ORIGINAL ARTICLE

The relationship between power, speed and agility in youth volleyball players

Relation entre puissance musculaire, vitesse et agilité chez les jeunes volleyeurs

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Abstract

Introduction: In youth volleyball players, no previous study has investigated the relationships between the components of the force-velocity test (FVt) and those of the horizontal jump approach, speed test, and agility test.

Aim: To determine the relationships that exist between lower-body power measured via a laboratory test (i.e.; FVt) and some field tests [horizontal jump (i.e.; 5-jump test (5JT)), speed test (i.e.; 20-m sprint) and agility test (i.e.; changing of direction (CoD)] in youth volleyball players.

Methods: Thirty-one youth volleyball players were investigated for CoD, 5JT, and absolute/relative peak leg power (P_{peak}) during the FVt. Speeds (s) during a 20-m sprint were measured at 5, 10, and 20 m (T_5, T_{10} and T_{20}, respectively). 5JT performance was expressed in absolute terms ($5JT_A$, m), and relative to leg length and body-mass. Pearson correlation coefficient (r) was performed among the variables of the FVt, 20-m sprint, CoD, and 5JT tests. "r" was considered "high" when it was > 0.70, "good" when it was between 0.50-0.70, "fair" when it was between 0.30-0.50, and "weak or no association" when it was < 0.30.

Results: This study identified i) "high" correlations between $FVtP_{peak}$ (W) and 20-m sprint [T_5 (r=-0.858), T_{10} (r=-0.707), and T_{20} (r=-0.762)], and CoD (r=-0.745), ii) "good" correlations between $FVtP_{peak}$ (W.kg) and $5JT_A$ (r=0.531), and iii) "fair" correlations between $FVtP_{peak}$ (W) and $5JT_A$ (r=0.499), between $FVtP_{peak}$ ($W.kg^{-0.67}$) and $5JT_A$ (r=0.489), and 20-m sprint [T_5 (r=-0.370), T_{10} (r=-0.364)].

Conclusion: CoD, 20-m sprint, and 5JT can be used to evaluate lower limb explosive power in youth volleyball players.

Keywords: Agility, field-testing, leg power, muscle strength, speed, volleyball

Résumé

Introduction: Chez les jeunes volleyeurs, peu d'études ont exploré les relations entre le saut horizontal, les tests de vitesse et d'agilité, et les composantes du test force-vitesse (FVt).

Objectif: Analyser les relations entre la puissance des membres inférieurs mesurée en laboratoire (FVt) et des tests de terrain (saut horizontal: test de 5 sauts (T5S), sprint sur 20 m, et changement de direction (CdD)).

Méthodes: Trente et un jeunes volleyeurs masculins ont été évalués pour le CdD, le T5S, et la puissance pic des jambes absolue/relative (P_{pic}) durant le FVt. La vitesse (s) lors d'un sprint de 20 m a été mesurée aux distances de 5, 10 et 20 m (T_5, T_{10}, T_{20}). Les performances au T5S ont été exprimées en valeurs absolues ($T5S_A$, m), et en fonction de la longueur des jambes et du poids. Le coefficient de corrélation de Pearson (r) a été calculé entre les variables des tests FVt, sprint de 20 m, CdD et T5S. Le coefficient "r" a été considéré comme "élevé" lorsqu'il était > 0,70, "bon" lorsqu'il était compris entre 0,50 et 0,70, "moyen" entre 0,30 et 0,50, et "faible ou sans association" lorsqu'il était < 0,30.

Résultats: Cette étude a identifié des i) Corrélations «fortes» entre $FVtP_{peak}$ (W) et sprint 20 m [T_5 (r = -0,858), T_{10} (r = -0,707), T_{20} (r = -0,762)] ainsi que le CdD (r= -0,745); ii) Corrélations «bonnes» entre $FVtP_{pic}$ ($W·kg^{-1}$) et $T5S_A$ (r=0,531); iii) Corrélations «modérées» entre $FVtP_{pic}$ (W) et $T5S_A$ (r= 0,499), $FVtP_{pic}$ ($W.kg^{-0.67}$) et $T5S_A$ (r= 0,489), ainsi qu'avec le sprint 20 m [T_5 (r= -0,370), T_{10} (r = -0,364)].

Conclusion: Le CdD, le sprint 20 m et le T5S constituent des outils valides pour évaluer la puissance explosive des membres inférieurs chez les jeunes volleyeurs.

Mots-clés : Agilité, force musculaire, puissance musculaire, tests de terrain, vitesse, volleyball

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Introduction

Volleyball involves repeated, multidirectional movements requiring various physiological components during match play (1-4). Players execute maximal and high-intensity actions, including jumping, passing, attacking, blocking, sprinting, and rapid pace changes, depending on their position and role (1-7). These actions occur in short, high-intensity bouts with quick recovery periods, stressing anaerobic and aerobic energy systems (1, 2, 8, 9). Understanding the physical and physiological characteristics of young volleyball players (e.g.; strength, jump ability, agility, and speed) can guide targeted strength and conditioning programs (10). However, until late July 2025, few studies have examined specific performance metrics in young volleyball players competing in professional club environments (11). The high frequency of sprints, hops (blocking, spiking, change of direction (CoD)), and explosive movements during matches places significant demands on the neuromuscular system (11). Lower-body muscular strength and power, in addition to technical-tactical skills, are critical for successful volleyball performance (12). These qualities support agility, multidirectional movement, acceleration, and speed (4, 7), all of which are essential for the explosive efforts required during jumping, sprinting, and quick CoD actions in volleyball (7, 13-15). Players repeatedly perform stop-and-go CoD in response to unpredictable stimuli within a small court space (4, 7). The ability to start, stop, and change direction rapidly and efficiently is essential in team sports (15), particularly in volleyball, where these movements often occur in response to unplanned, unpredictable situations (16, 17). Lower-body strength and power are known prerequisites for effective CoD performance (15), and developing these qualities is essential for success (7, 11). This has led researchers to examine how these complex physical parameters can be improved through targeted training (4, 11, 15, 18-21).

