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ORIGINAL ARTICLE
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Who jumps the highest? Anthropometric and physiological correlations of vertical jump in youth elite female volleyball players

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ABSTRACT

BACKGROUND: The aim of the present study was to examine the relationship of vertical jump (Abalakov jump [AJ]) with anthropometric and physiological parameters in youth elite female volleyball players.

METHODS: Seventy-two selected volleyball players from the region of Athens (age 13.3±0.7 years, body mass 62.0±7.2 kg, height 171.5±5.7 cm, body fat 21.2±4.5%), classified into quartiles according to AJ performance (group A, 21.4-26.5 cm; group B, 26.8-29.9 cm; group C, 30.5-33.7 cm; group D, 33.8-45.9 cm), performed a series of physical fitness tests.

RESULTS: AJ was correlated with anthropometric (age at peak height velocity [APHV]: r=0.38, P<0.001; body mass: r=-0.43, P<0.001; Body Mass Index [BMI]: r=-0.37, P<0.001; body fat percentage [BF]: r=-0.64, P<0.001) and physiological parameters (isometric strength: r=0.50, P<0.001; squat jump [SJ]: r=0.92, P<0.001; countermovement jump [CMJ]: r=0.95, P<0.001, Bosco Test: r=0.70, P<0.001; mean power [P_{mean}]: r=0.61, P<0.001; Fatigue Index: r=-0.33, P=0.005) in the Wingate Anaerobic Test (WAnT). A one-way analysis of variance showed significant differences in APHV, chronological age, body mass, BMI, BF, aerobic capacity (step test and physical working capacity at heart rate 170 bpm), P_{mean} in the WAnT, isometric strength, SJ, CMJ and 30-s Bosco Test (P<0.05). A Bonferroni *post-hoc* analysis revealed that group D had older APHV and lower BMI, better aerobic capacity, isometric strength, SJ, CMJ, performance in the Bosco Test, and P_{mean} in the WAnT, was older and lighter than groups A, B, and C (P<0.05).

CONCLUSIONS: Both the findings of the comparison among groups differing for AJ and the correlation analysis highlighted the negative role of excess body mass and fat, and the positive role of muscle strength and power on AJ. Also, there was indication that volleyball players that jumped the highest were those who matured later than others.

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Women's volleyball is a very popular team sport, in which successful performance depends on a combination of anthropometric, physiological, socio-psychological and tactical-technical parameters.[1, 2] Vertical jump (VJ) occupies a dominant place among the physiological parameters usually used as selection criteria in talent identification and selection processes.[3] Recently, it has been shown that VJ discriminates female volleyball players from non-athletes [4] and from athletes of other sport disciplines.[5, 6] Moreover, volleyball players competing at a higher level jump higher than lower level players (*e.g*. university *versus* high-school,[7] national *versus* regional level,[8] comparison among different divisions in Slovenia,[9] Greece [10] and Taiwan,[11] comparison among teams differing for ranking in Olympic games).[12] There is also an effect of playing specialization on VJ performance.[13, 14] Therefore, being aware of correlates of VJ is of great practical importance for volleyball coaches and fitness trainers.

Previous studies have identified particular anthropometric and physiological parameters as correlates of jumping performance. Studies comparing jumping performance of groups differing for age, observed better performance in adult than in adolescent volleyball players and in older adolescents when compared to their younger counterparts.[14-16] Moreover, the negative role of anthropometric parameters such as body mass (BM) and body fat percentage (BF) for jumping performance has been demonstrated.[15] In addition to anthropometric parameters, correlations of jumping performance with muscle strength have also been observed.[6, 9, 17, 18]

Although the abovementioned studies have enhanced our understanding of correlates of jumping performance, some potentially important issues have not been addressed yet. Talent identification is usually undertaken in periods of life when growth and development are occurring very dynamically;[3] thus, the role of biological maturity for jumping performance should be investigated. Biological maturity refers mostly to the age at which peak height velocity (APHV) occurs, and biological age considers the difference (ΔAPHV) between the actual chronological age (CA) and APHV.[19] Notwithstanding, a review on anthropometric and physiological characteristics of adolescent volleyball players has highlighted the lack of information on biological age.[2] Moreover, to the best of our knowledge no research has ever profiled selected adolescent volleyball players with high jumping performance.

