the knee until a 90° knee angle and then extending the knee in one continuous movement. During the SJ and CMJ, their hands were kept on their hips. Finally, the countermovement jump with arms (CMJa) corresponds to the CMJ with the instruction to use their arms during the jump. Volunteers performed two trials per modality. The vertical jump height was evaluated with an Optojump (Optojump; Microgate, Bolzano, Italy). Horizontal jumps were composed of two modalities: the bilateral broad jump and the unilateral hop test. For the broad jump, participants started in a standing position. Firstly, they bent their knees and their hips to a self-selected depth, bringing their arms behind their body. Then, they achieved full extension in a continuous way, with the instruction to go as far as possible [34]. For the hop tests, volunteers were asked to stand on one leg, then to jump horizontally as far as possible, and to land on the same leg [35]. The hop test was performed using the right and left side, without considering the side dominance. For the broad jump and the hop tests, the distance was measured from the toe in the start position to the heel at the landing position [36].

Participants performed two trials for each test with 15 s between each trial and 1 min between jump modalities. Maintaining stability for two seconds was required after landing for acceptance of the jump.

The best performance was retained for the analysis of sprint and jump modalities. For the hop test, no difference was observed between the right and left sides ($p = 0.454$). Accordingly, the average between the right and left sides was used for the analysis.

2.3. Statistics

Statistical analyses were conducted using JASP (version 0.14, JASP TEAM 2020, University of Amsterdam). The normality of the data was tested and confirmed by the Shapiro–Wilk test. Student’s *t*-tests for unpaired samples were used to compare girls and boys for horizontal jump performance, sprint performance, and anthropometric data. A two-way analysis of variance (ANOVA) was then performed on the vertical jump tests to compare girls and boys (sex) and jump modalities (SJ, CMJ, and CMJa). Scheffe post-hoc tests were conducted if significant main effects were present. From the ANOVA, we reported partial eta-squared (η^2) effect sizes with a threshold as follows: 0.01 = small effect, 0.06 = moderate effect, and ≥ 0.14 = large effect. Cohen’s *d* was reported as a measure of the effect size for pairwise comparisons with values <0.5 , 0.5–1.2, and >1.2 representing small, medium, and large effects, respectively. The association between all tests was explored using Pearson’s correlation. All statistical analyses were conducted with a significance level fixed at 0.05.

3. Results

A significant difference was observed between girls and boys for the APHV ($p < 0.001$). No difference was observed for the other anthropometric data (Table 1). Similarly, no significant sex effect was observed in sprint and horizontal jump performance (Table 2).

Table 2. Sprint and jump performance.

	Girls–Boys Mean Values	Girls	Boys	<i>p</i> -Value (Sex Effect)	Mean Difference (95%CI)	<i>d</i>
5 m time (s)	1.38 (±0.11)	1.36 (±0.09)	1.41 (±0.12)	0.360	−0.04 (−1.16; 0.42)	−0.376
10 m time (s)	2.35 (±0.14)	2.46 (±0.34)	2.36 (±0.17)	0.919	0.01 (−0.74; 0.83)	0.042
20 m time (s)	4.13 (±0.23)	4.19 (±0.18)	4.13 (±0.27)	0.318	0.09 (−0.39; 1.20)	0.411
SJ (cm)	19.48 (±2.76)	18.28 (±2.51)	20.22 (±2.71)		−1.95 (−5.19; 1.31)	
CMJ (cm)	19.44 (±2.33)	17.91 (±1.35)	20.39 (±2.33)	<0.001 **	−2.48 (−5.73; 0.78)	0.574
CMJa (cm)	23.49 (±3.40)	21.51 (±1.86)	24.72 (±3.59)		−3.209 (−6.46; 0.05)	
Broad jump (m)	1.31 (±15.06)	1.27 (±0.07)	1.42 (±0.12)	0.115	−0.09 (−1.46; 0.16)	−0.658
Hop test (m)	0.87 (±9.00)	0.85 (±0.06)	0.90 (±0.10)	0.158	−0.05 (−1.45; 0.23)	−0.617

Values are mean (±SD). SJ: squat jump; CMJ: countermovement jump; CMJa: countermovement jump with arms. The 2-way ANOVA revealed a main sex effect for all vertical jumps. For that reason, the main effect is only presented. The significant sex effect is represented by ** ($p < 0.01$).