Rapid generation of lower-body force and power is critical for volleyball-specific skills (4, 7, 22). Significant relationships between lower-body strength and CoD speed have been reported in athletes from various sports (22). For example, Anderson et al. (22) identified correlations between strength measures and CoD performance in collegiate female soccer players. However, there is limited research examining the relationship between lower-body power (i.e.; peak leg power (P_{peak}) measured via cycle ergometer (force-velocity test, FVt)), horizontal and vertical jumps, CoD, and sprint speed specifically in volleyball players (7, 18, 23-25). Investigating these relationships in youth volleyball players is practically and scientifically relevant, as it can guide coaches in designing effective training programs that directly enhance on-court performance while offering insights into the transferability of laboratory-based assessments like FVt to field-based performance tests. A previous Tunisian study highlighted the utility of the five-jump test (5JT) as a practical field diagnostic tool for explosive strength in youth volleyball players (n=40 boys) (11). The study examined correlations between 5JT (expressed as absolute distance ($5JT_A$), relative to leg length (LL, $5JT_{LL}$), and body-mass (BM, $5JT_{BM}$) and laboratory-based explosive power measures obtained from countermovement jump (CMJ), and squat jump (SJ) tests [e.g.; P_{peak} of the jump, peak jumping force (Fpeak), peak jumping velocity, peak heights of CMJ and SJ (CMJ_H and SJ_H, respectively, cm)] (11). The authors reported significant correlations between $5JT_A$ and SJ/CMJ variables, $5JT_{LL}$ and SJ/CMJ variables, and between $5JT_{BM}$ and SJP_{peak} (11).

Therefore, the purpose of this study was to determine the relationships that exist between lower-body power measured via a laboratory test (i.e.; FVt) and some field tests [horizontal jump (i.e.; 5JT), speed test (i.e.; 20-m sprint) and pro-agility test (i.e.; CoD) in youth volleyball players. The hypothesis was that FVt (W) data were correlated with field tests data (e.g.; $5JT_A$ (m)).

Population and methods

Study design

This was a cross-sectional study carried out in October 2019. All the testing procedures took place at the hall of the professional sports club Esperance Sportive of Tunisia. Approval for this study was granted from the Farhat HACHED Hospital Ethics Committee (approval number: FHHEC19032018), and the study conformed to the Declaration of Helsinki for medical research involving human participants and performed according to the Ethical standards in sport and exercise science research (26). All included boys and their parents provided written consent for testing and data analysis and were informed about the experimental procedure. The boys were informed that they could withdraw from the study at any time without any penalty.

Participants

The participants were youth volleyball players (n = 31 boys, age: 12 to 14 years), competing for full selection within the professional sports club “youth categories” who volunteered to take part in this study. Young volleyball programs offer a unique context to study expertise development in team sports. The aforementioned programs intended to recognize young players estimated to have the essential physiological and anthropometric characteristics (e.g.; stature, standing reach stature, muscular power, speed, agility and technical abilities) for volleyball success, and to include them in a performance-coaching situation (11).

At the time of the research (October 2019: beginning of the season period), participants were specifically trained three times (of 75 minutes duration) per week. The volleyball activity was practiced in the club's indoor local volleyball hall. The volleyball training included technical exercises, an adapted fitness program (e.g.; elastic theraband, body weights and adapted dumbbells workout) and especially mini-volley games (e.g.; 2 vs. 2, 3 vs. 3) with adapted court and rules. In addition, players had physical education courses at college [i.e.; two sessions (of 60 minutes each) per week]. As suggested by the Tunisian volleyball league, very scarce specific track programs in volume and intensity were managed for the "under 14 years' category". All participants had experience in volleyball training and a competition background of 3-5 years. Participants had followed a 6-week pre-season training (from August 19th to September 30th, 2019). Participants were not included if they had chronic diseases that would limit their activity to perform exercise or if they presented injuries of the lower limbs. All participants were required to be actively competing and training with the team and were injury-free at the time of testing. Taking into consideration the strain caused by sprint exercises on the muscle-tendon tissue, participants were under continual health observation in case of injury. Participants were instructed to wear shorts and running shoes, to arrive for testing sessions in a rested state, while avoiding strenuous exercise in the previous 48 hours, and to abstain from any exhausting activities between the test sessions.

Anthropometry and pubertal stage

Height was measured to the nearest 0.1 cm (Vivioz Medical, Paris, France) with the participant 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). BM index was calculated (kg/m^2). Leg muscle volume was estimated by quantifying the circumferences at the maximal level of the calf and just above the ankle (i.e.; from trochanter major to lateral malleolus) and was added to the thigh volume (27). LL and circumferences were measured using a standardized anthropometric kit (Harpenden, Sweden). Pubertal status was evaluated simply by showing the boys and/or their parents an illustration of the external genitalia development (28). Five Tanner scales, described in Box 1, were identified.

Box 1. Puberty status: 5 Tanner scales.

Scale	Testicular volume (ml)	Penis' length	Scrotum
1.	< 1.5	Small: ≤ 3 cm	Skin on scrotum thins, reddens and enlarges
2.	1.6 to 5.9	Unchanged	Scrotum enlarges further
3.	6.0 to 11.9	About 6 cm	Scrotum enlarges further and darkens
4.	12.0 to 19.9	10 cm	-
5.	> 20.0	15 cm	Adult scrotum

Testing protocol

Figure 1 illustrates the study protocol. The latter includes five visits on Day$_1$, Day$_2$, Day$_3$, Day$_4$, and Day$_6$. Before the collection of tests' data, the following three actions were performed in a preliminary visit (Day$_1$): i) review and practice of the FVt, ii) demonstration of the techniques of 5JT, speed test, and pro-agility shuttle, and iii) collection of anthropometric data. All participants had prior experience in performing the tests used in this study. The following tests were performed during Day$_2$, Day$_3$, and Day$_4$: speed test, 5JT, and pro-agility shuttle. A rest day (Day$_5$) was administered before the FVt. Day$_6$ was reserved for FVt. One researcher (KBA in the authors' list) tested all the participants, and the tests were performed in the same order with identical equipment, positioning, and technique.

