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# Relationships of the 5-Jump Test (5JT) Performance of Youth Players With Volleyball Specific' Laboratory Tests for Explosive Power

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**Abstract**

Volleyball involves movements with and/or without horizontal approaches (i.e., spike jumps, jump setting, blocking). The 5-jump test (5JT) was suggested to assess lower limb explosive power of athletes competing in some disciplines (e.g., soccer, judo, running). It appears that no previous study has investigated the 5JT performance components in volleyball players. This study aimed to test the relationship between 5JT performance and two specific laboratory tests for explosive power (i.e., countermovement jump [CMJ] and squat jump [SJ]). Forty volleyball players (boys, mean age: 12.4 ± 0.8 years) were tested for 5JT, CMJ, and SJ tests. 5JT performance was expressed in absolute terms (m), and relative to leg length ($5JT_{LL}$) and body mass ($5JT_{BM}$). The SJ and CMJ tests were evaluated using the optojump photoelectric cells and the following data were collected: peak power (Pp) of jump (W, $W.kg^{-0.67}$), peak jumping force ($F_{peak}$, N), peak jumping velocity ($V_{peak}$, m/s), peak heights of CMJ and SJ ($CMJ_H$ and $SJ_H$, respectively, cm). Only significant ($p < .05$) Pearson product-moment correlations ($r$) > 0.30 were considered. 5JT performance was significantly correlated with SJ, $V_{peak}$ ($r = 0.90$), $SJ_H$ ($r = 0.88$), Pp [$W.kg^{-0.67}$ ($r = 0.86$), W ($r = 0.72$)], $F_{peak}$ ($r = 0.45$); and CMJ, $V_{peak}$ ($r = 0.82$), $CMJ_H$ ($r = 0.80$), Pp [$W.kg^{-0.67}$ ($r = 0.89$), W ($r = 0.85$)], $F_{peak}$ ($r = 0.73$). $5JT_{LL}$ values were significantly related to SJ, Pp [W ($r = 0.81$), $W.kg^{-0.67}$ ($r = 0.74$)], $V_{peak}$ ($r = 0.82$); and CMJ, Pp [W ($r = 0.73$), $W.kg^{-0.67}$ ($r = 0.84$)], $V_{peak}$ ($r = 0.75$), $F_{peak}$ ($r = 0.67$)]. $5JT_{BM}$ values were significantly related to SJ, Pp (W, $r = -0.43$). To conclude, in youth volleyball players, the 5JT may be viewed as an explosive strength diagnostic instrument under field circumstances.

**Keywords**

explosive power, vertical jump, leg strength, volleyball, youth

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Volleyball, a complex sport that depends on technical, tactical, and physical abilities, is characterized by several ballistic efforts, such as vertical jumps, shots, and rapid changes of direction (Forthomme et al., 2017). Thus, neuromuscular jumping performance might play an important role in team success and should be relevant for the player's physical preparation (Lehnert et al., 2017). The jumping activities can include movements with and/or without horizontal approaches (i.e., spike jumps, jump setting, blocking; Sheppard et al., 2008). In the literature, several ways were described to assess performances of volleyball players (e.g., anthropometric characteristics; Duncan et al., 2006). Considering the tactical nature of

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the jumping activities (e.g., during spike performance) and the frequency with which they occur in volleyball practice, these activities are considered as critical performance indicators (Forthomme et al., 2017). For example, in adults' high-level volleyball practice, Forthomme et al. (2017) concluded that "some specific strength and physical characteristics correlated significantly with spike performance."