Vertical jump height was significantly influenced by the modality ($p < 0.001$; $\eta^2 = 0.619$) and by sex ($p < 0.001$; $\eta^2 = 0.263$), but no sex–modality interaction was observed ($p = 0.470$; $\eta^2 = 0.031$). Post-hoc tests indicated that vertical jump height was higher during CMJa compared to CMJ ($p < 0.001$; $d = 1.519$) and SJ ($p < 0.001$; $d = 1.479$). No difference was observed between SJ and CMJ ($p = 0.990$; $d = 0.040$). Sex differences revealed higher vertical jump values for boys compared to girls ($p < 0.001$; $d = 0.574$).

Significant relationships were observed between the three vertical jumps (SJ, CMJ, and CMJa) and all sprinting performances (5 m, 10 m, and 20 m time) (Figure 1; Table S1). No correlation was observed between the broad jump and sprint performance. A significant relationship was observed between the hop test and 20 m time ($p = 0.014$; $r = -0.506$). Significant relationships were also observed between SJ, CMJ, and CMJa. However, the broad jump performance was correlated with CMJ and CMJa performance. In addition to that, CMJa performance was also correlated with the hop test.

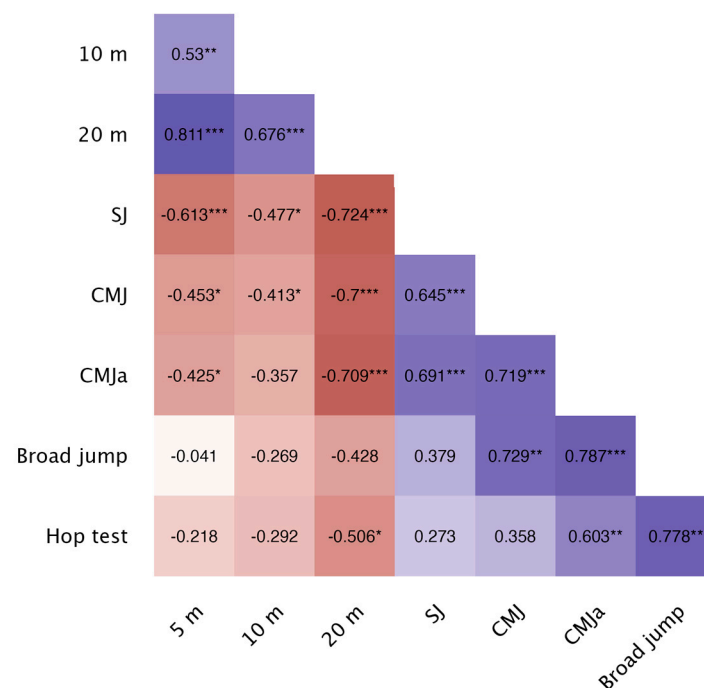


Figure 1. Correlation matrix between the different sprinting and jumping performances. 5 m, 10 m, and 20 m are the sprinting performances over the three different distances; SJ: squat jump; CMJ: countermovement jump; CMJa: countermovement jump with arms. Significant correlations are shown by * ($p < 0.05$), ** ($p < 0.01$), and *** ($p < 0.001$).

4. Discussion

The main aim of this study was to explore the relationships between several vertical and horizontal jump modalities and short-sprint performance in children. Our results revealed that vertical jump was correlated with all sprinting performances. The horizontal jump was only correlated with the 20 m performance. These results partly confirmed our hypothesis.

