

Jumping performance and take-off efficiency in two different age categories of female volleyball players

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Purpose: Vertical jump height is recognised as a determinant factor in elite volleyball performance. In previous studies there are different opinions on whether vertical jump height performance improves during maturation or not. The aim of this study was to assess the differences in jumping abilities in two different age groups of female volleyball players and to determine the take-off efficiency during repeated jumps. *Methods:* Seventeen female volleyball players from two different age categories – adults and under 16 years – participated in this study. Quattro Jump 9290BA force platform (Kistler, Winterthur, Switzerland) was used to assess the jumping performance during squat jumps, counter movement jumps, and 45-second continuous jumps. *Results:* Jumping performance did not differ significantly between the two groups. The main efficiency of the conversion of mechanical work into mechanical energy was only 24% and it decreased during the test. *Conclusions:* The influence of age on the jumping performance in a group of female volleyball players was not confirmed. Take-off efficiency was in both groups quite low and it did not improve during the test.

Key words: biomechanics, vertical jump, height, power, age

1. Introduction

Vertical jump height is recognised as a determinant factor in elite volleyball performance and it might be related to increased lower limb muscle power [22]. The production of power using the lower limbs is critical for performance in numerous volleyball game actions that involve jumping activities such as serving, attacking, blocking, and setting [21].

Volleyball players should possess adequate short-term muscle power, which is usually assessed using jumping tests including single jumps such as the squat jump (SJ), counter movement jump (CMJ), and continuous jumps (CJ). These tests are widely used to assess jumping performance in volleyball [20], [22], [29].

The continuous jump test is often used by volleyball players and also by athletes whose performance depends on anaerobic capability [7], [18], [24] and also for testing talented individuals involved in anaerobic

activities [15], [18]. The continuous jump, is a test of endurance in eccentric-concentric conditions [5]. With respect to the character of the game (often repeated jumps during the match), it is also very useful tool to test talented individuals.

During vertical jumps, potential energy and kinetic energy are transformed mutually. During the take-off phase muscular work, which is converted into mechanical energy during the flight phase, is performed by the athlete. When an anaerobic performance for CJ is being monitored, take-off efficiency can be also monitored [9].

The effectiveness of training focused on improving jumping performance depends on a number of characteristics of the subject, such as sex [4], [27], age [4], [25], or the volume and frequency of training [13], [23]. In previous studies, it was observed that vertical jump height performance improves during maturation in males, but not in females [11]. Kitamura et al. [12] reported that squat jump (SJ) and

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Received: February 27th, 2019

Accepted for publication: April 23rd, 2019

CMJ height values were higher for groups of professional male volleyball players and players under 21 years of age than for a group of players under 17 years of age.

In a group of female volleyball players, the impact of age on the height of a vertical jump was examined by the study carried out by Nikolaidis et al. [16]. The jump height for CMJ and SJ in an Under-18 group (age: 16.0 ± 1.0 years) was lower than in an 18+ group (age: 24.8 ± 5.2 years). In an Under-19 group (age: 16.2 ± 1.5 years) was the average jump height for CMJ lower during the preparation stage than during the competition stage [19]. The results of the measurements of a vertical jump in younger female volleyball players (age: 13.3 ± 0.7 years) are studied by the research carried out by Nikolaidis et al. [17], who reported great differences between individuals.

Nowadays, there is a trend to select young, tall female players into ambitious teams. Very tall players are usually directed towards the specialization in the position of middle blocker or spiker. This sometimes happens without taking into account their jumping abilities and smaller players play in the defensive libero position. Body height is usually used as a basic selection criterion in talent identification [26] and it is not often taken into account that the growth of individuals in the adolescence takes place at different speeds. It very often happens that talent identification may not reveal the perspective of some slow-growing players in that period. The athletes who have the best vertical jump performance are those that reach maturity later [17]. With regard to the fact that one of a determinant factor in elite volleyball performance is vertical jump height [22], it seems to be very important to find out whether there are differences in the jump height of young players (U16), compared to more experienced and older ones. An other aspect of the female volleyball performance might be the efficiency of the jumps. Volleyball is characterized by requirement to perform many repeated jumps during the game. According to some theories, fatigue might increase efficiency [28]. By contrast to this theory, decrease of efficiency of mechanical work during the repeated jumps when it is reduced by the internal friction in muscles and between individual muscle groups and joints was reported [9]. The aim of this study was to assess the differences in jumping performance in two different groups of competitive female volleyball players – an adult group of professional volleyball players and younger players aged under 16. In addition the aim of the study is to determine the efficiency (η) of the transformation of an athlete's mechanical