The relevance of the relationships among strength, power, and vertical jump performance is supported by several studies (Goncalves et al., 2019; Sheppard et al., 2008). It seems that specific relationships among the aforementioned different variables may vary from one sport to another and depend on the development levels of players. Vertical jump performance has been used to indicate performance improvements in stretch shortening cycle utilization and lower limb abilities (Chamari et al., 2008; Paavolainen et al., 1999; Spurrs et al., 2003). Ridderikhoff et al. (1999) identified that maximal jump power is not significantly different between vertical and horizontal jumps and concluded that "a jump for distance may be achieved using control of a vertical jump according to a 'rotation-extension' strategy." Despite the popularity of the vertical jumping test, this method requires specified testing protocols and expensive equipments (i.e., force platforms, optojump photoelectric cells), which may limit its use in field conditions (Chamari et al., 2008). Two previous studies had suggested the 5-jump test (5JT, also called the 5-bound test; Spurrs et al., 2003) for horizontal jump distance as a practical alternative to evaluate lower limb abilities of trained young judokas (good correlation-coefficient ($r$) between 5JT and countermovement jump [CMJ] at 0.63; Bouhlel et al., 2006) and adult soccer players (high $r$ between 5JT and peak jumping velocity [$V_{peak}$] at squat jump [SJ] around 0.73; Chamari et al., 2008). The 5JT, consisting of five successive horizontal jumps, is easy to perform and does not require an expensive equipment (Stolen et al., 2005). This test includes the subject's $5JT_{LL}$ (5JT divided by leg length) and $5JT_{BM}$ (5JT divided by body mass [BM]; Stolen et al., 2005). The 5JT is an additional mean of assessing muscle explosive power (Bouhlel et al., 2006; Paavolainen et al., 1999). A certain analogy between the vertical rebound and 5JT (shortness and maximal character of the exercise) suggests similarities in the evaluation of power and/or performance (Bouhlel et al., 2006). A previous study has shown that explosive strength training by means of the 5JT increases muscle power by improving neuromuscular characteristics (e.g., increasing muscle strength, recruitment of motor units) or by a significant increase in muscle mass (Paavolainen et al., 1999). The 5JT therefore makes it possible to train the power qualities of muscle groups in the lower limbs. The 5JT is sometimes used as an alternative to the vertical jump test (Bouhlel et al., 2006; Chamari et al., 2008; Paavolainen et al., 1999). Both tests indirectly measure jump performances (Paavolainen et al., 1999). When studying a group of children, Diallo et al. (2001) hypothesized that the increase in 5JT performances denotes a change in the level of neuromuscular activation (neural factors) and motor coordination in response to specific plyometric training. The 5JT is presently used in field circumstances to evaluate athletes' lower limb explosive power and to calculate the distance covered (Bouhlel et al., 2006; Chamari et al., 2008; Diallo et al., 2001). Absolute performance of the 5JT (in meter) can mask the results if the body size is not considered (Bouhlel et al., 2006; Chamari et al., 2008). In order to make an analysis of the leg muscle power reliable, two relative expressions of 5JT performance (i.e., $5JT_{LL}$ and $5JT_{BM}$) were advanced in the literature (Chamari et al., 2004, 2008; Stolen et al., 2005). Despite the popularity and practicability of the 5JT in different sports (e.g., soccer, judo, running; Ben Ayed et al., 2011; Bouhlel et al., 2006; Chamari et al., 2008; Paavolainen et al., 1999; Spurrs et al., 2003), it appears that no previous study has investigated the performance components of the 5JT in volleyball players.

Since the volleyball game involves jumping activities with and/or without horizontal approaches (i.e., spike jumps, jump setting, blocking; Sheppard et al., 2008), the primary aim of this study was to characterize the horizontal power and jumping performance in volleyball youth players. Consequently, the objective of this study was to test the relationships of the 5JT performance with laboratory tests for explosive power (CMJ and SJ tests).

## Participants and Methods

### Study Design

This was a cross-sectional study carried out during the second half of August 2013 in the Department of Physiology of the Faculty of Medicine of Sousse (Tunisia). All the testing procedures were in accordance with the Helsinki Declaration and were approved (approval number: 19032018) by the Ethics Committee of the Farhat Hached Hospital (Sousse, Tunisa). All the boys and their parents were informed about the experimental procedure. The parents were asked to complete a written informed consent approving the participation of their boys. The boys were informed that they could withdraw from the study at any time and for any reason.

### Participants

Youth volleyball players (boys, mean age: 12.4 ± 0.8 years), competing for full selection within the Sport

Academy "Talent Volleyball Program," volunteered to take part in this study. The Academy aimed to identify young players deemed to have the necessary physiological and anthropometric characteristics (e.g., stature, standing reach stature, muscular power, speed, agility and technical abilities) for volleyball success and therefore to include them in a performance coaching environment. At the time of the experiment (pre-season period), the average weekly training schedule of the volleyball players included 8 hr/week, essentially volleyball-related activities (technical and tactical training, weekend competitions), in addition to physical education courses at school (3 hr/week). As recommended by the Tunisian Volleyball League, very rare specific track programs in volume and intensity were administered for the 10–14 years' category. All volleyball players had a 2- to 4-year background of volleyball training and competition experience at the Volleyball Promotion School Centre Competition Program. Players had followed a 4-week preseason training (July 15 to August 15) after 2 months of off-season training (May 15 to July 15). Boys were not included if they had chronic conditions that would limit their activity to perform exercise or if they presented injuries of the lower limbs. The players were asked to wear shorts and running shoes and to abstain from exercise one day before the applied tests (SJ, CMJ, and 5JT).