The difference between the SJ and CMJ performance informs us about children's ability to use the elastic energy stored during the eccentric phase [37]. Thanks to this elastic energy, a better performance is observed during a CMJ than during an SJ for adults [38]. In this study, no difference was observed between the CMJ and SJ performance. This is consistent with previous studies highlighting an inefficient use of the stretch-shortening cycle in children [13]. The ability to efficiently use the stretch-shortening cycle generally increases during growth, in association with some changes in muscle and tendons [16] and neural properties [14,15]. Some studies showed that CMJ performance could be higher than SJ performance for children too [12,39], emphasizing the importance of taking into consideration the training level. A recent study including young gymnast girls showed a significant difference in DJ performance between the regional level and the recreational level, but not between the elite and regional levels [40].

The difference between the CMJa and CMJ performance can be considered a coordination indicator, reflecting the ability to use arm swings to improve jump performance. In this study, a significant difference was observed between CMJ and CMJa values, which is consistent with previous studies [39,41] and confirms the fact that children can enhance their jump performances using their arms.

Relationships between jump performances and sprint performances were explored and some strong correlations were identified. Firstly, all vertical jump modalities (SJ, CMJ, and CMJa) were correlated with the sprint performances (5 m, 10 m, and 20 m). This agrees with previous studies that demonstrated a relationship between vertical jump and 30 m sprint performance in 7- to 10-year-old children [27] and a relationship between CMJ

and 15 m sprint performance [28]. It was expected that the acceleration capacity would be correlated with SJ performance, and the results partially confirmed this hypothesis. As explained previously, SJ and CMJ performances are equal in children; for that reason, it is not possible to differentiate the relation of these two jump modalities with short-sprint performance. But for several reasons, it is reasonable to suppose that an SJ is more representative of one's acceleration capacity.

Indeed, the SJ and short-sprint performance relationship could probably be explained by some similar parameters used to perform these two abilities. The SJ and sprint acceleration phase correspond to a predominantly concentric contraction of the lower limbs [42,43]. Consequently, similar physiological factors could influence SJ and short-sprint performance. Indeed, during these two actions, rapid force production is crucial. The ability to rapidly produce force is influenced by muscle–tendon mechanical properties and neural contributions. Indeed, the tendons' efficiency to transfer muscular force is related to their stiffness. In this way, a positive correlation is identified between tendon stiffness and the rate of force development [44]. With children, a correlation between electromechanical delay (EMD) and tendon stiffness has already been shown [45]. Moreover, an increase in tendon stiffness after a resistance training protocol implies an EMD decrease in prepubertal boys [46]. The ability to rapidly produce force is also influenced by the rate of muscle activation [47]. Mitchell et al. [48] showed a greater rate of torque development associated with a greater rate of muscle activation in children trained in gymnastics than children trained in endurance.

This relationship between sprint and jump abilities in children highlights the importance of lower body strength and power output for these two actions. A recent article [49] has already suggested that inter-individual differences in children's sprint performance could be linked to the ability to produce force, and not to a technical difference. This idea is supported by some studies that have demonstrated the positive effect of strength development on sprint and jump performance. A 6-week strength training program composed of full squats performed twice a week [50] induced sprint and jump performance improvement with under 13-year-old soccer players. It also has been demonstrated that an electromyostimulation protocol training developing strength resulted in an improvement in specific jumps among gymnast prepubertal girls [51].

In contrast, no correlation was observed between horizontal jump and short-sprint performance. Different hypotheses could explain this result. Firstly, different joint contributions between horizontal and vertical jumps could induce different associations with sprinting. Indeed, vertical jumping implies a similar contribution of the hip, knee, and ankle articulation, while horizontal jump performance is mostly determined by hip and ankle action [36]. Considering that the sprint acceleration phase is characterized by greater knee flexion at foot strike and a greater knee extensor contribution [52], this suggests a greater similitude between the acceleration phase's motor pattern and that of vertical jumping, compared with horizontal jumping. Secondly, a low-balance capacity causing a submaximal performance during a horizontal jump is plausible. It could affect the stabilization phase and reduce performance. Indeed, an association between horizontal jump performance and balance capacity has already been shown in children [53,54]. This problem could be accentuated by the technical aspects associated with this jump modality. However, this study noticed a correlation between 20 m sprint time and the hop test performance, as shown by a previous study with 15-year-old adolescents [55]. This could suggest that unilateral jump performance could be more associated with long-sprint performance in children. This hypothesis needs to be explored. However, even if the horizontal jump is commonly used to assess general fitness conditions in children [56] and presents a method that is easily applied in practice without a specific instrument, it is probably not appropriate to assess acceleration capacity in children.