work during take-off into mechanical energy during the flight phase with respect to the physical laws and to formulate a formula to calculate this parameter. We assumed that η might be different in two groups of volleyball players (adults and younger U16 group) and we expected lower values in the U16.

2. Materials and methods

Participants

Seven adult female volleyball players (G18+) and ten young competitive female volleyball players (U16) participated in this study voluntarily (Table 1). The training history of the players was at least four years. The exclusion criteria included a previous musculoskeletal injury within one year and suffering from musculoskeletal pain and none of the participants had injuries that could limit the range of motion of their body or extremities. The study was approved by the Institutional Review Board for the Testing of Human Subjects (the protocols were performed under a licence obtained from this board) and was performed in accordance with the ethical standards of the Helsinki Declaration. Parental consent and assent were obtained for those under the age of 18.

Data collection

The Quattro Jump 9290BA force platform (Kistler, Winterthur, Switzerland) was used to measure vertical force and to assess the jumping performance during squat jumps (SJ), counter movement jumps (CMJ), and 45-second continuous jumps with bent knees (CJ). This measuring system allows data to be recorded with the frequency of 500 Hz. The stored data was analysed with the comprehensive performance analysis software Quattro Jump Software (Kistler, Winterthur, Switzerland) after the measuring had finished.

Protocol

Data was collected for each subject during a single session. The participants were first familiarised with the experimental protocol and subsequently signed an informed consent form. Anthropometric data was recorded at the beginning of the data collection. The participants were measured for height with a portable A 213 anthropometer (Trystom, Olomouc, Czech Republic) and for mass – using an electronic scale (Amboss, New York, NY, USA), and their age was recorded in years.

Data was collected after a standardised warm-up protocol (including self-selected moderated running for five minutes, active stretching, and sub-maximal vertical jumps). The participants were asked to perform SJ starting from a semi-squat position and jumping as high as possible without any preparatory movement (two attempts were measured). After two minutes of rest, CMJ (two attempts) was performed with the subjects starting from a standing position and executing a downward movement followed by complete extension of the legs, freely determining the amplitude of the counter-movement. In SJ and CMJ the athletes' hands were on their hips. The best attempt at each jump was considered for analysis. After five minutes' rest they had to perform 45-second continuous vertical jumps (CJ) with 90-degree knee bending and with their hands on their hips according to previous study [14]. The whole jumping section was filmed and the knee angle controlled. The attempts that did not fill the 90 degree knee angle request were not used for the analysis. The athletes had to jump as high as possible throughout the whole 45-second period.

Calculated parameters

When squat jump and counter movement jump performance were being analysed, the vertical force was recorded. The jump height (jh) was observed by double integration of force. In addition, peak power output normalized to body weight (P_{BW}) was calculated. When the 45-second CJ was being analysed, the maximal jump height (jh_{max}) and mean jump height (jh_{ave}) were evaluated. Peak power output normalized to body weight (P_{BW}) and average normalized power output during the whole section of CJ ($P_{BW_{ave}}$) were analysed. The average contact time (CT_{ave}) and fatigue index were evaluated. According to physical laws, we calculated the efficiency (η) of the conversion of mechanical work into mechanical energy at the moment of take-off (Eq. (1)):

$$\eta = \frac{W_2}{W_1} = \frac{mgjh}{mP_{BW}CT}, \quad (1)$$

where η is the efficiency; W_1 represents a subject's power input calculated as the product of a subject's body weight (m), a subject's peak power normalized to body weight (P_{BW}), and the length of contact time with a force plate (CT). W_2 represents a subject's power output, which is equal to the potential energy at the highest jump point. It is calculated as the product of a subject's body weight (m), the gravitational acceleration of the Earth ($g = 9.8 \text{ kg}\cdot\text{m}\cdot\text{s}^{-2}$), and the jump height (jh).