Therefore, the aim of the present study was twofold: 1) to evaluate the relationship of VJ with anthropometric and physiological characteristics, including biological age, and 2) to examine the profile of volleyball players with high jumping ability with regards to their counterparts with lower ability.

Materials and methods

A cross-sectional design was used to examine the relationship of vertical jump with anthropometric and physiological parameters in youth elite female volleyball players. To accomplish this aim, 72 volleyball players from teams of the region of Athens were measured in the context of the physical fitness assessment of candidates who had been selected by the volleyball federation for the national team of Greece (Table I). Testing procedures were carried during the preparative period of seasons 2014-2015 and 2015-2016, respectively. The participants were familiar with the testing procedures, because the fitness battery was routinely administered to these teams in the past. They visited the laboratory, where they were examined for anthropometric characteristics (BM, height, sitting height, Body Mass Index [BMI], BF), sit-and-reach test (SAR), isometric muscle strength, physical working capacity at heart rate (HR) 170 beats per minute (bpm), 3-minute step test, single (squat jump [SJ], countermovement

TABLE I.—*Anthropometric characteristics of volleyball players according to jumping performance.*

	Total (N.=72)	Group A (N.=17)	Group B (N.=18)	Group C (N.=19)	Group D (N.=18)
CA (years)	13.3±0.7	13.1±0.8 ^{D}	13.2±0.7	13.4±0.7	13.7±0.5 ^{A}
APHV (years)	11.4±0.5	11.2±0.4 ^{D}	11.3±0.4 ^{D}	11.6±0.5	11.7±0.4 $^{A, B}$
ΔAPHV (years)	1.9±0.5	1.8±0.7	1.9±0.3	1.8±0.5	2.0±0.5
BM (kg)	62.0±7.2	64.9±7.4	65.1±7.0 ^{D}	59.6±6.6	58.7±5.8 ^{B}
Height (cm)	171.5±5.7	172.8±7.5	172.1±4.0	170.0±5.2	171.3±5.6
BMI (kg/m^2)	21.1±2.2	21.8±2.5	22.0±2.3 ^{D}	20.6±1.8	20.0±1.8 ^{B}
BF (%)	21.2±4.5	23.7±4.2 ^{D}	23.5±3.8 ^{D}	20.3±3.2	17.3±4.0 $^{A, B}$

Values are presented as mean±SD. Volleyball players were grouped by performance in the Abalakov jump.
CA: chronological age; APHV: age at peak height velocity; ΔAPHV: difference between CA and APHV; BM: body mass; BMI: Body Mass Index; BF: body fat percentage.
Superscript letters A, B, C, and D indicate significant difference from the corresponding group at $P<0.05$.

jump [CMJ], and Abalakov jump [AJ]) and continuous (30-second Bosco Test) jumping tests and the Wingate anaerobic test (WAnT), under standard environmental conditions (temperature: 22-24 °C, humidity: 50-54%). The study was carried out according to the ethical standards of Declaration of Helsinki of the World Medical Association in 1964 as it was modified in 2013 and approved by the local institutional review board. Informed consent was provided by all players and their parents.

Protocols and equipment

All participants followed the same procedures. First, the participants were examined for anthropometric characteristics and flexibility. Then, a standardized warm-up session, consisting of 12-minute submaximal aerobic exercise (cycling and step, *i.e.* the two submaximal tests of aerobic capacity) and 10-minute static stretching, was administered. After the warm-up, the participants were tested for isometric muscle strength, jumping tests and the WAnT.

Anthropometry. We used an electronic body mass scale (HD-351 Tanita, Arlington Heights, IL, USA) and a portable stadiometer (SECA, Leicester, UK) to measure BM to the nearest 0.1 kg and stature to the nearest 1 mm with participants being barefoot and in minimal clothing, respectively. These measurements were used to calculate BMI as the quotient of body mass (kg) to stature squared (m^2). In addition to standing height, sitting height was measured, too. Body fat percentage was calculated from the sum of 10 skinfolds,[20] which were taken with a skinfold caliper (Harpenden, West Sussex, UK). Chronological age (CA) for each participant was calculated using a table of decimals of year.[21] Peak height velocity (PHV), which reflects the maximum velocity in growth of height, was used as an indicator of biological maturity. APHV was predicted by equation taking into account sex, date of birth, date of measurement, height, sitting height and body mass,[19] and difference (ΔAPHV) between CA and APHV was used as a measure of biological age.