### Anthropometry

Standing height was measured to the nearest 0.1 cm (Vivioz Medical, Paris, France) with the player standing barefoot and head in the horizontal plane. BM was assessed to the nearest 0.1 kg (TBF-543, Tanita Corporation, Arlington Heights, Illinois, USA). Leg muscle volume was estimated by quantifying the circumferences at the maximal level of the calf and just above the ankle (from trochanter major to lateral malleolus) and was added to the thigh volume (Davies et al., 1972; Jones & Pearson, 1969). Body fat percentage was calculated based on four skinfolds (biceps, triceps, subscapularis, and supra-iliac) measurements (Siri, 1961) using a standardized kit (Harpenden Skinfold Caliper, Sweden). Maturity status was visually assessed using the indices for pubic hair development (Tanner, 1962).

### Testing Protocol

Figure 1 illustrates the study protocol. During the 24-hr period before performing the tests, the players did not engage in any activity that was considered unduly fatiguing with respect to jumping. Following their arrival at the evaluation site, the players were asked to sit comfortably. Five min later, anthropometric measurements were performed. BM and height were measured before the

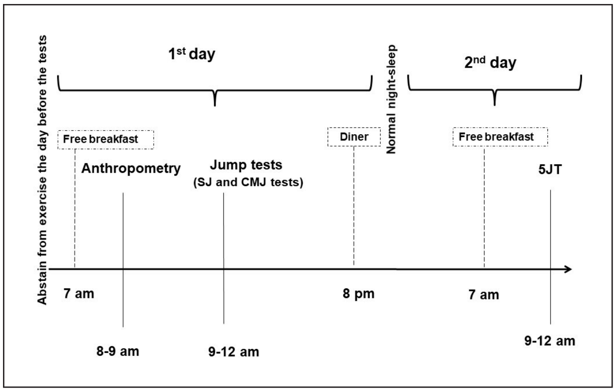


**Figure 1.** Study flowchart.
CMJ = countermovement jump; SJ = squat jump; 5JT = 5-jump test.

warm-up protocol in the first testing session. The first day of testing included measurements of the anthropometric and vertical jumping (SJ and CMJ tests) data. During the second day, the players performed three trials of field 5JT. All the players completed jump tests and 5JT in order to assess their ability during jumping on the optojump system. As for the first day, the players completed their typical warm-up practice before all the testing sessions. The warm-up included 10 min of general activity (e.g., walking, jogging, light stretching), followed by 10 min of dynamic activity with progressive increase in speed and intensity (e.g., skipping, leg and arm swings), 10 min of two players' volleyball skill rally setting, and 5 min of rest before the first testing session. In order to avoid the effect of the circadian rhythm, all tests were performed in the morning between 9:00 and 12:00 am with a temperature ranging between 22.5 and 23.0 °C. The tests were carried out after an unvarying free breakfast for each player. All the players were liberally hydrated throughout the tests.

### Applied Tests: Explosive Force and 5JT

Dynamic explosive force was measured on the optojump photoelectric cells (Microgate, Bolzano, Italy). Each player performed a maximal CMJ and SJ. The peak height of the jump ($_H$), jumping force ($F_{peak}$), $V_{peak}$, and peak power (Pp) of the jump were assessed for both SJ and CMJ tests. The players were carefully familiarized with the testing procedure during a pre-measurements session. First, the players performed the SJ from a semi squatting position maintained for 4 s, without countermovement (i.e., 90° angle of the knee joint), and with hands held at their hips. Second, the players performed the CMJ with free countermovement positions while squatting down and extending the knees in a continuous movement, and their hands were freely used while jumping. In volleyball players, the SJ and the CMJ assess

**Table 1.** Anthropometrical Data ($n$ = 40).

| | | Mean ± *SD* | Minimum | Maximum | 95% CI |
|---|---|---|---|---|---|
| Age | (years) | 12.4 ± 0.8 | 11.0 | 13.6 | [12.1, 12.6] |
| Height | (cm) | 150 ± 8 | 134 | 162 | [147, 152] |
| Body mass | (kg) | 39.1 ± 5.4 | 28.0 | 48.0 | [37.4, 40.8] |
| Body mass index | (kg/m$^2$) | 17.4 ± 2.1 | 14.3 | 22.2 | [16.7, 18.1] |
| Leg length | (cm) | 74.7 ± 4.5 | 67.0 | 84.0 | [74.8, 78.3] |
| Body fat | (%) | 14.2 ± 1.1 | 13.2 | 15.1 | [13.8, 14.4] |
| Leg muscle volume | (l) | 4.7 ± 0.6 | 3.2 | 5.5 | [4.5, 4.9] |