Statistical analysis

Statistical analysis of the collected data was performed using the Statistica program (version 12, StatSoft, Inc., Tulsa, OK, USA). In order to check for homoscedasticity, the Levene's test was applied. The Mann-Whitney U -test was used to assess the differences between groups. The value of the r score ($r = Z/\sqrt{N}$, where N is the total number of observations) was used to evaluate the effect size [8]; the effect size was considered large for values ≥ 0.5 and moderate for values ≥ 0.3 and < 0.5 . All the data is presented as mean and standard deviation. The level of significance was set to $p \leq 0.05$.

3. Results

This study focused on the jumping performance analysis in two different age groups of volleyball players. The data stemming from the anthropometric characteristics (Table 1) of both groups of volleyball players (G18, U16) shows no significant differences in terms of height and body weight ($p \leq 0.05$). The BMI parameter distinguished these two groups ($p = 0.002$, $r = 0.75$); the U16 group had a significantly lower BMI parameter.

Table 1. Differences in anthropometric parameters

	G18+	U16	G18+ vs U16
Age	25.3 \pm 4.11	15.5 \pm 0.88	0.001
Body height [m]	1.80 \pm 0.05	1.78 \pm 0.06	0.33
Body mass [kg]	73.00 \pm 4.99	67.50 \pm 7.06	0.17
BMI [$\text{kg}\cdot\text{m}^{-2}$]	22.45 \pm 1.09	18.94 \pm 1.74	0.002

Single vertical jumps

The results from the single vertical jumps (SJ and CMJ) are shown in Table 2. In the G18+ group the jump height values for SJ ranged from 33.5 cm to 41.7 cm and in the U16 group the values were between 34.1 cm and 42.2 cm. These results did not confirm the hypothesis that older players jump higher than players from U16 group, because they were not significantly different from both the groups of volleyball players (G18+, U16) in terms of age. The P_{BW} values for SJ did not differ in the G18+ and U16 groups ($p > 0.05$) either, the difference being only $0.22 \text{ W}\cdot\text{kg}^{-1}$.

The jump height for CMJ did not differ significantly in the G18+ and U16 groups either, in spite of the fact that the main values in the G18+ group were slightly higher than in the U16 one. The difference

was 1.11 cm. The values in the G18+ group ranged between 33.2 cm and 44.2 cm. The main value in this group was higher (the effect of prestretch was approximately 5 percent) than the main value for SJ when the jump was performed without knee prestretch movement. In addition, the values in the U16 group varied in the range between 34.8 cm and 44.7 cm and the main value was higher than that for SJ, too (approximately 3 percent). In the G18+ and U16 groups the P_{BW} values for CMJ were not (significantly) different either ($p > 0.05$); the U16 values were lower by $0.83 \text{ W}\cdot\text{kg}^{-1}$.

Continuous vertical jumps

The results from the 45-second continuous vertical jumps (CJ) are shown in Table 2.

The mean number of jumps was very similar in both groups (G18+ = 31.5 ± 3.21 ; U16 = 31.1 ± 6.61). The maximum jump height for CJ did not differ significantly in the G18+ and U16 groups ($p > 0.05$), even if the jh_{\max} values in the G18+ group were higher by 3.36 cm. In addition, the effect size pointed to moderate effect ($d = 0.448$). In the G18+ group, the jh_{\max} values varied in the range from 36.5 cm to 44 cm. In the U16 group, the jh_{\max} values were between 30.6 cm and 43.1 cm. As far as average jump height is concerned, there were no significant differences between both groups ($p > 0.05$); in the G18+ group the range of the values was from 29.4 cm to 36.2 cm, and in the case of the U16 group it was from 21.7 cm to 35 cm. No significant influence of age was identified.