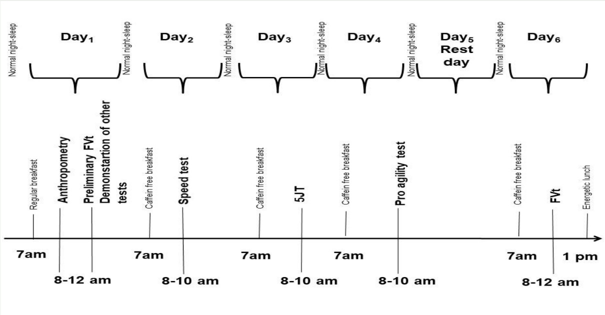

Figure 1. Study flowchart.
FVt: force-velocity test. **5JT**: 5-jump test.

Applied tests: speed test (20-m sprint), 5JT, pro-agility shuttle, and FVt (Figure 2)

All testing sessions were completed indoors, in the morning (8:00 - 12:00 am), under thermoneutral conditions (e.g.; 23.5±1.7 °C, 50.5±8.2% of relative humidity). Before all the testing sessions, the participants completed a typical warm-up practice for 10 minutes and consisted of running and lower extremity dynamic stretching exercises. To sum up, this warm-up included eight minutes of general activity (e.g.; jogging around the volleyball court, light stretching), followed by 12 minutes of dynamic activity with a progressive increase in speed and intensity (e.g.; skipping, leg and arm swings, and proprioceptive exercises), five minutes of two players' volleyball skill rally setting with lateral and front-back movements, and five minutes of rest. For each test, the participant was asked to perform a maximal effort and was vigorously encouraged throughout the sprint. Participants were allowed to drink water ad libitum before and throughout testing. A light meal (i.e.; grilled chicken with steamed vegetables) was consumed at 13:00 during the protocol, which provided 30% of the daily energy requirements for each individual. All tests were carried out after a standardized caffeine-free breakfast and an energetic-free lunch for each participant. On the night before each session, the participants were asked to keep their usual sleep routine, with a minimum of eight hours of sleep. Participants also replicated their dietary intake 48 hours before each measurement session and were fully hydrated. To minimize confounding factors, instructions related to sleep and diet were given to all participants before the experiment. Following their arrival at the sports hall, the participants were asked to sit comfortably for the anthropometric measurements. The researcher (KBA in the authors' list) received assistance from the head coach, the physiotherapist, and the co-authors (IL and MAH in the authors' list) during the evaluation to guarantee the accurate tests' achievement.
20-m sprints were performed on Day$_2$ (Figure 2A). The participants were informed that they had to choose which foot to put on the starting line for the sprint

standing position start. Then, they performed three 20-m sprints with five minutes of recovery in between. Speeds were measured with infrared photoelectric cells (PowerMax TC Gates, Brower Timing System, UT, USA), positioned exactly 0, 5 (T_5), 10 (T_{10}), and 20 (T_{20}) meters from the starting line at a one-meter height. Once ready, the participant began 50-cm behind the first gate to initiate timing once they broke the first gate and were instructed to perform a maximal sprint from the starting line through the last gate (29). The participant had to start from a standing position putting his forward foot just behind the start line according to his natural starting position. Before testing, each participant performed a submaximal sprint to acquaint himself with the test process. The speed test achieving the best performance was selected for analysis and the time for each interval was recorded to the nearest 0.01s (30).

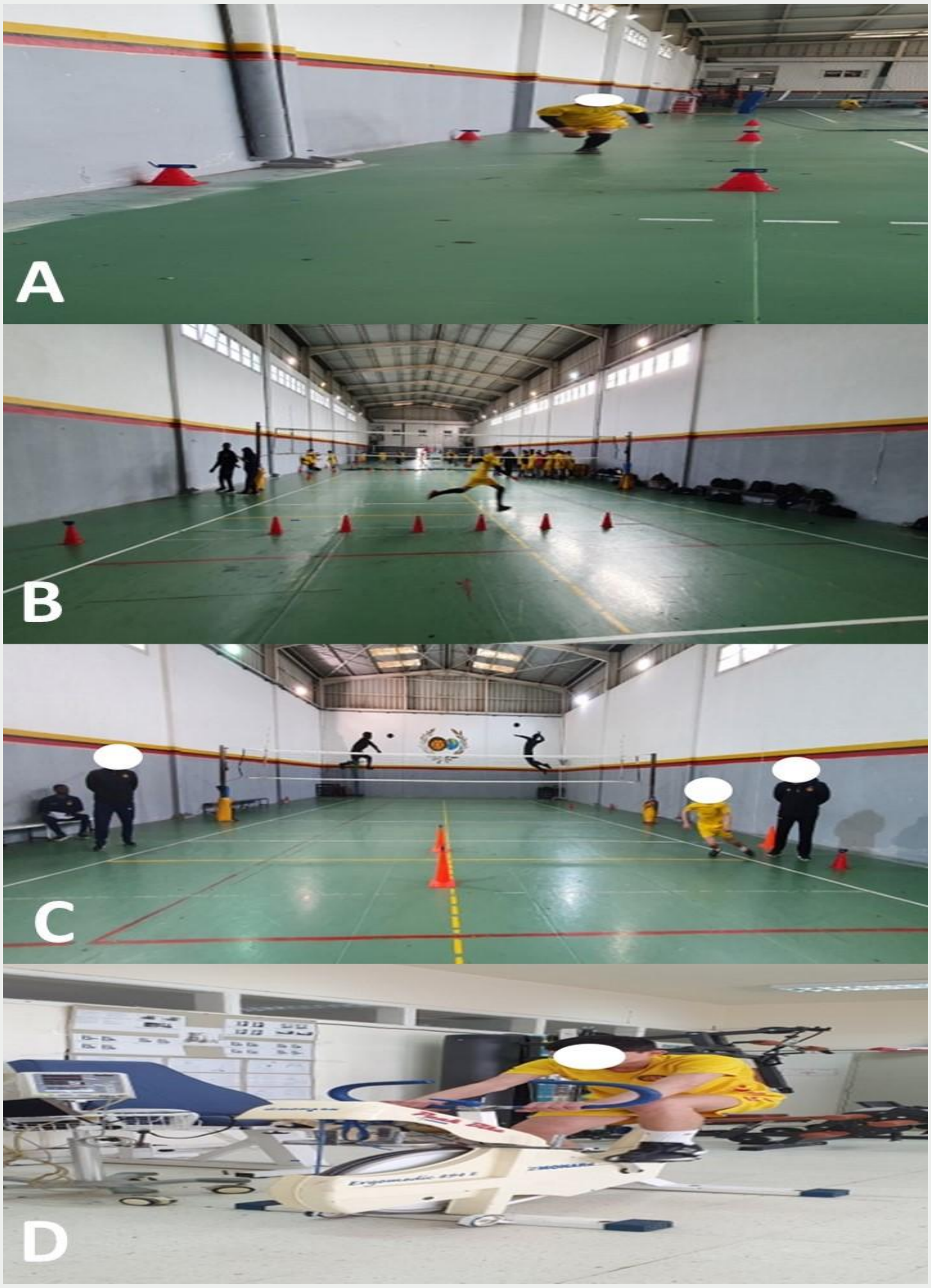

Figure 2. Applied tests.