*Note.* CI = confidence interval [low limit, high limit]; SD = standard deviation.

volleyball-specific skills (Berriel et al., 2020; Formenti et al., 2020). These tests appear more appropriate considering the metabolic pathways and biomechanics properties of spike jump, block jump, and other volleyball-related moves (Wagner et al., 2009). These tests are used to evaluate players' performance at different training times during a championship preseason (Berriel et al., 2020). The CMJ test plays a role in discriminating players of different competitive levels (Formenti et al., 2020).

The 5JT is presently used in field circumstances to evaluate athletes' lower limb explosive power and to determine the distance covered (Bouhlel et al., 2006; Chamari et al., 2008; Paavolainen et al., 1999). The 5JT was performed in an indoor hall. Each player started the test with joined feet and he had to select which foot to put first at the start of the exercise. Throughout the last stride, the player was asked to end with joined feet. Before finishing the tests, each player completed numerous familiarization trials (Chamari et al., 2008; Farhat et al., 2016). Absolute distance of the 5JT was measured with a tape, and two relative expressions of 5JT performance—that is, $5JT_{LL}$ (= 5JT/LL) and $5JT_{BM}$ (= 5JT/BM)—were considered in this study. A dimensional scaling based on BM was used to allow direct comparisons with comparable studies (Chamari et al., 2004, 2008; Markovic & Jaric, 2007).

### Statistical Analysis

*Sample Size.* A cross-sectional study was performed to estimate the correlation between two quantitative variables of interest: 5JT and CMJ. The sample size was obtained by computing $N = [((Z_{\alpha/2} + Z_{1-\beta})^2) / (1/4 (\log_e ((1 + r) / (1 - r))] + 3$, where "$Z_{\alpha/2}$" is the normal deviates for type I error (= 1.96 for 5% significance level); "$Z_{1-\beta}$" was the study power (= 1.64 for 95% power). In a previous Tunisian study, including 18 trained judokas (age: 12 ± 0.4 years), the $r$ between 5JT and vertical jump (CMJ) was 0.63 (Bouhlel et al., 2006). The appraised sample size for the two-tailed alternative test gave a sample of 38 players.

*Data Expression and Applied Statistical Tests.* The experimental values were expressed as mean ± standard-deviation (*SD*; minimum–maximum; [95% confidence interval]).

Pearson product-moment correlation "Pearson $r$" was performed between the data of the vertical (SJ and CMJ) and horizontal (5JT) jumps. The Pearson $r$ was considered "high" when it was >0.70, "good" when it was between 0.50 and 0.70, "fair" if it was between 0.30 and 0.50, and "weak or no association" if it was <0.30 (Hinkle et al., 2003). The presence of a significant ($p <$ 0.05) Pearson $r$ >0.30 was considered a valid criterion for the 5JT to assess lower limb explosive power in youth volleyball players.

The data were analyzed using Statistica 6.0 (Staistica Kernel version 6, Statsoft, France). The threshold for statistical significance was set at $p < .05$.

## Results

Forty volleyball players participated in this study. All were at the second stage of maturation. Table 1 presents their physical characteristics, while Table 2 summarizes the data of the different applied tests.

Figure 2 illustrates the relationship between 5JT (m) and $CMJ_H$ (Figure 2A) and $SJ_H$ (Figure 2B). Both correlations were "high" at 0.797 and 0.877, respectively. Table 3 presents the Pearson $r$ values between 5JT performance (5JT, $5JT_{LL}$, $5JT_{BM}$), SJ, and CMJ. For 5JT, the correlation was "high" with SJ ($P_p$ and $V_{peak}$) and CMJ ($P_p$, $F_{peak}$, $V_{peak}$), and "fair" with $F_{peak}$ SJ. For $5JT_{LL}$, the correlation was "high" with SJ ($P_p$, $V_{peak}$) and CMJ ($P_p$, $V_{peak}$); "good" with $F_{peak}$ CMJ; and absent with $F_{peak}$ SJ. For $5JT_{BM}$, the correlation was "fair" with $P_p$ SJ (W) and absent with the remaining data.