A significant difference between girls and boys was identified in the APHV, which is coherent with previous studies demonstrating earlier development for girls than for boys [32]. A significant sex effect was observed for the vertical jump performances, while no difference between girls and boys was observed for horizontal jump performances.

These results support the idea of a lower sensitivity for horizontal jumps than vertical jumps to reveal performance differences.

5. Conclusions

This study showed a relationship between vertical jumps and short-sprint performance. These results suggest that vertical jump tests are more sensitive than horizontal jump tests to assess lower limb power in prepubertal children and are a better index for short-sprint performance. Our results suggest recommending to trainers and physical education professionals working with children to give priority to vertical jumps in physical evaluations. However, this study included prepubertal children from the same handball group, implying a homogeneous training level and habits. Thus, the results of this study need to be explored in other sports.

Moreover, this relationship between jump and sprint performance in children highlights the importance of lower limb strength in these two actions. In this way, strength needs to be developed to improve sprint and jump abilities in children too. These results support previous studies that recommended introducing neuromuscular training with children to develop fundamental abilities and enhance performance.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app14083535/s1>, Table S1: Results of the Pearson Correlation.

Author Contributions: Conceptualization, B.C., N.B. and C.C.; data collection, B.C.; statistical analysis, B.C.; writing—original draft preparation, B.C.; writing, reviewing, and editing, N.B. and C.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Approval for this study was obtained from the health department of the institution where the study was conducted. The dataset for this study is part of the daily monitoring routine employed at the institution.

Informed Consent Statement: Written informed consent was obtained from all participants.

Data Availability Statement: The data presented are available on request from the corresponding author.

Acknowledgments: We thank the participants for their participation in this study.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Gathercole, R.; Sporer, B.; Stellingwerff, T.; Sleivert, G. Alternative Countermovement-Jump Analysis to Quantify Acute Neuromuscular Fatigue. *Int. J. Sports Physiol. Perform.* **2015**, *10*, 84–92. [[CrossRef](#)] [[PubMed](#)]
2. Fitzpatrick, J.F.; Hicks, K.M.; Russell, M.; Hayes, P.R. The Reliability of Potential Fatigue-Monitoring Measures in Elite Youth Soccer Players. *J. Strength Cond. Res.* **2021**, *35*, 3448–3452. [[CrossRef](#)] [[PubMed](#)]
3. Gómez-Bruton, A.; Marín-Puyalto, J.; Muñoz-Pardos, B.; Lozano-Berges, G.; Cadenas-Sanchez, C.; Matute-Llorente, A.; Gómez-Cabello, A.; Moreno, L.A.; Gonzalez-Agüero, A.; Casajus, J.A.; et al. Association Between Physical Fitness and Bone Strength and Structure in 3- to 5-Year-Old Children. *Sports Health* **2020**, *12*, 431–440. [[CrossRef](#)] [[PubMed](#)]
4. Tomkinson, G.R.; Carver, K.D.; Atkinson, F.; Daniell, N.D.; Lewis, L.K.; Fitzgerald, J.S.; Lang, J.J.; Ortega, F.B. European Normative Values for Physical Fitness in Children and Adolescents Aged 9–17 Years: Results from 2,779,165 Eurofit Performances Representing 30 Countries. *Br. J. Sports Med.* **2018**, *52*, 1445–1456. [[CrossRef](#)] [[PubMed](#)]
5. Ortega, F.B.; Cadenas-Sánchez, C.; Sánchez-Delgado, G.; Mora-González, J.; Martínez-Téllez, B.; Artero, E.G.; Castro-Piñero, J.; Labayen, I.; Chillón, P.; Löf, M.; et al. Systematic Review and Proposal of a Field-Based Physical Fitness-Test Battery in Preschool Children: The PREFIT Battery. *Sports Med.* **2015**, *45*, 533–555. [[CrossRef](#)] [[PubMed](#)]
6. Collins, H.; Booth, J.N.; Duncan, A.; Fawcner, S. The Effect of Resistance Training Interventions on Fundamental Movement Skills in Youth: A Meta-Analysis. *Sports Med. Open* **2019**, *5*, 17. [[CrossRef](#)] [[PubMed](#)]
7. Vaeyens, R.; Malina, R.M.; Janssens, M.; Van Renterghem, B.; Bourgeois, J.; Vrijens, J.; Philippaerts, R.M. A Multidisciplinary Selection Model for Youth Soccer: The Ghent Youth Soccer Project. *Br. J. Sports Med.* **2006**, *40*, 928–934. [[CrossRef](#)] [[PubMed](#)]
8. Viru, A.; Loko, J.; Harro, M.; Volver, A.; Laaneots, L.; Viru, M. Critical Periods in the Development of Performance Capacity During Childhood and Adolescence. *Eur. J. Phys. Educ.* **1999**, *4*, 75–119. [[CrossRef](#)]