2A. Speed test (20-m sprint). **2B**. 5-jump test. **2C**. Pro-agility shuttle. 2D. Force-velocity test.

Three trials of the 5JT were performed at Day_3 (Figure 2B). The 5JT is used in field conditions to estimate the athletes' lower limb explosive power and measure the distance covered by the participant (23, 31). The 5JT is a suitable training means and is used to evaluate lower limb muscle power in youth male volleyball players (11). A full description of procedures is available elsewhere (11). The 5JT, which implies five successive horizontal jumps, is often used as an alternative to the vertical jump test (6, 11, 32). Both aforementioned tests indirectly measure jump performances (31). In children, the increase in 5JT performance indicates a change in the level of neuromuscular activation (neural factors) and motor coordination in response to the specific plyometric training (33). Moreover, the 5JT is used in field circumstances to evaluate the youth players' lower limb explosive power and to calculate the distance covered (11, 23). The absolute performance of the 5JT (i.e.; $5JT_A$, m) can mask the results if the BM is not considered (32). In order to make the diagnosis of the leg muscle power in participants reliable, two relative expressions of 5JT performance (i.e.; $5JT_{LL}$ and $5JT_{BM}$) (3) were considered in this study. Therefore, 5JT performance was divided by five to get an average tread value. One tread was then divided by the lower limbs' length ($5JT_{LL}$ = 1 tread/lower limbs' length). $5JT_A$ distance was measured with a tape. Dimensional scaling based on BM was used to allow direct comparisons with comparable studies (11, 23, 32, 34) and improve the diagnostic power of the 5JT.

Pro-agility shuttles were performed on Day_4 (Figure 2C). This test is one of the most common tests used to measure CoD speed in athletic populations (35). It was accomplished using conventional methods (13, 14, 29). Participants were on both sides of the middle line in a standpoint in between the timing gate. As per the timing system set-up, a one-timing gate (PowerMax TC Gates, Brower Timing System, UT, USA) was used. Once the participant was in the steady position, he could begin the test, starting on a centerline facing the researcher. The first movement of the hand-initiated timing (s). To start the test, the player turned and ran 5 yards (i.e.; ~4.57 m) to the right side and touches the line with the right hand (Figure 3). The participant then turns and runs 10 yards (i.e.; ~ 9.14 m) to the left side and touches the other line with the left hand, before turning and sprinting back through the start/finish line. Two coaches (represented by cones 1 and 2 in Figure 3) of the club were positioned at either end of the pro-agility shuttle to ensure that the participants touched the designated lines. If participants failed to touch a line, the trial was ignored and reattempted. The timing system started when the participant exited the starting line and stopped recording when the participant returned through the gate for the last time (plots in Figure 3). The participants were allowed trial practice before the test to familiarize themselves with the conditions.

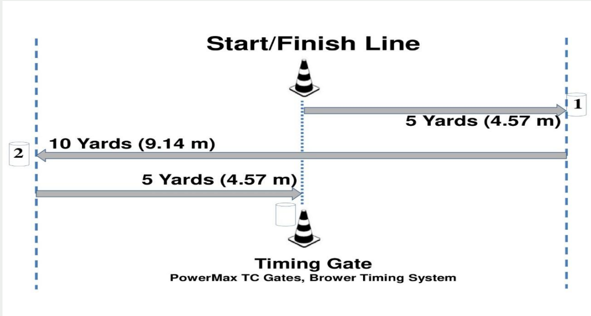

Figure 3. The pro-agility shuttle procedure

The laboratory test (FVt)

The laboratory test [i.e.; FVt (Figure 2D)] was performed twice (i.e.; on Day_1 and at Day_6 after a full rest day) in the physiotherapist clinic therapy room of the sports hall inside the professional sports' club. A cycle ergometer (Monark 894E, Peak Bike, Weight Ergometer, Sweden) was transported from the laboratory to the sports hall. On Day_1, all participants completed a preliminary cycle ergometer test in order to assess their ability during cycling. The FVt consists of repetitive sprints. It was performed on the same calibrated friction-loaded cycle ergometer against five short consecutive braking forces (e.g.; 2.5%; 5%; 7.5%, 9%, and 11.5%) applied in a random order of the individual's BM, which was interfaced to a microcomputer (ASUS, A6000 series, Entertainment Notebook, Taiwan) (34). This method allowed instantaneous power output and corrected flywheel acceleration to be monitored and recorded accurately. Anthropometric and individual data were introduced into a computer connected to the cycle ergometer. The sprint lasted five to seven seconds. The P_{peak} (W) was obtained when additional braking forces induced a decrease in power output. Each sprint was interspersed by five minutes recovery periods. Participants was instructed to sprint maximally for the duration of each sprint and were verbally encouraged while sprinting. Toe clips and tape were holding the participants' feet securely. The FVt commenced from a rolling start pedaling at 60 rpm against a minimal resistance (i.e.; with weight basket supported). When a constant pedal rate was attained, a countdown of '3-2-1-Go' was given, the braking force was applied, and the computer was activated on the signal 'Go'. For all tests, participants were instructed to remain seated on the saddle with their feet strapped to the pedal, and body position was standardized for each one. Throughout the sprint, the pedaling rate was continuously screened on the computer, and the participants were asked to stop sprinting as soon as it was clear that the velocity had reached its peak value and instantly dropped in power. The sprints lasted about 5 to 7 s. Most participants became breathless but not distressed or exhausted, and perceived exertion was assessed immediately after each sprint using the Borg category-ratio scale to objectively evaluate their fatigue level (35). The best absolute Ppeak (W) from the five performance exercises was collected for data analysis. In addition to the absolute mode (W), the P_{peak} was expressed in the following three allometric scales: $W.kg^{-0.67}$, W.kg, and W.l (35).

