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Can sport-specific training affect vertical jumping ability during puberty?

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ABSTRACT: Vertical jumping ability (VJ) is an important component for successful performance in various team sports such as volleyball, basketball, and soccer. There is evidence that the sport-specific training in these sports may affect the development of VJ throughout the developmental years. Thus, the main objective of this study was to investigate the sport-related effect (volleyball, basketball, soccer) on vertical jumping ability (VJ) and on the stretch-shortening cycle (SSC) during puberty. 320 boys (12–15 years old) – 80 basketball players (BP), 80 soccer players (SP), 80 volleyball players (VP) and 80 non-athletes (NA) – participated in the present study. VJ was evaluated by the squat jump (SJ) and countermovement jump (CMJ) tests, and the contribution of SSC was calculated. The SJ and CMJ were significantly higher in VP vs. NA at the age of 12 years old and significantly greater in all sports vs. NA at the age of 13, 14 and 15 years. Furthermore, 15-year-old VP demonstrated significantly higher SJ and CMJ compared with BP and SP ($p<0.01$), whereas no differences were observed between BP and SP ($p>0.05$). Finally, pairwise comparisons revealed non-significant sport- and age-related differences ($p > .05$) in SSC. The pattern of age-related increase in VJ is different between athletes and non-athletes during puberty. Furthermore, sport-specific training adaptations are evident at the age of 15 years old where VP demonstrate greater VJ than BP and SP, while in younger age groups, there are no significant differences in VJ between athletes of different sports.

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INTRODUCTION

Vertical jumping ability is widely used in sports settings as an objective index for the reliable evaluation of lower limb power in young athletes [1–3]. There is also evidence that vertical jumping ability is an essential element in the performance of several fundamental skills in various team sports (e.g. volleyball, basketball and soccer) [2, 4–5]. Many athletic skills such as the rebounding in basketball, the blocking in volleyball as well as the header in soccer require high levels of vertical jumping ability [4, 6–7]. Earlier reports from different Junior World Championships suggested that this parameter tends to differentiate successful from unsuccessful players in these sports. Thus, the evaluation of vertical jumping ability may be used by coaches and athletic trainers for performance enhancement and/or for talent selection.

It is well known that vertical jumping ability, as well as strength and power of lower limbs, increases with chronological age in young athletes (soccer players, basketball players, etc.) and non-athletes during growth and development [8–13]. Structural, neural and metabolic changes of the skeletal muscle that occur during growth and development [14] may contribute to the age-related increases in strength and vertical jumping ability. There is a notion, however, that the pattern of improvement in muscle strength and power may be different when examining populations with different characteristics (e.g. athletes vs. non-athletes or athletes of different sports) [15–17]. Team sports such as volleyball, basketball and soccer require different skills and muscle actions during training and competition [18–19], and thus the development of vertical jumping ability may be different between athletes of these sports. Therefore, it is of interest to investigate the sport-specific effect in the pattern of improvement of vertical jumping ability during puberty.

To the best of our knowledge, there are no reports on the sport-related effect on vertical jumping ability during puberty. Although several studies have examined the effect of sport-specific training on vertical jumping ability in adult male and/or female athletes [7, 20–23], there is limited information in young athletes. The few studies that have examined the sport-related effect on jumping performance of young athletes have been performed in a single age group (11 years old or approximately 15 years old) [6, 24], demonstrating equivocal findings. Furthermore, even though other types of jumps (e.g. standing long jump) differ kinematically from the physiological demands of the team sports such as soccer, basketball and volleyball, there are no reports on the sport-related effect on standing long jump across puberty. It should also be mentioned that previous studies that examined the sport-related effect on standing long jump of young athletes have been performed in a single age group. Taking all the above into consideration, it is of crucial importance to examine the sport-related effect on vertical jumping ability of young athletes across puberty.