## Discussion

This study identified a "high" relationship between 5JT and the parameters' power of the SJ and CMJ tests. Specifically, 5JT (m) was highly correlated with $SJ_H$ ($r$ = 0.88) and $CMJ_H$ ($r$ = 0.80).

**Table 2.** 5-Jump Test (5JT), Squat Jump (SJ), and Countermovement Jump (CMJ) Data ($n$ = 40).

| | | | Mean ± *SD* | Minimum | Maximum | 95% CI |
|---|---|---|---|---|---|---|
| 5JT | 5JT | m | 8.8 ± 0.0 | 8.7 | 8.8 | [8.8, 8.8] |
| | $5JT_{BM}$ | m/kg | 343.6 ± 47.7 | 246.8 | 421.2 | [328.3, 358.8] |
| | $5JT_{LL}$ | m/l | 2.4 ± 0.1 | 2.1 | 2.6 | [2.3, 2.4] |
| SJ | $P_p$ | W | 2322.0 ± 522.5 | 1407.0 | 3451.0 | [2154.8, 2489.1] |
| | $P_p$ | $W.kg^{-0.67}$ | 196.5 ± 47.7 | 122.2 | 283.5 | [181.2, 211.8] |
| | $F_{peak}$ | N | 900.6 ± 186.7 | 659.9 | 1365.7 | [840.9, 960.3] |
| | $V_{peak}$ | m/s | 2.4 ± 0.2 | 2.0 | 2.8 | [2.3, 2.5] |
| | $SJ_H$ | cm | 33.1 ± 1.6 | 30.2 | 35.8 | [32.6, 33.7] |
| CMJ | $P_p$ | W | 3152.8 ± 645.4 | 1930.6 | 4378.0 | [2946.4, 3359.2] |
| | $P_p$ | $W.kg^{-0.67}$ | 269.2 ± 62.0 | 155.3 | 388.8 | [249.4, 289.1] |
| | $F_{peak}$ | N | 1165.8 ± 127.9 | 907.0 | 1393.0 | [1124.9, 1206.7] |
| | $V_{peak}$ | m/s | 2.7 ± 0.3 | 2.0 | 3.2 | [2.5, 2.8] |
| | $CMJ_H$ | cm | 35.1 ± 2.8 | 30.0 | 39.2 | [34.2, 36.0] |

*Note.* 5JT (m) = absolute performance of the 5JT; $5JT_{BM}$ = 5JT/body-mass; $5JT_{LL}$ = 5JT/leg length; CI = confidence interval [low limit, high limit]; SD = standard deviation; $F_{peak}$ = peak force; $_H$ = height; $P_p$ = peak power; $V_{peak}$ = peak velocity.

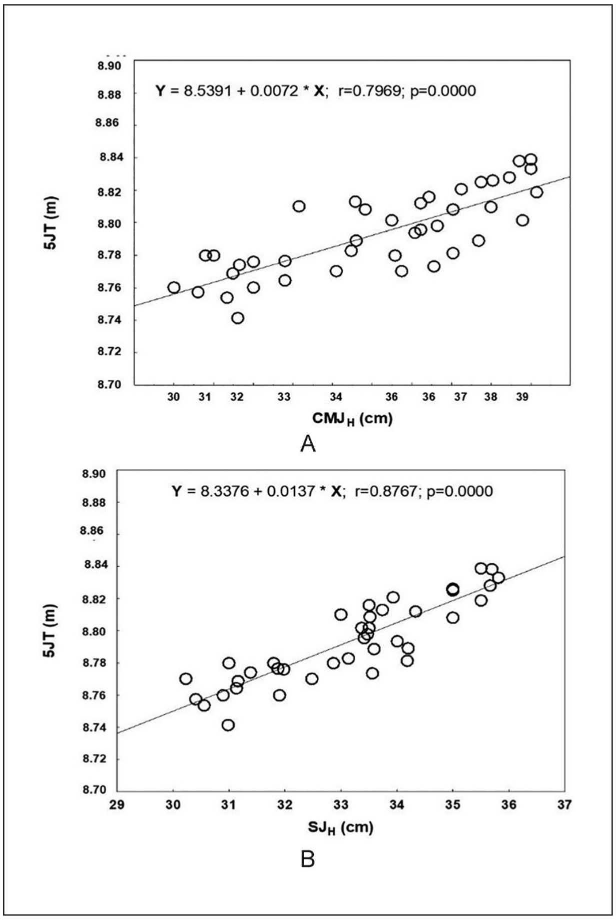


**Figure 2.** Relationships between the 5-jump test (5JT) and peak heights of countermovement jump ($CMJ_H$) (A) and squat jump ($SJ_H$) (B). The solid line denotes linear regression.
*p* = probability; *r* = Pearson product-moment correlation.