In the G18+ and U16 groups, the P_{BW} values for CJ were not statistically different ($p > 0.05$) even if the P_{BW} values were higher by $2.52 \text{ W}\cdot\text{kg}^{-1}$ in the G18+ group. Contact time with the ground was the next variable that was measured during CJ. The figures did not show any significant differences between the values in both groups ($p > 0.05$), although the CT_{ave} was shorter in the G18+ group. In all participants who were monitored, the contact time with the ground was gradually prolonged over 45-second CJ.

During the 45-second CJ, fatigue gradually increased, which could be observed in an ongoing reduction of jh and P_{BW} in both groups that were studied. Although we expected the lowest fatigue index in the G18+ group, the differences among groups were not significant.

When the results of the calculated efficiency (η) of the conversion of mechanical work into mechanical energy were analysed, the highest η was in the G18+ group. These athletes were able to take off during the 45-second CJ with the efficiency of 24.04% and the highest values reached 33%. The values in the U16

group were slightly lower (23.43%). In all participants the efficiency of the conversion of mechanical work into mechanical energy decreased slightly during the 45-second CJ.

Table 2. Differences in vertical jump performance

	G18+	U16	G18+ vs. U16
Single jump			
Squat jump			
Jump height [cm]	38.5 ± 2.36	38.3 ± 2.90	0.92
Power [$\text{W}\cdot\text{kg}^{-1}$]	19.7 ± 1.07	19.5 ± 2.25	0.77
Countermovement jump			
Jump height [cm]	40.5 ± 3.44	39.4 ± 3.08	0.46
Power [$\text{W}\cdot\text{kg}^{-1}$]	24.8 ± 2.39	24.0 ± 2.89	0.81
Continuous jumps			
Max. jump height [cm]	39.5 ± 2.75	36.1 ± 3.87	0.27
Avg. jump height [cm]	32.7 ± 2.30	30.2 ± 3.83	0.25
Max. power [$\text{W}\cdot\text{kg}^{-1}$]	22.4 ± 1.80	19.9 ± 3.18	0.17
Avg. power [$\text{W}\cdot\text{kg}^{-1}$]	17.4 ± 0.98	16.1 ± 2.53	0.48
Avg. contact time [ms]	791 ± 121.3	798 ± 100.4	0.96
Efficiency [%]	24.0 ± 2.73	23.4 ± 2.55	0.68
Fatigue index [%]	72.1 ± 5.83	73.1 ± 7.83	0.79

4. Discussion

The primary finding of the present investigation was that age did not influence either the jumping performance for SJ, CMJ, and CJ or the efficiency of take-off in female volleyball players (G18+, U16).

The results of the anthropometric measurements of the G18+ and U16 groups did not show any statistically significant differences in terms of height and body weight; however, the BMI parameter of the U16 group was considerably lower ($p = 0.002$). It might be explained by the fact that recruitment into elite volleyball teams is carried out on the basis of the height predispositions of players in their adolescence. In most cases, the female growth spurt is completed before 16 years of age, and, as a result, female height is very close to that found in adulthood (https://www.cdc.gov/growthcharts/html_charts/statage.htm#females). As far as body weight is concerned, there is a tendency towards its gradual increase, which is why height and body weight ratio (BMI) were lower in the case of the younger volleyball players.

In order to analyse jumping performance in single jumps, SJ and CMJ were used. The results of both tests indicated similar performance in the G18+ and U16 groups. The older G18+ group performed slightly

higher jumps than the U16 group, but the differences were not significant. P_{BW} in both single vertical jumps was similar in the both groups. These results are in accordance with the statement that vertical jump height performance does not improve during maturation in females [11] and ageing per se is not a guarantee of improving vertical jumping ability [12]. On the contrary, another previous study [16] reported a role of age in that the performance of adult female players was higher than that of a younger group of adolescent players. In our G18+ group the jump height values for SJ were in the range from 33.5 cm to 41.7 cm and in the U16 group they were in the range from 34.1 cm to 42.2 cm. These values are higher than those reported in previous studies [2, 16] for similar age categories but they were obtained from lower-level athletes than in our study. The role of performance level is positive [6].