Allometric scaling of the participants

The effect of body size plays a fundamental role in physical performance variables (i.e.; power) (36). To account for this effect, the usual practice is to divide the performance variable by body size, which has been strongly discouraged especially when dealing with children/adolescents (37). An alternative is allometric scaling, which is an effective method to normalize power capacity (38). The allometric scaling procedure first raises the body size by a power exponent based on geometric symmetry theory (39). The procedure used in this study was described by Vanderburgh et al. (40). The equation $Y = a \cdot X^b$ ["Y" = outcome variable (i.e.; P_{peak}), "X" = anthropometric variable (i.e.; BM), "a" is the constant multiplier, and "b" is a constant exponent] was transformed into a log-linear model so that linear regression could be used to solve the value of "b" (i.e.; the allometric exponent) for each variable of interest. The relationship between the performance variables (i.e.; Ppeak) and body size descriptor (i.e.; BM) was described as following $\log Y = \log a + b \cdot \log X$, where "Y" was the dependent variable, "a" was the constant multiplier, "b" was the allometric exponent, and "X" was the body size descriptor. An allometric exponent "b" equal to 2/3 (i.e.; 0.67), which was recommended by Jaric et al. (38) for parameter Ppeak, was used in this study.

Sample size and statistical analysis

Sample size

An observational study was performed to estimate a correlation-coefficient (r) between two quantitative variables of interest: laboratory test data (i.e.; FVt) and field test data (e.g.; 5JT). The sample size was obtained by computing $N= [((Z_{\alpha/2} + Z_{1-\beta})2)/(1/4 (\log_e ((1+r)/(1-r))] + 3$ (41), where "$Z_{\alpha/2}$" is the normal deviates for type I error (= 1.64 for 10% significance level); "$Z_{1-\beta}$" was the study power (= 0.84 for 80% power). Given the pioneer character of this study and its exploratory nature, the "r" between FVt and 5JT was collected from a previous Tunisian study including 18 trained judokas aged 12±0.4 years, where the "r" between FVt (W) and $5JT_A$ (m) was statistically significant at 0.46 (42). The injection of the aforementioned data into the formula results in a sample of 28 participants. The assumption of 40% loss during the four visits (Days$_{2}$, $_{3}$, $_{4}$ and $_{6}$) gives a revised sample of 46 participants (= 28/ (1-0.40)).

Statistical analysis

The quantitative values were expressed as a mean ± standard-deviation (minimum-maximum) [95% confidence interval]. Pearson "r" was performed among the variables of the FVt, 20-m sprint, CoD, and 5JT tests. "r" was considered "high" when it was > 0.70, "good" when it was between 0.50-0.70, "fair" when it was between 0.30-0.50, and "weak or no association" when it was < 0.30 (43). The data were analyzed using Statistica 10 (Statistica 10, StatSoft, France). The threshold for statistical significance was set at $p < 0.05$.

Results

Forty-six participants volunteered to take part in this study. At the end of the protocol, only data of 31 boys were retained for final statistical analysis. The reasons for the missing of the 15 boys were the following: injury after the conditioning period (n=6), absence during Day$_6$ (n=4), and exam period (n=5). All the boys were at stage 3 of puberty. Table 1 presents the boys' anthropometric characteristics, and table 2 summarizes the data collected during the four applied tests.

Table 1. Anthropometric data of participants (n=31).

Data	Unit	Mean ± standard deviation	Minimum-Maximum	95% confidence interval
Age	(years)	13.1±0.3	12.5-13.6	13.0 to 13.2
Height	(cm)	156.0±5.4	146.8-164.0	154.0 to 158.0
Body-mass	(kg)	42.0±4.0	36.0-51.0	40.5 to 43.4
Body-mass index	(kg/m^2)	16.6±1.2	14.3-19.0	16.2 to 17.1
Leg length	(cm)	79.6±2.8	74.2-86.2	77.2 to 82.8
Leg muscle volume	(l)	3.7±0.2	3.3-4.2	3.6 to 3.8

Table 2. Data measured during the force-velocity test (FVt), 5-jump test (5JT), 20-m sprint (T_5, T_{10}, T_{20}), and change of direction (CoD) (n=31).

Data	Category	Unit	Mean± standard deviation	Minimum-Maximum	95% confidence interval
FVt	**P_{peak}**	W	414.0±8.9	398.0-427.1	410.7 to 417.3
		$W.kg^{-0.67}$	36.1±4.9	28.8-44.8	34.4 to 37.9
		W.kg	10.0±1.3	8.0-12.5	9.6 to 10.5
		W.l	85.8±12.2	71.8-134.7	81.3 to 90.2
5JT	**$5JT_A$**	m	8.80±0.02	8.77-8.82	8.79 to 8.80
	$5JT_{BM}$	m.kg	336.37±45.19	246.85-402.84	319.80 to 352.95
	$5JT_{LL}$	m.l	2.38±0.15	2.11-2.63	2.32 to 2.44
20-m sprint	**T_5**	s	1.77±0.13	1.58-1.99	1.73 to 1.82
	T_{10}	s	2.85±0.26	2.51-3.57	2.76 to 2.95
	T_{20}	s	4.93±0.65	4.11-6.34	4.69 to 5.17
CoD	-	s	5.09±0.30	4.61-5.75	4.98 to 5.20

$5JT_A$: absolute performance of the 5JT. **$5JT_{BM}$**: relative 5JT to body-mass. **$5JT_{LL}$**: relative 5JT to leg length. **P_{peak}**: peak leg power. **T_x**: time at x second.