Volleyball is characterized by short bouts of explosive activity containing jumps, dives, sprints, spikes, and multidirectional court movements (Markovic et al., 2007; Markovic & Mikulic, 2010). In addition to technical and tactical skills, muscular strength and power are two vital points underlying effective performance (Markovic et al., 2007; Markovic & Mikulic, 2010). Lower-limb exercises, that is, jumping, hopping, and bounding, are characterized by the use of the stretch-shortening cycle that develops during the transition from a rapid eccentric muscle contraction (deceleration/negative phase) to a rapid concentric muscle contraction (acceleration/positive phase) (Markovic et al., 2007; Markovic & Mikulic, 2010). The stretch-shortening cycle exercises capitalize on the elastic properties of connective tissue and muscle fibers by permitting the muscle to store elastic energy during the deceleration/negative phase and release it later during the acceleration/positive phase to enhance muscle force and power output (Hakkinen et al., 1985; Markovic & Mikulic, 2010). During the game, the volleyball players achieved numerous different categories of jumping, differentiated by execution and height of the jump reach. The jump height was related to the speed of movements preceding the jump-up (Mroczek et al., 2018). It was also found that the approaches to numerous jump movements need different properties of strength (Young et al., 1995). Based on this information, Mroczek et al. (2018) revealed that the greater progress was for the vertical jump with a three-step approach. It should be understood that the faster the execution of the three-step approach (maximum speed/high intensity of movement), the higher the height reached in the jump (Mroczek et al., 2018). Mroczek et al. (2018) hypothesized that it could be because of the bigger resemblance of the movement structure of the

**Table 3.** Correlation Matrix Between 5JT and Jump Tests (SJ and CMJ), $n = 40$.

| | | 5JT | $5JT_{LL}$ | $5JT_{BM}$ | SJ | | | | CMJ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | m/l | m/kg | $P_pJ$ (W) | $P_pJ$ (W.kg$^{-0.67}$) | $F_{peak}$ (N) | $V_{peak}$ (m/s) | $P_pJ$ (W) | $P_pJ$ (W.kg$^{-0.67}$) | $F_{peak}$ (N) | $V_{peak}$ (m/s) |
| 5JT | (m) | 1 | | | | | | | | | | |
| $5JT_{LL}$ | (m/l) | 0.75* | 1 | | | | | | | | | |
| $5JT_{BM}$ | (m/kg) | −0.19 | −0.43* | 1 | | | | | | | | |
| SJ | $P_p$ (W) | 0.72* | 0.81* | −0.43* | 1 | | | | | | | |
| | $P_p$ (W.kg$^{-0.67}$) | 0.86* | 0.74* | −0.13 | 0.72* | 1 | | | | | | |
| | $F_{peak}$ (N) | 0.45* | 0.15 | 0.10 | 0.37* | 0.36* | 1 | | | | | |
| | $V_{peak}$ (m/s) | 0.90* | 0.82* | −0.17 | 0.81* | 0.91* | 0.37* | 1 | | | | |
| CMJ | $P_p$ (W) | 0.85* | 0.73* | −0.21 | 0.76* | 0.83* | 0.35* | 0.82* | 1 | | | |
| | $P_p$ (W.kg$^{-0.67}$) | 0.89* | 0.84* | −0.18 | 0.77* | 0.87* | 0.31* | 0.92* | 0.88* | 1 | | |
| | $F_{peak}$ (N) | 0.73* | 0.67* | −0.20 | 0.54* | 0.65* | 0.12 | 0.67* | 0.84* | 0.77* | 1 | |
| | $V_{peak}$ (m/s) | 0.82* | 0.75* | −0.18 | 0.79* | 0.86* | 0.34* | 0.85* | 0.90* | 0.87* | 0.69* | 1 |

*Note.* 5JT = 5-jump test; $5JT_{BM}$ = 5JT/body mass; $5JT_{LL}$ = 5JT/leg length; CMJ = countermovement jump; $F_{peak}$ = peak force; $P_p$ = peak power; SJ = squat jump; $V_{peak}$ = peak velocity.
Data were Pearson product-moment correlation.
*$p < .05$.

achieved jump exercises with the attack jump approach in volleyball. This is very vital information from a practical standpoint, in that the maximum speed of short distance movement (3–5 m) should also be encompassed into volleyball training (Mroczek et al., 2018). Given the "pioneer" design of this study and despite the fact that youth are not miniature adults (Miladi et al., 2020), 5JT data comparison will be made with related studies achieved on adults.