Aerobic capacity

HR was recorded continuously during all testing sessions by Team2 Pro (Polar Electro Oy, Kempele, Finland). Physical working capacity in HR 170 bpm/min (PWC_{170}) was measured according to the Eurofit guidelines [22] on a cycle ergometer (828 Ergomedic, Monark, Sweden). Seat height was adjusted to each participant's satisfaction, and toe clips with straps were used to prevent the feet from slipping off the pedals. We instructed participants before the test to pedal with a steady cadence of 60 revolutions per minute, which was given by both visual (ergometer's screen showing pedaling cadence) and audio means (metronome set at 60 bpm). Three stages, each lasting 3 min, against incremental braking force in order to elicit HR between 120 and 170 bpm, were performed. Based on the linear relationship between HR and power output, PWC_{170} was calculated as the power corresponding to HR 170 bpm and expressed as W and W/kg. Step test was performed on a 30-cm-high step for 3 minutes using a 24-ascent/min cadence.[23] HR was recorded in the end of this test ($Step_{ex}$) as well as in the end of the first minute of recovery ($Step_{rec}$).

Neuromuscular fitness tests

The SAR protocol assessed low back and hamstring flexibility.[24] An advantage of 15 cm was set at the position of just reaching the toes. Two trials were performed and the best was recorded. In the handgrip muscle strength test, the participants were asked to stand with their elbow bent at approximately 90° and instructed to squeeze the handle of the handgrip dynamometer (Takei, Tokyo, Japan) as hard as possible for 5 seconds. This test was administered twice for each hand. Right (RH) and left handgrip muscle strength (LH) were calculated as the best effort for right and left hand, respectively, and were expressed in absolute (kg). In addition, two isometric tests were performed with a back strength dynamometer (Takei); in the first test (the back strength test), their legs and backs were straightened to allow the bar to be at the level of the patella, while in the second test (combined back-and-leg test), the chain length on the dynamometer was adjusted so that the participants squatted over the dynamometer with their knees flexed at approximately 30°.[25] Total isometric strength was calculated as the sum of the four measures — RH, LH, back strength and combined back-and-leg — and was expressed in absolute (kg) and in relative values (kg/kg of body mass).

Single and continuous jumping tests

The participants performed two trials for each single jumping exercise and the best result was recorded.[26] Height of each jump was estimated using the Optojump (Microgate Engineering, Bolzano, Italy) [27] and was expressed in cm. The Bosco test was conducted on the same equipment as the abovementioned jump tests. The participants were instructed to jump as high as possible for 30 s, while trying to retain short ground contact times.[28] They were also requested to keep their hands on their waist throughout the test. The mean power during the 30-s test was recorded in W/kg.

Wingate anaerobic test (WAnT)

The WAnT was performed on a cycle ergometer (Ergomedics 874, Monark, Sweden).[29] Briefly, participants were asked to pedal as fast as possible for 30 s against a braking force that was determined by the product of body mass in kg by 0.075. Peak power (P_{peak}) was estimated as the average power over a 5-s period with the highest performance, which occurs usually in the first 5 s of the test. Mean power (P_{mean}) was calculated as the average power during the 30-s period. Both P_{peak} and P_{mean} were expressed as W and W/kg. Fatigue index (FI) was calculated as:

$$100 \times (P_{peak} - \text{minimal power})/P_{peak}.$$

Although we acknowledged that FI was less reliable index than P_{peak} and P_{mean},[29] we included it in the analysis according to the protocol of the WAnT.