Additionally, no study has examined the sport-specific training effect on stretch-shortening cycle (SSC) during growth and development. This is of crucial importance since the capacity of an athlete to store and use elastic energy, in conjunction with some other factors, has been proposed to contribute to the enhancement of jumping performance [25–26]. Therefore, the main objective of this study was to investigate the sport- (volleyball vs. basketball vs. soccer vs. control) and age-related effects (12 vs. 13 vs. 14 vs. 15 years old) on vertical jumping ability as well as on SSC. For the calculation of the stretch-shortening cycle, we calculated the difference between the two jumps, which is a common practice in the literature. The variability in the contribution of SSC to vertical jumping performance within age groups and sports was also investigated. In the present study, in order to diminish the effect of pre-selection, we chose young athletes from three different team sports (volleyball, basketball, soccer) with similar physiological demands in the power of leg extensor muscles.

MATERIALS AND METHODS

Subjects

Three hundred and twenty young boys – 80 basketball players, 80 soccer players, 80 volleyball players and 80 non-athletes – were recruited to participate in the present study. The athletes trained at least three times per week, for more than 12 months. Following completion of a medical history form, the participants (in each sport) were divided according to their chronological age into four equal groups (n=20) aged 12, 13, 14 and 15 years old. Before the initiation

TABLE 1. Physical and training characteristics (Mean ± SD) of the participants per age-group and sport.

Variables	12 year-old	13 year-old	14 year-old	15 year-old
Age (year-old)				
Basketball	11.09 ± 0.01	12.08 ± 0.02	13.09 ± 0.01	14.09 ± 0.01
Soccer	11.08 ± 0.02	12.09 ± 0.01	13.08 ± 0.02	14.08 ± 0.02
Volleyball	11.09 ± 0.01	12.09 ± 0.01	13.09 ± 0.01	14.09 ± 0.01
Control	11.08 ± 0.01	12.08 ± 0.02	13.08 ± 0.01	14.08 ± 0.01
Height (cm)				
Basketball	157.92 ± 8.29	168.20 ± 10.29	177.43 ± 8.67	180.83 ± 10.64
Soccer	148.17 ± 5.67	155.69 ± 8.65	170.10 ± 7.35	170.68 ± 5.68
Volleyball	164.75 ± 9.44	164.00 ± 8.22	173.50 ± 6.10	178.74 ± 6.74
Control	157.10 ± 8.21	162.80 ± 9.91	170.85 ± 6.43	175.15 ± 5.30
Body mass (kg)				
Basketball	51.40 ± 12.12	63.30 ± 17.42	67.15 ± 13.88	73.30 ± 13.18
Soccer	46.58 ± 4.64	52.15 ± 10.16	60.33 ± 7.84	62.60 ± 8.50
Volleyball	54.60 ± 9.66	56.74 ± 10.83	62.42 ± 8.71	66.74 ± 9.18
Control	51.60 ± 10.97	56.50 ± 13.76	64.25 ± 14.32	68.35 ± 12.07
Training experience (years)				
Basketball	3.00 ± 1.40	3.90 ± 1.50	4.20 ± 1.80	4.50 ± 1.80
Soccer	3.30 ± 1.43	4.11 ± 2.00	4.28 ± 1.62	4.70 ± 1.60
Volleyball	2.95 ± 2.00	3.76 ± 1.50	4.10 ± 1.83	4.30 ± 1.33
Control	–	–	–	–
Training frequency (training session/week)				
Basketball	3.90 ± 0.70	4.10 ± 0.50	4.20 ± 2.50	4.70 ± 1.30
Soccer	4.10 ± 1.70	4.26 ± 1.20	4.71 ± 1.22	5.10 ± 1.50
Volleyball	3.70 ± 0.30	4.00 ± 0.60	4.50 ± 1.00	5.00 ± 1.50
Control	–	–	–	–

of the study, the children's parents completed a physical activity questionnaire, as modified by Bar-Or [27]. All participants were healthy and free of any lesion or impairment in the lower limbs. The participants were engaged in conventional basketball, volleyball or soccer training, and did not follow any specific power training programme for the improvement of vertical jumping ability or power of leg extensor muscles. The children's parents were also informed about the experimental procedures and signed an informed consent form. The study was conducted according to the Declaration of Helsinki and ethical approval was granted by the Ethics Committee of the University of Thessaly. The physical and training characteristics of the participants per sport and age group are presented in Table 1.