In our measurement, jh for CMJ did not differ significantly in the G18+ and U16 groups either, and the role of age was not confirmed. In the G18+ group the jh values were slightly higher (40.5 ± 3.44 cm) than in the U16 group (39.39 ± 3.08 cm). Lower values for CMJ as well as for SJ were reported [6] in the eighth volleyball team in the Spanish first league (CMJ: 28.84 ± 3.86 cm, SJ: 27.20 ± 2.68 cm). In addition, higher jump height values in CMJ in 16-year-old female volleyball players (43 cm) were reported [1]. These values, however, were measured by means of a different method, using a portable jump mat, which calculated jh from flight time and not as a double integration of force as obtained in our study.

Analysing CJ performance, the maximal jump height did not differ significantly in the G18+ and U16 groups ($p > 0.05$). The difference in the jh_{max} values was 3.36 cm and the G18+ group jumped higher. The best performance was 44 cm (G18+). This height was achieved by the volleyball player whose jh was also the highest for SJ and CMJ. This athlete achieved 44.2 cm for CMJ, which corresponds with her maximum jump height for CJ. In the case of this volleyball player, the average jh was the highest one (36.2 cm), which reflects a very good level of anaerobic characteristics. If we compare jh_{max} with other athletes, the performance of volleyball players is higher than, for example, in the case of female 400-m runners, whose jh_{max} was reported to be 33.29 cm [24]. In our measurement the jh_{max} values ranged from 36.5 cm to 44 cm in the G18+ group, and in the U16 group the jh_{max} values were between 30.6 cm and 43.1 cm. The impact of age on the jh_{max} was not confirmed. However, in contrast to our results, Nikolaidis et al. [16] found a greater jump height in the case of

older female volleyball players (age: 24.8 ± 5.2 years), who have better technique at take-off and experience with repeated jumps during training and match than younger players (U16).

The difference between the G18+ and U16 groups was not significant and the influence of age reported in a previous study [16] was not confirmed. In terms of the significance of the differences, it is similar to that of jh_{max} . The G18+ jh_{ave} (32.70 ± 2.30 cm) is followed by the U16 jh_{ave} (30.15 ± 3.83 cm). In comparison with the results of female 400-m runners [24] our values were higher. But it is necessary to take into account the fact that our measurement lasted only 45 seconds and in the above-mentioned study (60 seconds test) there was a very significant decrease in jh in the last ten seconds of the test. The height of the jump decreases with growing fatigue, even in highly trained athletes [6].

Similarly to jh_{max} , differences in P_{BW} and $P_{BW_{ave}}$ between the G18+ and U16 groups were not found for CJ, although the values for the G18+ group were slightly higher. The values identified by means of the Kistler Quatro Jump were between 19.5 and 24 $W \cdot kg^{-1}$ in the G18+ group. These values can be compared only with studies in which force plates were used for measurement, or, alternatively, flight time was measured, as the P_{BW} values found in the Wingate test are significantly lower than those found in the Bosco test [5], [17]. Higher mean power output can be observed in top male volleyball players, where mean power output was reported at about 25 $W \cdot kg^{-1}$ [10], and in handball players at about 26 $W \cdot kg^{-1}$ [3]. Nevertheless, the aforementioned studies were conducted over a shorter period of time (15 or 30 seconds). In addition, lower values (18.93 $W \cdot kg^{-1}$) in a 15-second Bosco test [14] and also during a 60-second Bosco test (16.4 $W \cdot kg^{-1}$) [24] were reported. It is difficult to compare test results with different duration, because it appears that, for example, in handball players the duration of the test affects the measured anaerobic parameters [18].

The contact time with the ground during CJ was longer in U16 group, but the differences were not significant. Although the participants were instructed to jump as high as possible for 45 seconds, while trying to retain short ground contact times, there was a gradual increase in contact time with the force plate during the 45-second CJ test. This is attributed to the onset of fatigue in all participants.