Statistical analysis

Statistical analyses were performed using SPSS v. 20.0 (IBM Corp., Chicago, IL, USA). Data were expressed as mean and standard deviations of the mean (SD). The variability of data was described using 90% confidence intervals (CI).[30] The participants were classified into quartiles according to AJ performance (group A, 21.4-26.5 cm; group B, 26.8-29.9 cm; group C, 30.5-33.7 cm; group D, 33.8-45.9 cm). Compared to the other two single jumps (SJ and CMJ), AJ was used as a descriptor of VJ, because it included the arm-swing which was more sport-specific. One-way analysis of variance (ANOVA) with a subsequent Bonferroni *post-hoc* test (if difference among the groups was revealed) was used to examine differences in physical and physiological characteristics among the four AJ groups. To interpret the effect size for statistical differences in the ANOVA we used eta-squared classified as small ($0.01<\eta^2\leq0.06$), medium ($0.06<\eta^2\leq0.14$) and large ($\eta^2>0.14$). The Pearson product-moment correlation coefficient (*r*) examined the relationship of AJ with all parameters. The magnitude of r was considered as trivial ($r<0.1$), small ($0.1\leq r<0.3$), moderate ($0.3\leq r<0.5$), large ($0.5\leq r<0.7$), very large ($0.7\leq r<0.9$) and nearly perfect ($r>0.9$) and perfect ($r=1$).[31] A stepwise regression analysis was used to predict performance in AJ from anthropometric and physiological parameters. All parameters were included in this analysis, except the jumping tests (SJ, CMJ and Bosco Test). The level of significance was set at $\alpha=0.05$.

Results

The comparison among AJ groups for anthropometric characteristics revealed significant differences with regards to CA ($P=0.034$, $\eta^2=0.12$), APHV ($P=0.004$, $\eta^2=0.18$), body mass ($P=0.006$, $\eta^2=0.17$), BMI ($P=0.019$, $\eta^2=0.14$) and BF ($P<0.001$, $\eta^2=0.33$). The effect size was medium for age and BMI, and large for APHV, body mass and BF. It should be highlighted that the outcome of the ANOVA provided information about whether groups differed or not, but not about which grouped differed. This was the reason to conduct post-hoc analysis (Bonferroni test), whose findings can be seen in Table I. No difference was observed for ΔAPHV ($P=0.582$, $\eta^2=0.03$) and height ($P=0.484$, $\eta^2=0.04$). Group D was older than A (+0.7 years; 90% CI: 0.1;1.2), and had higher APHV than A (+0.5 years; 90% CI: 0.1;0.8) and B (+0.4 years; 90% CI: 0.1;0.7). Also, group D was lighter than B (-6.3 kg; 90% CI: -11.8;-0.9) with lower BMI than B (-2.0 kg/m²; 90% CI: -3.7;-0.2) and lower BF than A (-6.4%; 90% CI: -9.6;-3.2) and B (-6.1%;90% CI: -9.3;-3.0).

With regard to aerobic and neuromuscular fitness, AJ groups differed for $Step_{ex}$ ($P=0.005$, $\eta^2=0.17$), $Step_{rec}$ ($P=0.033$, $\eta^2=0.12$) and relative total isometric strength ($P=0.007$, $\eta^2=0.16$). The effect size was medium for $Step_{rec}$, and large for $Step_{ex}$ and relative isometric strength. The post-hoc comparisons using Bonferroni test can be seen in Table II. SAR ($P=0.541$, $\eta^2=0.03$), RH ($P=0.185$, $\eta^2=0.07$), LH ($P=0.531$, $\eta^2=0.03$), Trunk ($P=0.489$, $\eta^2=0.04$), Trunk-legs ($P=0.565$, $\eta^2=0.03$), Sum4 ($P=0.581$, $\eta^2=0.03$), PWC_{170} ($P=0.415$, $\eta^2=0.04$)

TABLE II.—*Neuromuscular and aerobic fitness of volleyball players according to jumping performance.*