Procedure

A week before the initiation of the study, the participants were informed about the evaluation procedure, were familiarized with the instrumentation and the testing procedures and were instructed to follow their normal diet and avoid intense exercise activity for 48 h before the testing. On the same day, the body mass and height were measured, using a calibrated physician's scale (Seca, Hamburg, Germany). Following the familiarization session, the participants reported to the laboratory to perform the vertical jump testing. All measures were performed at the same time of the day (10–11 a.m.) to prevent potential confounding effects of daily biorhythms.

Measurements

Prior to testing, the participants performed a standardized 10 min warm-up that included 5 min of stationary cycling and 5 min of dynamic stretching exercises. Thereafter, vertical jumping performance was assessed by squat jump (SJ) and countermovement jump (CMJ) tests using a force-platform (Bertec Corp., Worthington, OH). Before the initiation of the testing, the participants underwent 2–3 familiarization trials to ensure the proper execution technique for the SJ and CMJ. During SJ and CMJ, the participants kept their trunk in an upright position and their hands on the hips. The SJ test started from a semi-squatting position with the knees flexed at 90° that was maintained for 3 s before jumping vertically. No countermovement was allowed during the SJ. For the CMJ, the participants were allowed a downward movement by rapidly bending (at 90°) and extending their knees to jump as high as possible. The selection of a 90° knee angle (semi-squat position) was based on the fact that at this angle the knee is better stabilized during the phase of contact with the ground [1]. To ensure consistency in jumping technique, the 90° knee angle was measured using a goniometer (Gollehon, Lafayette). The main testing protocol consisted of three maximal trials for each type of jump with a rest period of 60 s. The best performance (jump height in cm) was considered for analysis [1].

The difference between the two tests (SJ and CMJ) was calculated using the following equations:

a) % difference: [(CMJ-SJ) ÷ SJ] x 100 and

b) delta scores: CMJ – SJ, respectively [10].

Statistics

The statistical software GPower 3.0 was used for the calculation of the statistical power of the population size of the study. The statistical power in the manuscript for the n size used ranged from 0.85 to 0.94 for all performance parameters. All data are presented as means ± SD and were analysed using SPSS Statistics for Windows, version 18.0 (SPSS Inc., Chicago, Ill., USA). The normality of data was examined using the Kolmogorov-Smirnov test. Two-way analysis of variance (sport: basketball, soccer, volleyball, control x age: 12, 13, 14, 15) (4 x 4) was used to examine the effects of sport and age on squat jump, countermovement jump and on the difference between the two tests. ANOVAs were followed by Tukey's comparisons. The effect sizes were calculated using the following equation: d=difference between means/pooled SD. Furthermore, an analysis

TABLE 2. Squat jump (SJ) and countermovement jump (CMJ) performance (jumping height) in basketball players (n=80), soccer players (n=80), volleyball players (n=80) and in controls (n=80) throughout the developmental years.

Variables SJ (cm)	12 year-old	13 year-old	14 year-old	15 year-old
Basketball	23.84 ± 2.65†	26.73 ± 3.55*†	29.83 ± 3.20*	30.84 ± 1.98*
Soccer	23.50 ± 2.60†	27.45 ± 4.98*†	28.7 ± 2.71*	29.08 ± 3.43*
Volleyball	25.82 ± 4.32*†	27.27 ± 3.16*†	30.85 ± 4.75*§	33.21 ± 2.54*#
Control	21.97 ± 1.79	23.38 ± 0.90	23.33 ± 1.90	26.97 ± 1.98†
CMJ (cm)				
Basketball	25.53 ± 3.34†	29.27 ± 4.53*†	32.78 ± 3.43*	33.26 ± 2.43*
Soccer	25.18 ± 2.70†	30.78 ± 5.59*†	32.54 ± 4.10*	32.21 ± 3.23*
Volleyball	28.10 ± 4.14*†	30.30 ± 3.69*†	34.39 ± 5.24*	35.76 ± 2.94*#
Control	23.69 ± 2.42	25.20 ± 2.27	25.84 ± 1.85	29.51 ± 2.71†

*p<0.05 vs. controls; #p<0.05 vs. basketball and soccer players; †p<0.05 vs. all other age-groups within the sport; §p<0.05 vs. 15 year-old children within the sport.

of covariance (ANCOVA), using the variables "age" and "training experience" as covariates, was conducted to examine the sport-related differences in squat jump, in countermovement jump and in relative (% difference) and absolute (delta score) difference between the two tests. The variability in the difference between the two tests within age groups and sports was assessed by the coefficient of variation: CV (%) = (SD ÷ mean) x 100. The level of significance for all statistical analyses was set at $p < 0.05$.