9. Philippaerts, R.M.; Vaeyens, R.; Janssens, M.; Van Renterghem, B.; Matthyss, D.; Craen, R.; Bourgois, J.; Vrijens, J.; Beunen, G.; Malina, R.M. The Relationship between Peak Height Velocity and Physical Performance in Youth Soccer Players. *J. Sports Sci.* **2006**, *24*, 221–230. [[CrossRef](#)]
10. Malina, R.M.; Bouchard, C.; Bar-Or, O. *Growth, Maturation, and Physical Activity*; Google Livres; Human Kinetics: Champaign, IL, USA, 2004. Available online: https://books.google.fr/books?hl=fr&lr=&id=VqFcFsykj6EC&oi=fnd&pg=PA1&ots=ykWOLYITD2&sig=Nxo7BD4hyvNaQepQrhkEnrC74Gg&redir_esc=y#v=onepage&q&f=false (accessed on 12 May 2023).
11. Tumkur Anil Kumar, N.; Oliver, J.L.; Lloyd, R.S.; Pedley, J.S.; Radnor, J.M. The Influence of Growth, Maturation and Resistance Training on Muscle-Tendon and Neuromuscular Adaptations: A Narrative Review. *Sports* **2021**, *9*, 59. [[CrossRef](#)]
12. Harrison, A.J.; Gaffney, S. Motor Development and Gender Effects on Stretch-Shortening Cycle Performance. *J. Sci. Med. Sport* **2001**, *4*, 406–415. [[CrossRef](#)] [[PubMed](#)]
13. Radnor, J.M.; Oliver, J.L.; Waugh, C.M.; Myer, G.D.; Moore, I.S.; Lloyd, R.S. The Influence of Growth and Maturation on Stretch-Shortening Cycle Function in Youth. *Sports Med.* **2018**, *48*, 57–71. [[CrossRef](#)] [[PubMed](#)]
14. Lazaridis, S.; Bassa, E.; Patikas, D.; Giakas, G.; Gollhofer, A.; Kotzamanidis, C. Neuromuscular Differences between Prepubescent Boys and Adult Men during Drop Jump. *Eur. J. Appl. Physiol.* **2010**, *110*, 67–74. [[CrossRef](#)] [[PubMed](#)]
15. Oliver, J.L.; Smith, P.M. Neural Control of Leg Stiffness during Hopping in Boys and Men. *J. Electromyogr. Kinesiol.* **2010**, *20*, 973–979. [[CrossRef](#)]
16. Kubo, K.; Kanehisa, H.; Kawakami, Y.; Fukunaga, T. Growth Changes in the Elastic Properties of Human Tendon Structures. *Int. J. Sports Med.* **2001**, *22*, 138–143. [[CrossRef](#)] [[PubMed](#)]
17. Lambertz, D.; Mora, I.; Grosset, J.F.; Pérot, C. Evaluation of Musculotendinous Stiffness in Prepubertal Children and Adults, Taking into Account Muscle Activity. *J. Appl. Physiol.* **2003**, *95*, 64–72. [[CrossRef](#)]
18. 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*, 285–288. [[CrossRef](#)]
19. Dobbs, C.W.; Gill, N.D.; Smart, D.J.; McGuigan, M.R. Relationship between Vertical and Horizontal Jump Variables and Muscular Performance in Athletes. *J. Strength Cond. Res.* **2015**, *29*, 661–671. [[CrossRef](#)]
20. Comfort, P.; Stewart, A.; Bloom, L.; Clarkson, B. Relationships between Strength, Sprint, and Jump Performance in Well-Trained Youth Soccer Players. *J. Strength Cond. Res.* **2014**, *28*, 173–177. [[CrossRef](#)]
21. Hernández-Davo, J.L.; Loturco, I.; Pereira, L.A.; Cesari, R.; Pradesaba, J.; Madruga-Parera, M.; Sanz-Rivas, D.; Fernández-Fernández, J. Relationship between Sprint, Change of Direction, Jump, and Hexagon Test Performance in Young Tennis Players. *J. Sports Sci. Med.* **2021**, *20*, 197–203. [[CrossRef](#)]