Table 3 presents the 'r' values between FVtP_{peak}, and 5JT performance, 20-m sprint, and CoD. For FVtP_{peak} expressed in:

i) W, the correlations were "high" with 20-m sprint (T_5, T_{10}, T_{20}) and CoD, "good" with FVtPpeak ($W.kg^{-0.67}$), and "fair" with 5JTA;

ii) $W.kg^{-0.67}$, the correlations were "fair" with FVtP_{peak}

(W.kg), $5JT_A$, and 20-m sprint (T_5, T_{10});
iii) W.kg, the correlation was "good" with $5JT_A$, and
iv) W.l, no significant correlation was found.
For the 5JT, "fair" correlations were found between $5JT_A$ and 20-m sprint (T_5) and CoD, and between $5JT_{BM}$ and $5JT_{LL}$.

For the 20-m sprint, the correlations were "good" between T_5 and T_{10}, T_{20}, and CoD; "good" between T_{10} and T_{20}; "fair" between T_{10} and CoD, and "fair" between T_{20} and CoD.

Table 3. Correlation matrix (r) between force-velocity test (FVt), 5-jump test (5JT), 20-m sprint, and change of direction (CoD) (n=31).

Data			FVt				5JT			20-m sprint			CoD
	Category		P_{peak}				$5JT_A$	$5JT_{BM}$	$5JT_{LL}$	T_5	T_{10}	T_{20}	-
		Unit	W	$W.kg^{-0.67}$	W.kg	W.l	m	m.l	m.kg	s	s	s	s
FVt	P_{peak}	W	1	0.505^{*b}	0.103^{d}	0.300^{d}	0.499^{*c}	-0.065^{d}	0.056^{d}	-0.858^{*a}	-0.707^{*a}	-0.762^{*a}	-0.745^{*a}
		$W.kg^{-0.67}$	0.505^{*b}	1	0.466^{*c}	0.203^{d}	0.489^{*c}	-0.019^{d}	0.150^{d}	-0.370^{*c}	-0.364^{*c}	-0.309^{d}	0.302^{d}
		W.kg	0.103^{d}	0.466^{*c}	1	0.060	0.531^{*b}	0.052^{d}	0.174^{d}	0.022^{d}	-0.042^{d}	-0.048^{d}	-0.154^{d}
		W.l	0.300^{d}	0.203^{d}	0.060	1	0.310^{d}	0.023^{d}	0.006^{d}	-0.098^{d}	-0.199^{d}	-0.110^{d}	-0.296^{d}
5JT	$5JT_A$	m	0.499^{*c}	0.489^{*c}	0.531^{*b}	0.310^{d}	1	0.099^{d}	0.306^{d}	-0.383^{*c}	-0.337^{d}	-0.272^{d}	-0.409^{*c}
	$5JT_{BM}$	m.l	-0.065^{d}	-0.019^{d}	0.052^{d}	0.023^{d}	0.099^{d}	1	-0.432^{*c}	0.179^{d}	-0.018^{d}	0.200^{d}	-0.109^{d}
	$5JT_{LL}$	m.kg	0.056^{d}	0.150^{d}	0.174^{d}	0.006^{d}	0.306^{d}	-0.432^{*c}	1	-0.104^{d}	0.067^{d}	-0.133^{d}	0.212^{d}
20-m sprint	T_5	s	-0.858^{*a}	-0.370^{*c}	0.022^{d}	-0.098^{d}	-0.383^{*c}	0.179^{d}	-0.104^{d}	1	0.534^{*b}	0.589^{*b}	0.637^{*b}
	T_{10}	s	-0.707^{*a}	-0.364^{*c}	-0.042^{d}	-0.199^{d}	-0.337^{d}	-0.018^{d}	0.067^{d}	0.534^{*b}	1	0.689^{*b}	0.471^{*c}
	T_{20}	s	-0.762^{*a}	-0.309^{d}	-0.048^{d}	-0.110^{d}	-0.272^{d}	0.200^{d}	-0.133^{d}	0.589^{*b}	0.689^{*b}	1	0.439^{*c}
CoD	-	s	-0.745^{*a}	-0.302^{d}	-0.154^{d}	-0.296^{d}	-0.409^{*c}	-0.109^{d}	0.212^{d}	0.637^{*b}	0.471^{*c}	0.439^{*c}	1

$5JT_A$: absolute performance of the 5JT. **$5JT_{BM}$**: relative 5JT to body-mass. **$5JT_{LL}$**: relative 5JT to leg length. **P_{peak}**: peak leg power. **T_x**: time at x second.
Correlations were:
[a]**High**: "r" > 0.70;
[b]**Good**: "r": 0.50-0.70;
[c]**Fair**: "r" between 0.30-0.50;
[d]**Weak** or no association: "r" < 0.30.
***p**< 0.05.

Discussion

This study identified i) "high-negative" correlations between $FVtP_{peak}$ (W) and 20-m sprint (T_5, T_{10}, T_{20}), and CoD, ii) "good" correlations between $FVtP_{peak}$ (W.kg) and $5JT_A$, and iii) "fair" correlations between $FVtP_{peak}$ (W) and $5JT_A$, between $FVtP_{peak}$ ($W.kg^{-0.67}$) and $5JT_A$, and 20-m sprint (T_5, T_{10}).
The results of this study suggest that emphasizing the development of leg power within the youth volleyball population may improve sprint, horizontal approach, and agility within this population. Additionally, our findings may be beneficial for volleyball coaches in youth categories, and strength conditioning coaches to determine which lower-body power tests should be prioritized when developing an athletic testing battery within this population.