When monitoring anaerobic performance, the efficiency of take-off is an important aspect, and one that is influenced by fatigue. So far it has received comparatively little attention and there are still many

questions to be answered. Efficiency of the conversion of mechanical work into mechanical energy is significantly dependent on the number of jumps performed when the efficiency decreased during the last third of the test [9]. In contrary to these results there are some theories according to them fatigue might increase efficiency [28]. In our study at the beginning of CJ some athletes can attain values of η of about 50%, but in this study the main efficiency was highest in the G18+ group: $24 \pm 2.73\%$ and slightly lower in the U16 group: $23.4 \pm 2.55\%$. Higher values in older volleyball players might result from the longer-term practice in jumping during training and play in the G18+ group, which allowed them to perform repeated jumps more efficiently [16].

In the case of the athletes with the highest anaerobic performance, the efficiency of conversion of mechanical work into mechanical energy was greatest. In comparison, the lowest efficiency of this conversion was observed in the last vertical jumps of each of the participants. In accordance with a previous study [9], η does not change significantly at the beginning of the test. A significant decrease in efficiency can be observed in the last third of the jumps and our results did not confirm the theory that fatigue might increase efficiency.

Similar to the efficiency of any machine, the efficiency of mechanical work is reduced by the internal friction in muscles and between individual muscle groups and joints [9]. The decrease in efficiency as a result of fatigue can be explained because the force exerted by the exerciser's feet does not only contribute to the jump take-off but also to the maintenance of a stable position before take-off. Therefore, η in females only rarely reaches a value of 33%, but it is usually lower with increasing fatigue, so jumpers should pay more attention to the achievement of the right squat position and to stabilising their posture and focusing less on their take-off. Thus the η of individual take-offs will decrease gradually in the course of the test [9].

One of the limitations of this study is the fact that the sample size of the G18+ and U16 groups was not big enough and this reduced number of subjects might influence the normality of the data. The use of non-parametric statistics may be considered as a limitation of the study.

5. Conclusions

Summarizing, the performance of players from G18+ and U16 group in single vertical jumps (SJ and CMJ) and continuous vertical jumps (CJ) only slightly

varied. When vertical jumps in the adult players (G18+) and under 16 players (U16) groups were compared, no significant differences in performance between the two age categories were observed, and the effect of age on the jumping performance was not confirmed. When efficiency during take-off was monitored, the highest values were at the beginning of the test and they decreased over the 45-second period. The values of the efficiency of the conversion of mechanical work into mechanical energy were very similar in both groups of volleyball players. In that respect, no significant differences between G18+ and U16 female volleyball player's groups were observed and the role of age was not confirmed.

These findings should be taken into account by volleyball coaches in the process of recruiting talented individuals and they should motivate fitness coaches to try to improve jump abilities in all age groups.

Acknowledgement

This work was supported by SGS 21120, Specific University Research Grant provided by the Ministry of Education, Youth and Sports of the Czech Republic.

References

- [1] AGOPYAN A., OZBAR N., OZDEMIR S., *Effects of 8-week Thera-Band training on spike speed, jump height and speed of upper limb performance of young female volleyball players*, IJAEP, 2018, 7 (1), 63–76, DOI: 10.22631/ijaep.v7i1.218.
- [2] BATTAGLIA G., PAOLI A., BELLAFFIORE M., BIANCO A., PALMA A., *Influence of a sport-specific training background on vertical jumping and throwing performance in young female basketball and volleyball players*, J. Sports Med. Phys. Fitness, 2014, 54 (5), 581–587.
- [3] BONIFAZI M., BOSCO C., COLLI R., LODI L., LUPO C., MASSAI L., MUSCETTOLA M., *Glucocorticoid receptors in human peripheral blood mononuclear cells in relation to explosive performance in elite handball players*, Life Sci., 2001, 69 (8), 961–968, DOI: 10.1016/S0024-3205(01)01190-0.
- [4] BOSCO C., KOMI P.V., *Influence of aging on the mechanical behavior of leg extensor muscles*, Eur. J. Appl. Physiol. Occup. Physiol., 1980, 45 (2–3), 209–219, DOI: 10.1007/BF00421329.
- [5] BOSCO C., LUHTANEN P., KOMI P.V., *A simple method for measurement of mechanical power in jumping*, Eur. J. Appl. Physiol. Occup. Physiol., 1983, 50(2), 273–282, DOI: 10.1007/BF00422166.
- [6] BRAZO-SAYAVERA J., NIKOLAIDIS P., CAMACHO-CARDENOSA A., CAMACHO-CARDENOSA M., TIMÓN R., OLIVARES P., *Acute effects of block jumps in female volleyball players: The role of performance level*, Sports, 2017, 5 (2), 30, DOI: 10.3390/sports5020030
- [7] FLORÍA P., HARRISON A.J., *Ground reaction force differences in the countermovement jump in girls with different levels of performance*, Res. Q. Exerc. Sport, 2013, 84 (3), 329–335, DOI: 10.1080/02701367.2013.813896.