22. Krolo, A.; Gilic, B.; Foretic, N.; Pojskic, H.; Hammami, R.; Spasic, M.; Uljevic, O.; Versic, S.; Sekulic, D. Agility Testing in Youth Football (Soccer) Players; Evaluating Reliability, Validity, and Correlates of Newly Developed Testing Protocols. *Int. J. Environ. Res. Public Health* **2020**, *17*, 294. [[CrossRef](#)]
23. Chelly, M.S.; Fathloun, M.; Cherif, N.; Ben Amar, M.; Tabka, Z.; Van Praagh, E. Effects of a Back Squat Training Program on Leg Power, Jump, and Sprint Performances in Junior Soccer Players. *J. Strength Cond. Res.* **2009**, *23*, 2241–2249. [[CrossRef](#)]
24. Diallo, O.; Dore, E.; Duche, P.; Van Praagh, E. Effects of Plyometric Training Followed by a Reduced Training Programme on Physical Performance in Prepubescent Soccer Players. *J. Sports Med. Phys. Fitness* **2001**, *41*, 342–348.
25. Kotzamanidis, C.; Chatzopoulos, D.; Michailidis, C.; Papaiaikovou, G.; Patikas, D. The Effect of a Combined High-Intensity Strength and Speed Training Program on the Running and Jumping Ability of Soccer Players. *J. Strength Cond. Res.* **2005**, *19*, 369–375. [[CrossRef](#)]
26. Mello, J.B.; Preissler, A.A.B.; Schons, P.; Ojeda-Aravena, A.; Hurtado, J.; Paez, J.; Gaya, A. Changes in the Relationship between Sprint and Horizontal Jump Performance According to Sprint Levels in Children and Adolescents. *Int. J. Perform. Anal. Sport.* **2023**, *24*, 90–103. [[CrossRef](#)]
27. Tambalis, K.D.; Panagiotakos, D.B.; Arnaoutis, G.; Sidossis, L.S. Endurance, Explosive Power, and Muscle Strength in Relation to Body Mass Index and Physical Fitness in Greek Children Aged 7–10 Years. *Pediatr. Exerc. Sci.* **2013**, *25*, 394–406. [[CrossRef](#)]
28. Ferrete, C.; Requena, B.; Suarez-Arrones, L.; De Villarreal, E.S. Effect of Strength and High-Intensity Training on Jumping, Sprinting, and Intermittent Endurance Performance in Prepubertal Soccer Players. *J. Strength Cond. Res.* **2014**, *28*, 413–422. [[CrossRef](#)]
29. Kawamori, N.; Nosaka, K.; Newton, R.U. Relationships between Ground Reaction Impulse and Sprint Acceleration Performance in Team Sport Athletes. *J. Strength Cond. Res.* **2013**, *27*, 568–573. [[CrossRef](#)] [[PubMed](#)]
30. Martínez-Valencia, M.A.; Romero-Arenas, S.; Elvira, J.L.L.; González-Ravé, J.M.; Navarro-Valdivielso, F.; Alcaraz, P.E. Effects of Sled Towing on Peak Force, the Rate of Force Development and Sprint Performance During the Acceleration Phase. *J. Hum. Kinet.* **2015**, *46*, 139. [[CrossRef](#)] [[PubMed](#)]
31. Young, W.; Mclean, B.; Ardagna, J. Relationship between Strength Qualities and Sprinting Performance. *J. Sports Med. Phys. Fit.* **1995**, *35*, 13–19.
32. Mirwald, R.L.; Baxter-Jones, A.D.G.; Bailey, D.A.; Beunen, G.P. An Assessment of Maturity from Anthropometric Measurements. *Med. Sci. Sports Exerc.* **2002**, *34*, 689–694. [[CrossRef](#)] [[PubMed](#)]
33. Rumeau, V.; Grospretre, S.; Babault, N. Post-Activation Performance Enhancement and Motor Imagery Are Efficient to Emphasize the Effects of a Standardized Warm-Up on Sprint-Running Performances. *Sports* **2023**, *11*, 108. [[CrossRef](#)]