Although the 5JT is an estimate of explosive leg muscle power (Paavolainen et al., 1999), only some studies have validated it in athletes such as soccer players, judoka, and runners (Ben Ayed et al., 2011; Bouhlel et al., 2006; Chamari et al., 2008; Paavolainen et al., 1999; Spurrs et al., 2003). The 5JT is an interesting means to evaluate children in terms of segmental coordination work compared to long distance runs, sprints, or jumps usually used by coaches to study the potential of their young groups, thus avoiding the use of more precise methods (Chamari et al., 2008; Paavolainen et al., 1999). It appears that the present study is the first to test the relationships of 5JT performance with tests for explosive power in volleyball youth players.

Some resemblances between the vertical and horizontal leg jumps are generally reported as independent tasks featuring dissimilar leg strength/power qualities (short and maximum characteristic achievement). Meylan et al. (2009) agree to recognize an association in the evaluation of performance in terms of muscular power. The authors, exploring the interrelationship in vertical and horizontal jump assessments, have reported a good correlation ($r$ = 0.64) and a shared variance of ~45% between single leg vertical and horizontal jump tests (Meylan et al., 2009). In this context, Dobbs et al. (2015) provided that horizontal mean and peak force are useful prognostic measures for many functional movements (i.e., sprint speed and jumps), and should be included with their vertical counterparts. This could provide fitness coaches with useful information about the physical qualities of their players, which is not fully captured by relying on vertical measures alone. The 5JT has been proposed as being a test for the assessment of athletes and for the improvement in running performance (Spurrs et al., 2003). Paavolainen et al. (1999) reported that explosive strength training using the 5JT may increase muscular strength by improving the neuromuscular characteristics. Chamari et al. (2008) indicated that the 5JT may be a suitable field test for computing stride power in soccer players. All these findings seem to confirm that this test satisfactorily estimates the muscle power of the lower limbs. In fact, the 5JT and the $5JT_{LL}$ are correlated with the power variables of SJ and CMJ jumps (Table 3). Potential mechanisms for developing jump performance in volleyball players include more efficient movements due to changes in the temporal sequencing of muscle activation, the preferential recruitment of fast motor units, and the increased nerve conduction velocity (Wragg et al., 2000). In fact, the performance of the $P_p$ depends on the capacity of using adenosine triphosphate (ATP)-creatine phosphate reserves, which are closely related to the muscle volume (Bencke et al., 2002; Van Praagh & Dore, 2002). Children have a lower glycolytic capacity than adults, but in contrast to the adults' muscle, this is associated with a very rapid creatine phosphate resynthesize rate and a higher oxidative capacity (Taylor et al., 1997). Short and intense efforts that last less than 1–2 s mainly involve ATP depots in the muscles, and performance will depend on the cross-section and type of muscle fibers as well as the central nerve innervation capacity (Taylor et al., 1997).