	Total (N.=72)	Group A (N.=17)	Group B (N.=18)	Group C (N.=19)	Group D (N.=18)
SAR (cm)	24.7±7.4	23.0±6.6	25.8±7.4	26.0±7.5	23.8±7.9
PWC_{170} (W)	122±26	120±20	124±33	116±28	129±21
PWC_{170} (W/kg)	1.98±0.42	1.86±0.35	1.91±0.47	1.95±0.46	2.21±0.28
$Step_{ex}$ (bpm)	163±14	161±12	173±11 ^{D}	162±16	158±13 ^{B}
$Step_{rec}$ (bpm)	110±16	106±16	120±14	107±17	107±15
RH (kg)	29.8±4.5	28.2±4.1	29.6±3.1	29.7±4.9	31.5±5.4
LH (kg)	29.5±4.3	28.3±3.9	29.7±5.2	29.5±4.2	30.5±3.7
Trunk (kg)	77.1±14.6	75.4±14.7	78.9±12.1	73.9±10.8	80.6±19.6
Trunk-legs (kg)	90.4±19.0	85.1±18.9	89.9±13.3	93.4±17.9	92.6±24.7
Sum (kg)	227±37	218±40	228±28	227±30	235±47
Sum (kg/kg)	3.70±0.64	3.37±0.50 ^{D}	3.52±0.40	3.82±0.48	4.04±0.88 ^{A}

Values were presented as mean±SD. Volleyball players were grouped by performance in the Abalakov jump.
SAR: sit-and-reach test; PWC_{170}: physical working capacity at heart rate 170 bpm; $Step_{ex}$: heart rate at the end of the step test; $Step_{rec}$: heart rate at the end of the first minute of recovery after the step test; RH: right handgrip muscle strength; LH: left handgrip muscle strength; Sum: sum of right, left handgrip, trunk and trunk-legs muscle strength.
Superscript letters A, B, C, and D indicate significant difference from the corresponding group at P<0.05.

TABLE III.—*Short-term muscle power of volleyball players according to jumping performance.*

	Total (N.=72)	Group A (N.=17)	Group B (N.=18)	Group C (N.=19)	Group D (N.=18)
P_{peak} (W)	543±77	558±87	566±90	523±72	527±51
P_{peak} (W/kg)	8.78±0.80	8.63±0.99	8.68±0.82	8.78±0.53	9.01±0.85
P_{mean} (W)	404±55	383±56	409±65	405±60	416±36
P_{mean} (W/kg)	6.56±0.80	5.95±0.76 $^{C, D}$	6.29±0.75 ^{D}	6.78±0.46 ^{A}	7.13±0.69 $^{A, B}$
FI (%)	44.1±9.6	48.8±9.0	44.8±10.1	42.5±7.3	40.9±10.8
HR_{WAnT} (bpm)	179±12	175±11	183±11	180±13	178±14
SJ (cm)	24.1±4.4	19.4±1.5 $^{B, C, D}$	22.4±2.7 $^{A, C, D}$	24.8±1.9 $^{A, B, D}$	29.6±3.1 $^{A, B, C}$
CMJ (cm)	25.2±4.4	19.9±1.6 $^{B, C, D}$	23.7±1.9 $^{A, C, D}$	26.3±1.6 $^{A, B, D}$	30.6±3.2 $^{A, B, C}$
AJ (cm)	30.8±5.0	24.8±1.5 $^{B, C, D}$	28.7±0.9 $^{A, C, D}$	32.1±0.9 $^{A, B, D}$	37.1±3.8 $^{A, B, C}$
Bosco (W/kg)	24.4±4.5	19.9±2.6 $^{B, C, D}$	23.3±3.3 $^{A, D}$	26.0±3.4 ^{A}	28.1±3.8 $^{A, B}$
HR_{Bosco} (bpm)	169±14	168±11	174±11	169±15	166±18

Values were presented as mean±SD. Volleyball players were grouped by performance in the Abalakov jump.
P_{peak}: peak power; P_{mean}: mean power; FI: Fatigue Index, HR_{WAnT}: peak heart rate response to the Wingate Anaerobic Test; SJ: squat jump; CMJ: countermovement jump; AJ: Abalakov jump; Bosco: mean power in the Bosco Test; HR_{Bosco}: peak heart rate response to the Bosco Test.
Superscript letters A, B, C, and D indicate significant difference from the corresponding group at P<0.05.

and $rPWC_{170}$ (P=0.059, η^2=0.10) did not differ. However, it should be highlighted that $rPWC_{170}$ approached but did not quite achieve statistical significance. Group D had lower $Step_{ex}$ than B (-15 bpm; 90% CI: -26;-5) and higher relative isometric strength than A (+0.67; 90% CI: 0.17;1.17).