34. Krishnan, A.; Sharma, D.; Bhatt, M.; Dixit, A.; Pradeep, P. Comparison between Standing Broad Jump Test and Wingate Test for Assessing Lower Limb Anaerobic Power in Elite Sportsmen. *Med. J. Armed Forces India* **2017**, *73*, 140–145. [[CrossRef](#)]
35. Augustsson, J.; Thomeé, R.; Lindén, C.; Folkesson, M.; Tranberg, R.; Karlsson, J. Single-Leg Hop Testing Following Fatiguing Exercise: Reliability and Biomechanical Analysis. *Scand. J. Med. Sci. Sports* **2006**, *16*, 111–120. [[CrossRef](#)] [[PubMed](#)]
36. Kotsifaki, A.; Korakakis, V.; Graham-Smith, P.; Sideris, V.; Whiteley, R. Vertical and Horizontal Hop Performance: Contributions of the Hip, Knee, and Ankle. *Sports Health* **2021**, *13*, 128–135. [[CrossRef](#)] [[PubMed](#)]
37. Komi, P.V.; Bosco, C. Utilization of Stored Elastic Energy in Leg Extensor Muscles by Men and Women. *Med. Sci. Sports* **1978**, *10*, 261–265.
38. Bosco, C.; Komi, P.V.; Ito, A. Prestretch Potentiation of Human Skeletal Muscle during Ballistic Movement. *Acta Physiol. Scand.* **1981**, *111*, 135–140. [[CrossRef](#)]
39. Gerodimos, V.; Zafeiridis, A.; Perkos, S.; Dipla, K.; Manou, V.; Kellis, S. The Contribution of Stretch-Shortening Cycle and Arm-Swing to Vertical Jumping Performance in Children, Adolescents, and Adult Basketball Players. *Pediatr. Exerc. Sci.* **2008**, *20*, 379–389. [[CrossRef](#)]
40. Moeskops, S.; Pedley, J.S.; Oliver, J.L.; Lloyd, R.S. The Influence of Competitive Level on Stretch-Shortening Cycle Function in Young Female Gymnasts. *Sports* **2022**, *10*, 107. [[CrossRef](#)]
41. Gillen, Z.M.; Shoemaker, M.E.; McKay, B.D.; Bohannon, N.A.; Gibson, S.M.; Cramer, J.T. Influences of the Stretch-Shortening Cycle and Arm Swing on Vertical Jump Performance in Children and Adolescents. *J. Strength. Cond. Res.* **2022**, *36*, 1245–1256. [[CrossRef](#)]
42. Mann, R.; Sprague, P. A Kinetic Analysis of the Ground Leg during Sprint Running. *Res. Q. Exerc. Sport.* **1980**, *51*, 334–348. [[CrossRef](#)]
43. Sleivert, G.; Taingahue, M. The Relationship between Maximal Jump-Squat Power and Sprint Acceleration in Athletes. *Eur. J. Appl. Physiol.* **2004**, *91*, 46–52. [[CrossRef](#)] [[PubMed](#)]
44. Bojsen-Møller, J.; Magnusson, S.P.; Rasmussen, L.R.; Kjaer, M.; Aagaard, P. Muscle Performance during Maximal Isometric and Dynamic Contractions Is Influenced by the Stiffness of the Tendinous Structures. *J. Appl. Physiol.* **2005**, *99*, 986–994. [[CrossRef](#)]
45. Waugh, C.M.; Korff, T.; Fath, F.; Blazevich, A.J. Rapid Force Production in Children and Adults: Mechanical and Neural Contributions. *Med. Sci. Sports Exerc.* **2013**, *45*, 762–771. [[CrossRef](#)]