- [8] FRITZ C.O., MORISS P.E., RICHLER J.J., *Effect size estimates: current use, calculation, and interpretation*, J. Exp. Psychol. Gen., 2012, 141 (1), 30, DOI: 10.1037/a0024338.
- [9] JANDOVA S., MUSILEK M., MARTIN A.J., COCHRANE D., ROZKOVEC J., *Take-off efficiency: Transformation of mechanical work into kinetic energy during the Bosco test*, Hum. Movement, 2017, 18 (3), 34–39, DOI: 10.1515/humo-2017-0023.
- [10] KALINSKI M.I., NORKOWSKI H., KERNER M.S., TKACZUK W.G., *Anaerobic power characteristics of elite athletes in national level team-sport games*, Eur. J. Sport Sci., 2002, 2 (3), 1–21, DOI: 10.1080/17461390200072303.
- [11] KELLIS S.E., TSITSKARIS G.K., NIKOPOULOU M.D., MOUSIKOU K.C., *The evaluation of jumping ability of male and female basketball players according to their chronological age and major leagues*, J. Strength Cond. Res., 1999, 13 (1), 40–46, DOI: 10.1519/1533-4287(1999)013<0040:TEOJAO>2.0.CO;2.
- [12] KITAMURA K., PEREIRA L.A., KOBAL R., ABAD C.C.C., FINOTTI R., NAKAMURA F.Y., LOTURCO I., *Loaded & unloaded jump performance of top-level volleyball players from different age categories*, Biol. Sport, 2017, 34 (3), 273–278, DOI: 10.5114/biolSport.2017.67123.
- [13] KRČMÁR M., ŠIMONEK J., VASILEOVSKÝ I., *The acute effect of lower-body training on average power output measured by loaded half-squat jump exercise*, Acta Gymnica, 2015, 45 (3), 103–111, DOI: 10.5507/ag.2015.016.
- [14] LA PORTA J.W., BROWN L.E., COBURN J.W., GALPIN A.J., TUFANO J.J., CAZAS V.L., TAN J.G., *Effects of different footwear on vertical jump and landing parameters*, J. Strength Cond. Res., 2013, 27(3), 733–737, DOI: 10.1519/JSC.0b013e318280c9ce.
- [15] LIDOR R., FALK B., ARNON M., COHEN Y., SEGAL G., LANDER Y., *Measurement of talent in team handball: The questionable use of motor and physical tests*, J. Strength Cond. Res., 2005, 19(2), 318–325, DOI: 10.1519/1533-4287(2005)19[318:MOTITH]2.0.CO;2.
- [16] NIKOLAIDIS P.T., AFONSO J., CLEMENTE-SUAREZ V.J., ALVARADO J.R.P., DRISS T., KNECHTLE B., TORRES-LUQUE G., *Vertical jumping tests versus Wingate anaerobic test in female volleyball players: The role of age*, Sports, 2016, 4 (1), 9, DOI: 10.3390/sports4010009.
- [17] NIKOLAIDIS P.T., GKLOUDAS K., AFONSO J., CLEMENTE-SUAREZ V.J., KNECHTLE B., KASABALIS S., KASABALIS A., DOUDA H., TOKMAKIDIS S., TORRES-LUQUE G., *Who jumps the highest? Anthropometric and physiological correlations of vertical jump in youth elite female volleyball players*, J. Sports Med. Phys. Fitness, 2017, 57(6), 802–810, DOI: 10.23736/s0022-4707.16.06298-8.
- [18] NIKOLAIDIS P.T., INGEBRIGTSEN J., *Physical and physiological characteristics of elite male handball players from teams with a different ranking*, J. Hum. Kinet., 2013, 38(1), 115–124, DOI: 10.2478/hukin-2013-0051.