Relation between FVt and 5JT

We reported significant correlations between $FVtP_{peak}$ (W, $W.kg^{-0.67}$, W.kg) and $5JT_A$ (Table 3). In a previous Tunisian study, Ben Ayed et al. (11) considered the 5JT as an assessment of lower limbs muscle power of young male volleyball players. Ben Ayed et al. (11) highlighted that the 5JT is a suitable field test for power assessment in volleyball players' power. The 5JT, as a horizontal approach, offers an interesting measurement of explosive power because of the limited facilities needed compared to the assessment of vertical jumping and lower limbs' power in youth volleyball players (11). Some authors (11, 43) described some similarities between the vertical and horizontal leg jumps generally reported as independent tasks featuring dissimilar leg strength/power qualities (i.e.; short and maximum characteristic achievement). Meylan et al. (44) recognized an association in the evaluation of performance in terms of muscular power. The authors reported a good correlation (r= 0.64) and a shared variance of ~45% between single leg vertical and horizontal jump tests (44). The jumping activities in volleyball can include movements with and/or without horizontal approaches (i.e.; spike jumps, jump setting, blocking) and a relatively greater portion (i.e.;~30%) of total movement distance in volleyball is performed while sprinting, particularly in linear sprinting (1). Previous studies demonstrated that explosive strength training using the 5JT might increase muscular strength by improving neuromuscular characteristics (23, 31, 32). It appears that the 5JT is a suitable field test for computing stride power in soccer players (23, 31, 32). In fact, the $5JT_A$ and the $5JT_{LL}$ are correlated with the power variables of jumps (11). All these findings seem to confirm that the 5JT satisfactorily estimates the muscle power of the lower limbs (11, 23, 32, 40). The correlation between $FVtP_{peak}$ and 5JT is explained by the similarities of the bio-energetic and bio-mechanical parameters between these two tests. First, the 5JT has five alternating bounds and requires good neuromuscular coordination and good technical skills (31), while the FVt is a test of pedaling with the legs, in which one of the two legs is activated while the other is passive (back pedal) (23). Second, some factors can affect the relationship between a field test (e.g.; 5JT) and the FVt, such as the pedaling ability, the pedaling velocity as well as motivation and coordination between and within the muscle fibers contractions (23). Third, Diallo et al. (33) reported necessary neuromuscular adaptations (motor coordination) when performing the 5JT. However, it is worth observing that many factors can influence the different tests' performances. Possibly, our cycle ergometer protocol approximates more closely the muscle contraction dynamics and the contraction times associated with the 5JT. Potential mechanisms developing jump performance in volleyball players include more efficient movements because the changes in the temporal sequencing of muscle activation, the preferential recruitment of fast motor units, and the increased nerve conduction velocity are characterized by stochastic, a cyclical and intermittent movement bouts, which are highly variable and unpredictable (21). In fact, the performance of the P_{peak} depends on the capacity of using adenosine triphosphate-phosphocreatine reserves, which are closely related to the muscle volume (12, 44). Given the physical demands of volleyball coupled with the length of a volleyball match, which may extend up to about 90 minutes (2), volleyball players need well-developed speed, agility, upper and lower body muscle power, as well as maximal aerobic power (10, 20, 23). Moreover, significant recruitment of motor units from the neuromuscular system during various jumps (e.g.; attack vs. net in volleyball) and intensive short repetitive movements during volleyball match (20), may partly explain the differences between young adults and boys. 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 stretch-shortening cycle (20). It is therefore comparable with the attack movement during the volleyball game (11, 45). In our study, the 5JT satisfactorily measures the "explosive" power of lower limbs.

Relation between the FVt and 20-m sprint

It has been previously revealed that performance in different types of jumps tests has positive relationships with faster linear and CoD in athletic populations (7, 13, 21, 25, 46). The FVt, as a strength/power test, utilized the stretch-shortening cycle (SSC) capacities of the lower body, and this is an important quality for speed linear (e.g.; T_5, T_{10}, and T_{20}). In line with all the cited findings about the importance of SSC, the current study identified "high-negative" correlations between FVt (W) and T_5, T_{10} and T_{20} (Table 3). Volleyball imposes players to make quick actions/movements when responding to setting or preparing the attack approach (i.e.; side-out phase or break phase).

In volleyball, as a complex sport that depends on technical, tactical, and physical abilities, the periods of maximal bouts last only a few seconds and are punctuated by rest or lower-intensity activity (2, 8, 19, 29, 47). The energy required during a single bout of brief (< 10 s) dynamic maximal exercise must be provided through anaerobic pathways demands (2). Volleyball is a team sport characterized by intermittent efforts with periods of short duration (i.e.; 3-9 s), high-intensity activities, interspersed with relatively long periods (i.e.;10-20 s) of recovery (8, 19). Actually, to measure the components of power/strength that are valid for sport, it is essential to reconstruct the activity of that sport as closely as possible (18-20, 24, 48). The energy requirements of volleyball are complex and difficult to quantify. Although previous studies revealed the positive effect of a strength and conditioning training program on jump performance in volleyball players, there exists a significant discrepancy in the literature as it relates to correlations between indicators of performance, specifically speed, horizontal jump approach, and Ppeak output in youth volleyball players (7, 13, 14, 47, 49).

Relation between the FVt and CoD

Previous studies revealed that a successful CoD need enhanced physical capacities of lower body strength and power (4, 7, 13, 15, 18, 21, 25, 30, 35, 43, 46). The results from the research of Banda et al. (13) confirmed that possessing a fitting level of lower-body power should assist an athlete in rapidly changing direction in reply to the demands of the competition. The authors mentioned that the value of lower-body power for CoD speed was measured by pro-agility shuttle (13). Accordingly, this was supported by our results. In fact, "high-negative" correlations were found between FVt (W) and pro-agility shuttle (r = -0.745), which represent the CoD required in a volleyball match. This demonstrated that youth volleyball players should enhance their acceleration and CoD performances on the court. Subsequently, the more developed these qualities are for youth volleyball players; the more likely they are to be successful (13).

Based on the time of each action spent on the court, volleyball drills can be classified as fast SSC exercises (50). Generally, exercises involving muscle power, linear sprint, agility, and CoD speed benefit from the mechanical properties of the SSC (44). It has been highlighted that these types of exercises enhanced neuromuscular (e.g.; improved neural drive to agonist's muscles) and/or mechanical/structural properties (e.g.; alterations to musculotendinous stiffness and architecture) (12). The alternating eccentric-concentric muscle work also leads to the accumulation of potential elastic energy through the series and parallel elastic components allowing more work to be performed in the concentric phase (44). These positive effects on neuromuscular and structural properties should have potential results in sports such as volleyball, which involve extensive movements equivalent to different types of jump drills, CoD, and linear speed. Accordingly, our data suggested that youth volleyball players should boost their SSC capacities of the lower-body to develop their agility, speed, acceleration, and horizontal approach performances. A suggested training modality involved capacities of power, acceleration, and explosiveness (vertical and horizontal) as important practices in the volleyball competition. Linear sprint ability over short distances is the most common type of movement and represents the basis for most speed training programs (7, 14).