The comparison among AJ groups for short-term muscle power revealed significant differences with regards to P_{mean} in $W.kg^{-1}$ (P<0.001, η^2=0.32), SJ (P<0.001, η^2=0.72), CMJ (P<0.001, η^2=0.77) and Bosco test (P<0.001, η^2=0.47). The effect size was large for all the above-mentioned parameters. The findings of Bonferroni test can be seen in Table III. No difference was observed for P_{peak} in W (P=0.242, η^2=0.06), P_{peak} in W/kg (P=0.526, η^2=0.03), P_{mean} in W (P=0.358, η^2=0.05), FI (P=0.094, η^2=0.09), HR_{WAnT} (P=0.319, η^2=0.05) and HR_{Bosco} (P=0.364, η^2=0.05). Group D had higher P_{mean} in W/kg than A (+1.17 W/kg; 90% CI: 0.60;1.74) and B (+0.84 W/kg; 90% CI: 0.29;1.39), and group C scored higher than A (+0.83 W/kg; 90% CI: 0.27;1.39). In SJ, group D jumped higher than C (+4.8 cm; 90% CI: 2.8;6.7), who scored better than B (+2.4 cm; 90% CI: 0.5;4.4), who in turn outperformed A (+3.0 cm; 90% CI: 1.0;5.0). Similarly, in CMJ, group D scored higher than C (+5.0 cm; 90% CI: 3.3;6.7), who outperformed B (+3.4 cm; 90% CI: 1.7;5.1), who scored better than A (+3.9 cm; 90% CI: 2.1;5.6). In the Bosco Test, group D scored higher than A (+8.2 W/kg; 90% CI: 5.4;10.9) and B (+4.7 W/kg; 90% CI: 2.0;7.4), and groups C and B outperformed A (+6.2 W/kg; 90% CI: 3.5;8.9; and +3.5 W/kg; 90% CI: 0.7;6.2, respectively).

AJ was correlated with anthropometric (APHV: r=0.38, P<0.001; body mass: r=-0.43, P<0.001; BMI: r=-0.37, P=0.001; BF: r=-0.64, P<0.001) and physiological parameters (PWC_{170}: r=0.29, P=0.013; isometric strength: r=0.50, P<0.001; SJ: r=0.92, P<0.001; CMJ: r=0.95, P<0.001; Bosco Test: r=0.70, P<0.001; P_{mean}: r=0.61, P<0.001; FI: r=-0.33, P=0.005) in the WAnT. The magnitude of these correlations was moderate for APHV, body mass, BMI and Fatigue Index, large for BF, isometric strength and P_{mean}, very large for Bosco Test, and nearly perfect for SJ and CMJ. A stepwise regression analysis showed that AJ could be predicted by BF, P_{mean} in $W.kg^{-1}$ and APHV using the following equation:

$$AJ = 3.54 – 0.46 \times BF + 2.21 \times P_{mean} + 1.96 \times APHV$$

Where R=0.75, R^2=0.55, and standard error of the estimate = 3.21. The correlations of AJ with the best two predictors (BF and P_{mean}) can be seen in Figures 1 and 2, respectively.

Discussion

The main findings of the present study, considering its two main aims, were that: 1) jumping performance correlated with both anthropometric (APHV, BM, BMI, and BF) and physiological parameters (isometric strength, SJ, CMJ, Bosco test, P_{mean} and FI in the WAnT); and 2) volleyball players with superior jumping performance (*i.e.* those with AJ ~37 cm) had also older CA and APHV and lower BF, isometric strength, SJ, CMJ, performance in the Bosco test and P_{mean} in the WAnT than their counterparts with lower jumping performance (*i.e.* those with AJ≈25 cm). The results of the correlation analysis, the comparison among groups differing for jumping performance and the stepwise regression analysis were in agreement highlighting the role of anthropometric and physiological parameters for jumping performance, as well as a potential advantage of those who matured later than others.