Similar to classical jumping movements (i.e., SJ and CMJ), acceleration of the centre of mass during the attack and volleyball movements is executed by both legs (Wagner et al., 2009). If one is interested in the intrinsic quality of the muscles being exercised, it is important to have a measurement reflecting the dimensions of the active muscles (Van Praagh & Dore, 2002). Since a volleyball player must move his BM to spike as high as possible, it is therefore necessary to calculate the $5JT_{BM}$. Chamari et al. (2008) reported significant correlations between the $5JT_{BM}$ and the power jump parameters data in adults' soccer players. The authors were able to demonstrate relationships between jump types, SJ and CMJ, with the $P_p$ ($r = 0.82$ and $r = 0.54$, respectively), and the $F_{peak}$ ($r = 0.67$ and $r = 0.65$, respectively; Chamari et al., 2008). The $5JT_{BM}$ yielded values that correlated with the variables of explosive power (Chamari et al., 2008). The different correlations identified in this study could be due to certain factors varying from one discipline to another (e.g., soccer vs. volleyball) and from one participant to another (e.g., adults vs. children). These differences might be attributed to segmental coordination that is necessary for the performance of different types of jumps in volleyball (Bencke et al., 2002), to differences in muscular fibers, and to neuromuscular activity (Kotzamanidis et al., 2005). Given the physical demands of volleyball coupled with the length of a volleyball match, volleyball players require well-developed speed, agility, and upper body and lower body muscle power (Gabbett & Georgieff, 2006, 2007; Goncalves et al., 2019). A significant recruitment of motor units from the neuromuscular system during various jumps (e.g., attack vs. block in volleyball; Gabbett & Georgieff, 2007) and intensive short repetitive movements during a volleyball match (Hakkinen, 1993) may partly explain the differences between adults and children. The latter suggests that lower limbs' muscular power might be explained by the production of high velocity during the vertical jump take-off coupled with force variable in the CMJ (stretch-shortening cycle). It is therefore comparable with the attack movement during the volleyball game (Hakkinen, 1993). In this study, the 5JT satisfactorily measures the power of lower limbs. However, strength and speed variables may influence the relationship between the 5JT and the $P_p$. Indeed, strong significant correlations were observed between the 5JT and SJ $V_{peak}$ ($r = 0.90$), the $5JT_{LL}$ and SJ $V_{peak}$ ($r = 0.82$), the 5JT and CMJ $V_{peak}$ ($r = 0.82$), and the $5JT_{LL}$ and CMJ $V_{peak}$ ($r = 0.75$). Conversely, Chamari et al. (2008) reported that this relationship is mainly explained by a strong production of strength ($F_{peak}$). The latter may be attributed to differences in maturation, muscular volume, and to the capacity of muscular recruitment of contractile units (motor units) to accomplish strength increase during the soccer players' movements compared with the youth volleyball players involved in this study. These differences might be attributed to the nature of the discipline (itself) practiced (e.g., soccer vs. volleyball). Some studies have reported a great adaptation of $P_p$ in prepubescent children during training and a positive effect on vertical jump performance through a plyometric training in children aged 11 years (Faigenbaum et al., 2002; Kotzamanidis, 2006). Therefore, the 5JT can be considered as a suitable training means and assessment of lower limbs muscle power in young male volleyball players. The findings of this study highlight that the 5JT may be a suitable field test for evaluating volleyball players' power. The 5JT offers an interesting measurement of explosive power because of the limited facilities needed compared to the assessment of vertical jumping and lower limbs' power, which requires sophisticated materials. Coaches who do not have direct access to laboratory equipments can use the 5JT in order to test lower limb horizontal explosive power.

This study presents three limitations. The first is related to its observational nature. For example, as the number of recorded factors increases, the likelihood of finding positive results increases. At least one of the recorded factors will be highly correlated with the data output simply by chance (von Elm et al., 2007). Moreover, in order to make their conclusions easier to understand and generalize, observational studies are called to conform to several criteria (von Elm et al., 2007). However, observational studies are reported to provide information on "real-world" use and practice and to help formulate hypotheses to be tested in subsequent experiments (von Elm et al., 2007). The second limitation is related to the horizontal approach during the 5JT. While during a volleyball match, players performed a maximum of three steps during a spike action, during the 5JT, they realized five steps. Therefore, the *interest* of a 5JT in volleyball is *questionable*. However, some studies have proposed the 5JT as a practical alternative to estimate lower limb explosive power of a selected population of athletes (Bouhlel et al., 2006; Chtara et al., 2005; Paavolainen et al., 1999; Spurrs et al., 2003). The third limitation concerns the real field applicability of the 5JT by volleyball coaches. In practice, some coaches preferred other muscle power tests (e.g., block jump and the attack jump tests [Sattler et al., 2012]; Abalakov jump and Wingate anaerobic test [Nikolaidis et al., 2016]; deep squat, triple hop for distance, triple jump for distance, sidearm medicine ball throw, and SJ [Tabatabaei et al., 2017]). Their choices are based more on the similarity of the tests with the movement patterns and performance capabilities in volleyball (Tabatabaei et al., 2017).

In conclusion, this study identified significant relationships between the calculated 5JT and $5JT_{LL}$, and the parameters of jumping. Supplementary data in this field may aid volleyball coaches in monitoring more precisely their training programs and in the detection of some talents. The authors strongly recommend the use of the 5JT to assess lower limb explosive power in youth volleyball players. The 5JT may prove effective in measuring the response of individual players to both training and evaluation. Further studies, with respect to different sports games and to the EMG response of the muscles involved in jumping performance, are needed to confirm the use of the 5JT as a field test.

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## Authors' contributions

**KBA, HBS and IL:** literature search, data collection, study design, analysis of data, manuscript preparation and review of manuscript.
**MAH:** performed the statistical analysis and helped draft the manuscript.
**All authors read and approved the final manuscript.**

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## Supplemental Material

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