RESULTS

Jumping performance

Squat jump (SJ) and counter movement jump (CMJ) performance in young athletes (basketball, soccer and volleyball players) and non-athletes is presented in Table 2. A significant "sport × age" interaction effect was observed on SJ ($F_{9,304}=2.62$; $p<0.01$) and on CMJ ($F_{9,304}=2.41$; $p<0.05$). Post-hoc comparisons between sports revealed that SJ and CMJ values were significantly higher in volleyball players vs. controls at the age of 12 years old ($p<0.01$; $d=2.50$), whereas no significant differences in SJ and CMJ were observed among basketball players, soccer players and controls ($p>0.05$). In 13- and 14-year-old children, SJ and CMJ values were significantly higher in athletes (basketball, soccer and volleyball players) vs. controls ($p<0.01$; $d=0.81$–2.74); however, no significant differences were observed among different sports ($p>0.05$). Furthermore, 15-year-old basketball, soccer and volleyball players exhibited higher SJ and CMJ values than their control peers ($p<0.01$; $d=0.78$–2.76), and 15-year-old volleyball players demonstrated significantly higher values compared with basketball and soccer players ($p<0.01$; $d=0.93$–1.38), whereas no differences were observed between basketball and soccer players ($p>0.05$).

Pair-wise comparisons within age revealed that SJ and CMJ performance increased with age in basketball, soccer and volleyball players ($p<0.01$–$p<0.05$; $d=0.81$–3.02), with the exceptions of 14- vs. 15-year-old children, who did not differ in SJ and CMJ performance. Within the control group, 15-year-old children exhibited higher SJ ($p<0.01$; $d=1.88$–2.65) and CMJ values ($p<0.01$; $d=1.60$–2.27) compared with the other age groups, while no differences were observed among 12-, 13- and 14-year-old untrained children ($p>0.05$).

Furthermore, ANCOVAs demonstrated statistically significant differences in SJ and CMJ among volleyball players, basketball players, soccer players and controls when adjusted for age and training experience ($p<0.01$). Pairwise comparisons between sports revealed that SJ and CMJ values were significantly higher in basketball, soccer and volleyball players vs. controls ($p<0.01$) and in volleyball players vs. basketball and soccer players ($p<0.01$), whereas no differences were observed between basketball and soccer players ($p>0.05$).

Difference between the two tests

ANOVAs indicated no significant main effects of "sport", "age" or "sport × age" interactions on the absolute (delta scores) and relative difference (% difference) between the two tests. The Tukey comparisons revealed no significant differences ($p>0.05$) among different sports (basketball, soccer, volleyball, control) and different age groups (12, 13, 14, and 15 years old) (Table 3). Additionally, ANCOVAs demonstrated that there are still no statistically significant differences in the absolute and relative difference between the two tests among volleyball players, basketball players, soccer players and controls when adjusted for age and training experience ($p>0.05$).

Variability of the indices used for the evaluation of the difference between the two tests

The coefficients of variation and the individual values for the difference between the two tests (% difference) in different sports and age groups are presented in Figure 1. Athletes (basketball, soccer and volleyball players) showed lower variability in the difference between the two tests than their control peers (74.80% in basketball, 79.06%

TABLE 3. The relative (% difference) and the absolute (delta scores) difference between the two jumps in basketball players (n = 80), soccer players (n = 80), volleyball players (n = 80), and in controls (n = 80). Values are means ± SD.