However, there was no difference among AJ groups with regards to biological age (ΔAPHV) and no correlation between AJ and ΔAPHV, a main finding was the positive and moderate correlation between AJ and APHV, and that the volleyball players with the highest AJ had older APHV than those with inferior jumping performance. An interpretation of the advantage of late mature athletes for jumping performance might be that these volleyball players had more time to learn and practice basic motor skills, such as jumping, compared with early mature players who tent to move earlier to more advanced motor skills without having spent sufficient

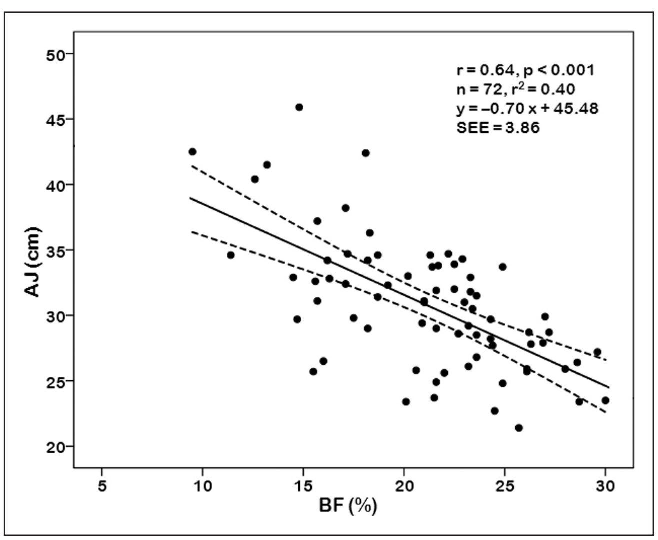

Figure 1.—Relationship between performances in the Abalakov jump (AJ) and body fat percentage (BF).
r^2: coefficient of determination; SEE: standard error of the estimate.

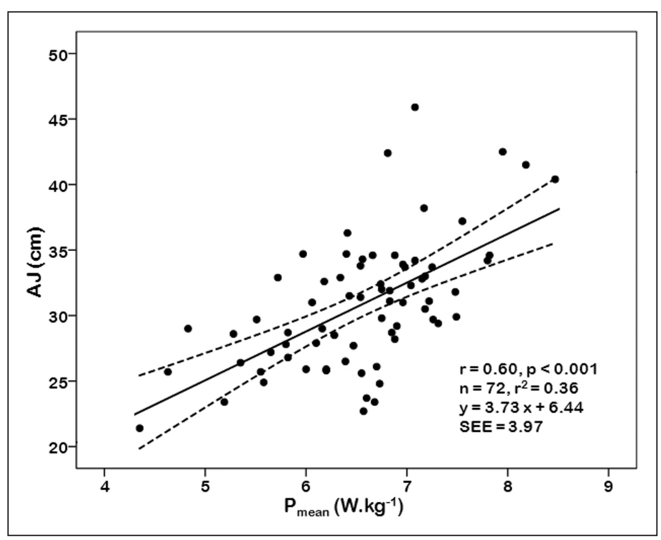

Figure 2.—Relationship between performances in the Abalakov jump (AJ) and relative mean power of the Wingate anaerobic test (P_{mean}).
r^2: coefficient of determination; SEE: standard error of the estimate.

time to the fundamental skills. Another explanation might be the negative relationship between APHV and body mass.[32, 33] Actually, there was evidence from studies in non-athletes that late mature players were lighter [33] and with lower prevalence of overweight [32] than their early mature counterparts. Considering the negative effect of body mass on jumping performance 15 — jump was an action performed against gravity — the lower body mass of late mature players might be an advantage for their jumping performance.

Only a few studies had previously examined physical fitness of early and late mature players. For instance, research on motor skills revealed that late more mature girls scored higher in test of static strength of upper body (bent arm hang), where the body had to be lifted.[34] Another study showed that late mature players had a more effective pattern of cardiovascular response to exercise on a cycle ergometer.[35] It has also been observed that late mature players had higher physical activity levels.[33, 36] Less data exist about sport populations, in which a research indicated that male basketball players differed for APHV by playing positions (guards later than forwards and centers).[37]