46. Waugh, C.M.; Korff, T.; Fath, F.; Blazevich, A.J. Effects of Resistance Training on Tendon Mechanical Properties and Rapid Force Production in Prepubertal Children. *J. Appl. Physiol.* **2014**, *117*, 257–266. [[CrossRef](#)] [[PubMed](#)]
47. Aagaard, P.; Simonsen, E.B.; Andersen, J.L.; Magnusson, P.; Dyhre-Poulsen, P. Increased Rate of Force Development and Neural Drive of Human Skeletal Muscle Following Resistance Training. *J. Appl. Physiol.* **2002**, *93*, 1318–1326. [[CrossRef](#)] [[PubMed](#)]
48. Mitchell, C.; Cohen, R.; Dotan, R.; Gabriel, D.; Klentrou, P.; Falk, B. Rate of Muscle Activation in Power- and Endurance-Trained Boys. *Int. J. Sports Physiol. Perform.* **2011**, *6*, 94–105. [[CrossRef](#)]
49. Wdowski, M.M.; Noon, M.; Mundy, P.D.; Gittoes, M.J.R.; Duncan, M.J. The Kinematic and Kinetic Development of Sprinting and Countermovement Jump Performance in Boys. *Front. Bioeng. Biotechnol.* **2020**, *8*, 547075. [[CrossRef](#)]
50. Rodríguez-Rosell, D.; Franco-Márquez, F.; Mora-Custodio, R.; González-Badillo, J.J. Effect of High-Speed Strength Training on Physical Performance in Young Soccer Players of Different Ages. *J. Strength Cond. Res.* **2017**, *31*, 2498–2508. [[CrossRef](#)]
51. Deley, G.; Cometti, C.; Fatnassi, A.; Paizis, C.; Babault, N. Effects of Combined Electromyostimulation and Gymnastics Training in Prepubertal Girls. *J. Strength Cond. Res.* **2011**, *25*, 520–526. [[CrossRef](#)]
52. Cronin, J.; Hansen, K.T. Resisted sprint training for the acceleration phase of sprinting. *Strength Cond. J.* **2006**, *28*, 42–51. [[CrossRef](#)]
53. Condon, C.; Cremin, K. Static Balance Norms in Children. *Physiother. Res. Int.* **2014**, *19*, 1–7. [[CrossRef](#)] [[PubMed](#)]
54. Hammami, R.; Chaouachi, A.; Makhlof, I.; Granacher, U.; Behm, D.G. Associations Between Balance and Muscle Strength, Power Performance in Male Youth Athletes of Different Maturity Status. *Pediatr. Exerc. Sci.* **2016**, *28*, 521–534. [[CrossRef](#)] [[PubMed](#)]
55. Pamuk, Ö.; Makaracı, Y.; Ceylan, L.; Küçük, H.; Kızılet, T.; Ceylan, T.; Kaya, E. Associations between Force-Time Related Single-Leg Counter Movement Jump Variables, Agility, and Linear Sprint in Competitive Youth Male Basketball Players. *Children* **2023**, *10*, 427. [[CrossRef](#)]
56. Castro-Piñero, J.; Ortega, F.B.; Artero, E.G.; Girela-Rejón, M.J.; Mora, J.; Sjöström, M.; Ruiz, J.R. Assessing Muscular Strength in Youth: Usefulness of Standing Long Jump as a General Index of Muscular Fitness. *J. Strength Cond. Res.* **2010**, *24*, 1810–1817. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.