- [19] ROUSANOGLU E.N., BARZOUKA K.G., BOUDOLOS K.D., *Seasonal changes of jumping performance and knee muscle strength in under-19 women volleyball players*, J. Strength Cond. Res., 2013, 27 (4), 1108–1117, DOI: 10.1519/JSC.0b013e3182606e05.
- [20] SARVESTAN J., CHERAGHI M., SEBYANI M., SHIRZAD E., SVOBODA Z., *Relationships between force-time curve variables and jump height during countermovement jumps in young elite volleyball players*, Acta Gymnica, 2018, 48 (1), 9–14, DOI: 10.5507/ag.2018.003.
- [21] SHEPPARD J.M., GABBETT T.J., STANGANELLI L.C.R., *An analysis of playing positions in elite men's volleyball: Considerations for competition demands and physiologic characteristics*, J. Strength Cond. Res., 2009, 23 (6), 1858–1866, DOI: 10.1519/JSC.0b013e3181b45c6a.
- [22] SHEPPARD J.M., NOLAN E., NEWTON R.U., *Changes in strength and power qualities over two years in volleyball players transitioning from junior to senior national team*, J. Strength Cond. Res., 2012, 26(1), 152–157, DOI: 10.1519/JSC.0b013e31821e4d5b.
- [23] STOJANOVIĆ E., RISTIĆ V., MCMASTER D.T., MILANOVIĆ Z., *Effect of plyometric training on vertical jump performance in female athletes: A systematic review and meta-analysis*, Sports Med., 2017, 47(5), 975–986, DOI: 10.1007/s40279-016-0634-6.
- [24] SZMATLAN-GABRYŚ U., STANULA A., GABRYŚ T., OZIMEK M., STANISZ L., *Applying the kinematic parameters from the bosco jump test to evaluate the athlete's preparadness and to select training parameters*, Life Sci. J., 2014, 11(5), 383–388, DOI: 10.7537/marslsj110514.52.
- [25] THOMAS K., FRENCH D., HAYES P.R., *The effect of two plyometric training techniques on muscular power and agility in youth soccer players*, J. Strength Cond. Res., 2009, 23 (1), 332–335, DOI: 10.1519/JSC.0b013e318183a01a.
- [26] VAEYENS R., LENOIR M., WILLIAMS A.M., PHILIPPAERTS R.M., *Talent identification and development programmes in sport: Current models and future directions*, Sports Med., 2008, 38 (9), 703–714, DOI: 10.2165/00007256-200838090-00001.
- [27] WEISS L.W., RELYEA G.E., ASHLEY C.D., PROPST R.C., *Using velocity-spectrum squats and body composition to predict standing vertical jump ability*, J. Strength Cond. Res., 1997, 11 (1), 14–20, DOI: 10.1519/00124278-199702000-00004.
- [28] WOLEDGE R.C., *Possible effects of fatigue on muscle efficiency*, Acta Physiol. Scand., 1998, 162 (3), 267–273, DOI: 10.1046/j.1365-201X.1998.0294e.x.
- [29] ZIV G., LIDOR R., *Vertical jump in female and male volleyball players: A review of observational and experimental studies*, Scand. J. Med. Sci. Sports, 2010, 20 (4), 556–567, DOI: 10.1111/j.1600-0838.2009.01083.x.