The findings of the present study on the relationship between jumping performance and anthropometry agreed with previous studies.[5, 13, 15, 16, 38, 39] Due to growth and development, an age effect has been previously observed, where adult volleyball players jumped higher than their adolescent counterparts.[14-16] On the other hand, a lack of differences in jumping performance between adult and those in late adolescence [16] might be due to similarities between adult and junior volleyball at the highest level.[40] The negative correlations of AJ with body mass and BF (larger magnitude in the case of BF) confirmed previous findings in adolescent and adult volleyball players.[5, 15] Jumping performance has been correlated with other anthropometric parameters, too, such as mid-thigh and calf corrected girths,[13] and mesomorphy and ectomorphy.[39] The findings of the above-mentioned cross-sectional studies were also in agreement with research using longitudinal design, in which changes in jumping performance correlated negatively with changes in BF, *e.g.* seasonal changes in female volleyball players,[41] and *vice versa* when there was no change in BF, jumping performance remained the same.[38]

The superior jumping performance of the group with the highest AJ (*i.e.*, group D) was confirmed by the scores in the other single jump tests (SJ, CMJ and Bosco Test). The large and positive correlations of AJ with isometric muscle strength (relative sum of four measures) and relative P_{mean} of the WAnT confirmed the relationship of jumping performance with other measures of muscle strength and power observed in previous studies conducted mostly in adult female volleyball players.[6, 9, 17, 18] For instance, changes in jumping performance during a competitive season correlated very largely with corresponding changes in isometric leg extension strength.[17] Another study found association of spike-jump and block-jump with isokinetic strength.[9] Moreover, CMJ was largely correlated with eccentric rate of force development and average in a study using force plate.[6]

The jumping performance not only was related to muscle strength and power, but also it related to aerobic capacity, which was indicated by the its correlation with PWC_{170} and the better performance in $Step_{ex}$ in group D than B. An interpretation of the relatively high aerobic capacity of those who jump the highest might be that a general effect of sport training despite intra-individual differences with regards to various physical fitness parameters.[42] On the other hand, strength training might improve aerobic capacity through amelioration of work economy.[43]

Nevertheless, the anthropometric and physiological parameters might not explain all the variance in jumping performance, and the role of other factors should be also considered. For instance, jumping performance was also influenced by motor skills (kinematic sequencing strategy), where a longer relative time delay (proximal-to-distal strategy) was correlated with higher CMJ and AJ, greater hip extensor and ankle plantar flexor net joint moments, and greater thigh and leg angular accelerations.[44] Another potential influence on VJ might be warm-up. In a comparison of the effect of three warm-up conditions (static stretching *vs*. dynamic stretching *vs*. no stretching) on CMJ, no differences among mean values were observed; however, important individual changes were recorded.[45] Caution would be needed when "translating" the findings of the present study into sport practice, because to study VJ performance we used three traditional tests (SJ, CMJ and AJ) within a laboratory setting. Although these tests have been valid and reliable, they differed from more sport-specific jumps, such as four-step approach spike jump [46] or traditional, swing and "chicken wing" blocking techniques.[47]

Limitations of the study

A limitation of the present study was the assessment method of maturation status; instead of skeletal age or secondary sex characteristics,[48] a relatively recently developed method assessed maturation using anthropometric, *i.e.* non-invasive, method. The method of Mirwald *et al.* was not as accurate as skeletal age; however, due to its non-invasive nature it would be easy to use by volleyball coaches and trainers in the context of talent identification. It should be also highlighted that the findings of the present study provided information only about the magnitude of the relationship among variables. Due to its correlation design, this study could not provide evidence about the cause-effect relationship.

Despite the abovementioned drawbacks, the findings of the present study would be useful for both sports scientists and volleyball specialists. The role of APHV and biological age, and the differences between early and late maturers, should be further examined in future studies on talent identification and players' selection, especially using samples from other countries. Considering the practical applications of the results in this study, volleyball experts were advised to concentrate on the optimization of both anthropometric and physiological parameters in order to achieve high vertical performance. Particularly, emphasis should be put on the development of proper exercise and nutrition interventions targeting BF values close to or lower than 20%. Moreover, strength exercises should be included in the weekly training program so as to improve muscle strength and power, and consequently, jumping performance.

Conclusions

In summary, the findings of the comparison among groups differing for jumping performance, the correlation analysis and the stepwise regression analysis highlighted the negative role of excess body mass and fat, and the positive role of muscle strength and power on jumping. Also, there was indication that volleyball players that jumped the highest were those who matured later than others. Since APHV was related to jumping performance, volleyball coaches and fitness trainers should also consider it within the context of talent identification.

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