Variables	12 year-old	13 year-old	14 year-old	15 year-old
% Difference				
Basketball	7.08 ± 6.70	9.44 ± 8.65	10.08 ± 5.48	7.86 ± 4.08
Soccer	7.45 ± 6.99	12.36 ± 8.54	13.52 ± 11.51	11.13 ± 6.52
Volleyball	9.49 ± 7.22	11.16 ± 5.28	11.77 ± 5.98	7.77 ± 6.03
Control	7.90 ± 7.32	7.91 ± 10.17	11.12 ± 7.93	9.50 ± 7.22
Delta scores				
Basketball	1.69 ± 1.66	2.54 ± 2.30	2.96 ± 1.59	2.42 ± 1.27
Soccer	1.69 ± 1.55	3.33 ± 2.18	3.84 ± 3.23	3.13 ± 1.77
Volleyball	2.28 ± 1.53	3.03 ± 1.44	3.54 ± 1.85	2.55 ± 1.95
Control	1.73 ± 1.62	1.82 ± 2.38	2.52 ± 1.70	2.55 ± 1.92

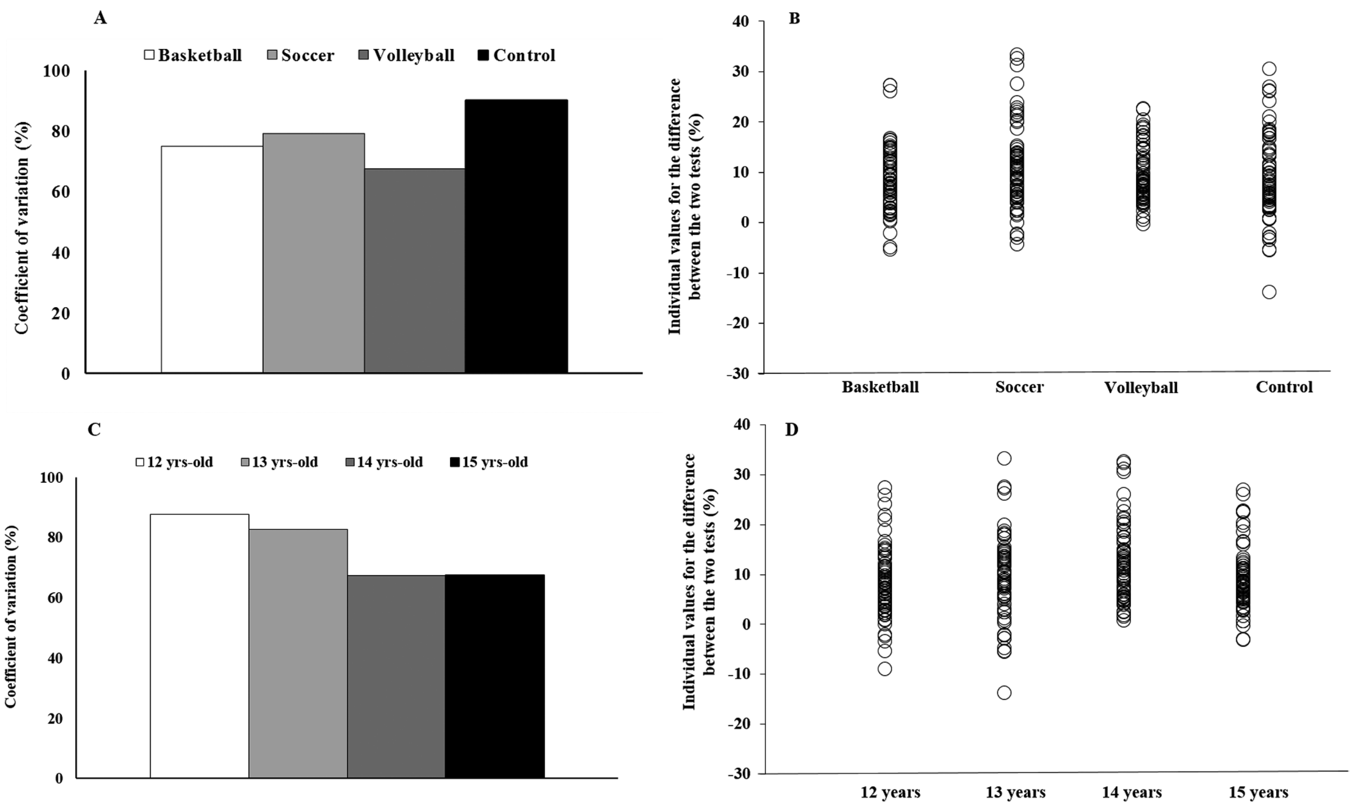

FIG. 1. Coefficients of variation of the difference between the two tests in different sports (A) and age groups (C), and the individual values for the difference between the two tests (% difference) in different sports (B) and age groups (D).