The horizontal jump approach (i.e.; defensive and offensive volleyball skills) and speed tests impose great demands on the stretching and shortening abilities of the leg muscles. The relation between intrinsic muscle components (i.e.; elastic and contractile components) is one of the determinant factors of performance in jumps and linear sprints (14). Our findings are consistent with most previous publications (4, 7, 11, 18, 20, 45, 46), given the fact that some studies shared a good variance between horizontal and vertical jumps (43). In fact, the relationships between the assessment of leg power to linear sprint speed were investigated in previous studies (7, 13-15, 30). McFarland et al. (15) determined a "good-negative" correlation between 30-m sprint time and pro-agility shuttle with the CMJ (r = -0.50 to -0.75) and SJ (r = -0.50 to -0.68) among a group of soccer players. In contrast, the above-cited study reported a significant relationship between 10-m time and CMJ_H (15). The latter reported "fair to good" negative" correlations between 10-m and 30-m sprint times to the CMJ (r= -0.48 and -0.57) and SJ (r= -0.44 and -0.55, respectively) among males at the same playing. Lockie et al. (7) identified limited relationships between performance in standing broad jump; which provided an indirect measure of horizontal power; and the 20-m sprint and pro-agility shuttle, which have important implication for volleyball and strength and conditioning coaches for youth categories. In addition, the authors reported no significant relationships between standing broad jump with 0-10 m sprint interval in division collegiate volleyball players and suggested that all jumps used in the study emphasized the SSC in the lower-body muscles power (7). Interestingly, even though the 10-m sprint distance is somewhat atypical to the distances that volleyball players may need to cover during a match (8). Our study reported a "fair-negative" correlation between the 5JT and the speed tests (Table 3). Several reasons can explain these correlations. For example, concentric power, as opposed to reactive power, may be more important for speed over short distances (51), and small yet impactful differences in distance between the two tests may contribute to this relationship. Future research should investigate shorter sprint acceleration distance and concentric power activity in youth volleyball players to explore how they improve power qualities over a short accelerations and horizontal jumps.

Study Limitations

This study has some limitations that should be acknowledged. First, its observational design limits causal interpretation, as the inclusion of multiple variables increases the likelihood of identifying chance correlations (52). Nevertheless, such studies remain valuable for capturing "real-world" practices and generating hypotheses for future experimental research (53). Second, potential sex- and age-related differences in performance on the pro-agility shuttle and 5JT were not fully explored, despite evidence that injury patterns and performance may differ between male and female youth athletes (54). Additionally, ethical constraints in pediatric research often restrict direct investigation of underlying physiological mechanisms, which may limit the depth of interpretation in studies involving young athletes. Third, while our study focused on the relationship between lower-limb power in field and laboratory tests, it did not directly assess strength, which is an important component influencing power. Including strength protocols, in future studies, could provide a more comprehensive understanding of lower-limb performance in youth volleyball players. Fourth, our sample was limited to players from a single youth volleyball club, which may reduce the generalizability of our findings. Future studies should consider including multiple teams to increase sample diversity and strengthen external validity. Fifth, the use of the FVt on a cycle ergometer, while practical and reliable, may limit ecological validity in volleyball, a jump-based sport. Although the FVt offers controlled assessment of lower-limb power, it does not fully replicate the neuromuscular demands of jumping tasks, and future research should compare it with sport-specific tests such as the CMJ or SJ to validate its relevance in volleyball settings. Sixth, while pubertal stage was reported, objective measures of biological maturation, such as Mirwald's peak height velocity estimation (55), were not used and may better classify maturation status and its effects on neuromuscular performance. Finally, psychological and motivational factors, which are known to influence physical performance, were not assessed in this study. Future research should integrate validated tools such as EMS-28 (a widely used French-language sport motivation scale based on self-determination theory (56)), LEMOVIS-I (a French observational tool designed to assess and measure athletes' motivation and related behavioral variables in sport settings, helping to capture situational motivational dynamics during training or competition. (57)), and psychophysiological measures such as heart rate variability to capture these influential variables. Together, addressing the aforementioned limitations in future studies will strengthen the understanding of lower-limb power assessment in youth volleyball players and improve the design of targeted performance evaluations in this population.

Practical recommendations

From a practical standpoint, coaches are encouraged to:

• Integrate specific strength exercises targeting concentric power (e.g.; sled pushes, trap bar deadlifts) into training programs.

• Emphasize short-distance sprint drills (5–10 m) to enhance early-phase acceleration.

• Incorporate horizontal plyometric exercises (e.g.; bounding, standing long jump) to develop the neuromuscular qualities associated with horizontal force application.

These recommendations may help enhance short sprint and jump performance, which are crucial for volleyball-specific actions such as blocking and quick direction changes.

Conclusion

The present study identified significant relationships between the FVt and 20-m sprint, pro-agility shuttle, and $5JT_A$. The authors strongly suggest the use of the pro-agility shuttle and 5JT to evaluate lower limb explosive power in youth volleyball players. Further studies, with respect to different sports games and to the electromyography response of the muscles involved in jumping performance, are needed to confirm the use of the pro-agility shuttle, speed test and the 5JT to determine which lower-body power tests should be prioritized when developing an athletic testing battery within this population.

List of abbreviations
BM: body-mass
CMJ: countermovement jump
CMJ_H: peak heights of CMJ
CoD: change of direction
FVt: force-velocity test
F_{peak}: peak jumping velocity
LL: leg-length
P_{peak}: peak leg power
r: correlation-coefficient
SJ: squat jump
SJH: peak heights of SJ
SSC: stretch-shortening cycle
T_x: time at x second
5JT: 5-jump test
$5JT_A$: absolute performance of the 5JT
$5JT_{BM}$: relative 5JT to body-mass
$5JT_{LL}$: relative 5JT to leg length

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DECLARATION. The authors wish to disclose that artificial intelligence tools (i.e.; ChatGPT ephemeral and QuillBot) were utilized to enhance the clarity and coherence of the manuscript' writing. The tools were utilized for language refinement purposes only, ensuring the text was clear and coherent without altering the scientific content or generating any new text (59, 60).

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