in soccer, 67.27% in volleyball vs. 90.01% in control). Furthermore, volleyball players demonstrated lower variability in the difference between the two tests compared with basketball and soccer players (67.27% in volleyball vs. 74.80% in basketball and 79.06% in soccer). Additionally, the variability in the difference between the two tests gradually decreased from 12- to 15-year-old children (87.59%, 82.66%, 67.4% and 67.4%).

DISCUSSION

The novel aspect of this study is that it examined the sport- and age-related differences in vertical jumping ability and in the stretch-shortening cycle (SSC) during puberty. Furthermore, it examined the variability in the contribution of SSC in young volleyball, basketball and soccer players as well as in control peers during puberty. The main findings of this study were that: a) young athletes aged 13 to 15 years demonstrated greater vertical jumping ability than non-athletes, b) vertical jumping ability was similar between volleyball, basketball and soccer players until the age of 14, whereas it was higher in volleyball players than in basketball and soccer players at the age of 15 years, c) athletes exhibited a different pattern in the age-related increase in vertical jumping ability than non-athletes, d) the contribution of SSC did not change with age and sport-specific training and e) the variability in the contribution of SSC is affected by age and sport-specific training.

Vertical jumping ability is an important parameter for succeeding in different sports and leisure activities. Several factors such as age, sex, physical activity, training experience and sport-specific training may affect the development of vertical jumping ability during growth and development [6, 9–10, 13, 24]. The gradually increasing values in vertical jumping ability with age observed in this study are in accordance with previous reports demonstrating an age-related increase in vertical jumping ability in trained and untrained boys during growth and development [9–10, 13]. Structural, neural and metabolic changes that occur during growth and development may affect the excitability, the neuromuscular activation and the contractile properties of the skeletal muscles [14, 28], the musculotendinous stiffness [29], the ability to store and use elastic energy, the stretch reflex potentiation [30], as well as the movement coordination [31] and control [32]. All the above changes that occur to the skeletal muscles in conjunction with changes in the technique of vertical jumps during the developmental years may have contributed to the age-related increases in vertical jumping ability [29].

There is a notion that the pattern of improvement in muscle strength and power of lower and upper limbs may be different between athletes and non-athletes across puberty. Camic et al. [15], Gerodimos et al. [16] and Mafulli et al. [17] showed that isometric strength, isokinetic strength and/or power of lower or upper limbs were similar between athletes and non-athletes until the age of 14 years old, whereas they were significantly higher in athletes at late puberty and adulthood, implying that there is an interaction between biological development and training responses. The pattern of improvement in vertical jumping ability between athletes and non-athletes has not been adequately examined throughout the developmental years. According to the results of the present study, VJ was similar between athletes and non-athletes (except for volleyball players vs. non-athletes) at the age of 12 years old, whereas it was significantly greater in athletes (basketball, soccer and volleyball players) vs. non-athletes at older age groups (13–15 years old). Furthermore, comparisons within age revealed that VJ increased with age (from 12 to 14 years old) in athletes (basketball, soccer and volleyball players), while in non-athletes, only 15-year-old children exhibited significantly higher VJ values compared with younger age groups. The mechanisms by which the mechanical stress imposed by sport participation (volleyball, basketball, soccer) resulted in greater adaptations in VJ cannot be directly answered by this study. Previous studies reported that during growth and development (especially during adolescence), testosterone, growth hormone and insulin growth factors result in skeletal muscle growth that may be influenced by exercise training [14], affecting therefore the VJ performance. Furthermore, increases in motor skill coordination and the development of technique during vertical jumps that arise in response to sport-specific training could also contribute to the higher adaptations in VJ observed during puberty in athletes vs. non-athletes.

The few studies that have investigated the effect of sport-specific training in jumping performance of young athletes demonstrated ambivalent findings [6, 24]. The equivocal findings among studies may be attributed to the chronological age and the training experience of the participants. Bencke et al. [24] compared the vertical jumping ability among young swimmers, tennis players, handball players and athletes of gymnastics aged 11 years, reporting no significant differences in SJ and CMJ. Meanwhile, Battaglia et al. [6], who compared the vertical jumping ability among young volleyball players, basketball players and non-athletes, reported higher jumping performance (not statistically significant) in young female volleyball players than in basketball players and aged-matched controls. In the same context, in the present study VJ was similar in basketball, volleyball and soccer players in the younger age groups, while 15-year-old volleyball players exhibited significantly greater VJ than basketball and soccer players. Furthermore, previous studies which have been conducted in adults males or females reported higher VJ values in volleyball players compared to basketball and/or soccer players [7, 20–22]. It appears that from the age of 15 years and later, when the sport-specific training adaptations are evident, jumping performance is greater in volleyball than in basketball and soccer players. This difference is explained by the sport-specific training stimulus exerted in these team sports (volleyball, basketball and soccer) and the physiological attributes that potentially affect the development of vertical jumping ability. Soccer and basketball players cover longer distances and perform a greater variety of movements (sprint, running, sudden change of direction, etc.) during training and competition than volleyball players, who are moving in a much smaller area and perform short and high-intensity movements and a greater number of jumps [18–19]. For example, previous studies reported that basketball players perform on average approximately 44 jumps per game [18], whereas volleyball players perform on average approximately 75 jumps per game [19].

Our results showed no sport- or age-related differences in the contribution of the stretch-shortening cycle. For the determination of the stretch-shortening cycle, we calculated the difference between the two jumps, which is a common practice in the literature. However, there is evidence in the literature that, apart from the stretch-shortening cycle and the elastic energy store and release, the difference between SJ and CMJ is influenced by some other factors, such as the lower motor unit-firing rate in SJ due to the pre-activation phase, the motor skill coordination and the development of technique. These findings support previous results showing no significant age effect in the contribution of the stretch-shortening cycle [10, 13, 33]. Meanwhile, Bosco and Komi [26] reported that the ability to use the stretch-shortening cycle is affected by the aging process. However, it should be mentioned that the above study [26] based its conclusions only on descriptive statistics, something that could influence the results of the study. Although there are no significant age- or sport-related differences in the contribution of SSC, the variability in the contribution of SSC was different between age- and sports-groups. Indeed, the variability in the contribution of SSC gradually decreased with age (87.59% at 12 years old, 82.66% at 13 years old, 67.4% at 14 years old and 67.4% at 15 years old). The gradual reduction of variability in the contribution of SSC with age in this and previous studies [10, 33] is in line with earlier reports suggesting that a process of motor development with age is characterized by reductions in the variability of VJ kinematics and supports the concept that the acquaintance of specialized movement skill is dependent on age, experience and practice [34]. We also found that non-athletes showed greater variability in the contribution of SSC than athletes (74.80% in basketball, 79.06% in soccer, 67.27% in volleyball vs. 90.01% in non-athletes). To the best of our knowledge, no previous study has compared the variability in the contribution of SSC between athletes of different sports; thus comparisons with the results of the present study are not possible.

CONCLUSIONS

In conclusion, the data presented in this study serve to provide a wide profile of vertical jumping ability in young volleyball, basketball and soccer players to assist both coaches and athletic trainers to make appropriate professional decisions regarding performance enhancement. The vertical jumping ability exhibited a different pattern of increase between athletes and non-athletes. Furthermore, the adaptations of sport-specific training in vertical jumping ability are evident at the age of 15 years old, when volleyball players demonstrated greater VJ than soccer and basketball players, while in younger age groups the VJ was similar between athletes of different sports. The contribution of SSC was not affected by age or sport-specific training. Finally, the variability in the contribution of SSC is higher in younger (12 and 13 years old) age groups than in older age groups (14 and 15 years old) as well as in non-athletes than in athletes.

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Conflict of interest:

The authors declare no conflict of interest.

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