Research Square

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The impact of the relations between the explosive power of the lower limbs measured by a force-velocity test versus field tests (horizontal jump, speed test and agility test) in young North African volleyball players.

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Research Article

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Abstract

Background: 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. We aimed to determine the relationships that exist between lower-body power measured via a laboratory test (***ie***; FVt) and some field tests [horizontal jump (***ie***; 5-jump test, speed test (***ie***; 20-m sprint) and agility test (***ie***; pro-agility shuttle)] in youth volleyball players.

Methods: Thirty-one youth volleyball players were investigated for changing of direction (pro-agility shuttle), 5-jump test, and absolute/relative peak leg power (Ppeak) 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). 5-jump test performance was expressed in absolute terms ($5JT_A$, m), and relative to leg length ($5JT_{LL}$) and body mass ($5JT_{BM}$).

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 pro-agility shuttle (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)].

Conclusions: Tthe pro-agility shuttle, 20-m sprint, and 5JT can be used to evaluate lower limb explosive power in youth volleyball players.

Introduction

Volleyball is a team sport with highly intermittent specific tasks that require different physiological components and multidirectional court movements that occur repeatedly during the competition(1–4). Several maximum and high-intensity muscle actions are necessary during a volleyball game, depending on the position and responsibilities assigned to the player on the court (eg; jumping, passing, attacking, blocking, sprinting, and quick-changing pace)(1–7). Volleyball players engage in recurring short and high intensity volleyball tasks (ie; in both vertical and horizontal directions), followed by periods of low-intensity activity and brief periods of recovery between each rally points(1, 8). High intensity exercise periods involved a good level of fitness to support efforts requiring mainly aerobic and anaerobic energy systems(2, 9). Some relevant studies can be useful in volleyball training programs, particularly strength and conditioning programs designed specifically for youth volleyball players(10). These investigations are related to the following two topics: i) the training development, such as physical attributes characteristics of the youth male and adolescent players, physiological attributes (eg; aerobic profile, strength, vertical jump ability, agility, and speed), and ii) volleyball technics(10). Currently, a few surveys examining detailed performance indicators within the young population exist, especially among young volleyball players competing in a professional sports club(11).

The neuromuscular system is put under significant strain during the volleyball match's numerous sprints, jumps (ie; blocking, spiking, and changing direction), and high-intensity court movement patterns(11). Muscular strength and power, in addition to technical and tactical abilities, are two critical components of effective performance(12). Volleyball players require well-developed speed, acceleration performance, multidirectional court movements, agility, and lower-body muscular power(4, 7). When speed and agility are combined with maximum strength, power is considered as the muscular power that allows a specific muscle to produce the same quantity of work in less time, or a greater magnitude of work at the same time, which is important for sprinting, jumping and quick changes of direction(7, 13–15). Players repeatedly achieve stop-and-go change of direction (COD) in a reaction to unpredictable stimuli (eg; partner, ball, offensive and defensive reaction techniques) above a relatively small court and throughout a single game(4, 7). Most team sports require the ability to start, stop, and change directions quickly and efficiently(15). In real-competition situations, a COD speed and agility are imperative for the volleyball player(16) and habitually executed in response to unpredictable visual stimuli, and agile manoeuvres may not be explicitly preplanned(17). In previous literature, successful COD ability involved prerequisites such as lower-body strength and power(15). As a result, the more these qualities are developed for players, the more chances they have to succeed(7, 11). This observation led the researchers to concentrate on determining the success of complex physical parameters in order to improve them with specific training(4, 11, 15, 18–21). To be successful, these skills depend heavily on the capacity to generate rapidly muscle strength or power in the lower body(4, 7, 22). Significant relationships between lower-body strength and COD velocity have been observed in athletes in a various of sports(22). Significant correlations between absolute and relative strength and COD in female collegiate soccer players were reported(22). Slight research exists on the relationship between power abilities [peak-leg power (P_{peak}) measured on a cycle ergometer (force-velocity test, FVt)], horizontal jump and vertical jump(7, 23), COD, and speed in volleyball players(7, 18, 24, 25). Understanding these relationships can help to develop training programs to improve court performance in this population. A previous study concluded that "in youth volleyball players (n = 40 boys), the 5-jump test (5JT) may be viewed as an explosive strength diagnostic instrument under field circumstances"(11). The authors tested the relationship between 5JT performance,[5JT expressed in absolute terms ($5JT_A$, m), and relative to leg length ($5JT_{LL}$), body mass ($5JT_{BM}$)],and two specific laboratory tests for explosive power [ie; countermovement jump (CMJ), and squat jump (SJ): P_{peak} of the jump, peak jumping force (F_{peak}), peak jumping velocity (V_{peak}), peak heights of CMJ and SJ (CMJ_H and SJ_H, respectively)](11). The authors concluded that i) $5JT_A$ was significantly correlated with SJ (V_{peak}, SJ_H, P_{peak}, F_{peak}) and CMJ (V_{peak}, CMJ_H, P_{peak}, F_{peak}); ii) $5JT_{LL}$ was significantly related to SJ (V_{peak}, P_{peak}), and CMJ (V_{peak}, P_{peak}, F_{peak}); and iii) $5JT_{BM}$ was significantly related to SJ (P_{peak}).

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

Participants

The participants were youth volleyball players (n = 31boys, 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 program intended to recognize young players estimated to have the essential physiological and anthropometric characteristics (***eg***, 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 and especially mini-volley games (***eg***, 2 *vs.* 2, 3 *vs.* 3) with adapted court and rules. In addition, players had physical education courses at college [***ie***, two sessions (of 60 minutes each) per week]. As suggested by the National local volleyball league, very scarce specific track programs in volume and intensity were managed for the "under 14 years' category". All participants had an experience in volleyball training and a competition background of 3-5years.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. Body mass (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 (***ie***, from trochanter major to lateral malleolus) and was added to the thigh volume **(26)**. Leg length (LL) and circumferences were measured using a standardized anthropometric kit (Harpenden, Sweden).

The pubertal status was evaluated simply by showing the boys and/or their parents an illustration of the external genitalia development**(27)**. Five Tanner scales, described in **Table 1**, were identified.

Testing protocol

Figure 1 illustrates the study protocol. The latter includes five visits onDay_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 administrated before the FVt. Day_6 was reserved for the FVt. One experienced researcher tested all the participants, and the tests were performed in the same order with identical equipment, positioning, and technique.

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

All testing sessions were completed indoors, in the morning (8:00 - 12:00 am) to minimize the effects of diurnal variation in the measured data**(28, 29)** and under thermoneutral conditions (***eg***, 23.5±1.7 °C, 50.5±8.2% of relative humidity). Additionally, all sessions were conducted far from the full moon to avoid the effect of circa-lunar variation on the measured parameters**(30)**. 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 (***eg***, jogging around the volleyball court, light stretching), followed by 12 minutes of dynamic activity with a progressive increase in speed and intensity (***eg***, 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. Participants were allowed to drink water ad libitum before and throughout testing. A light meal (***ie***, a 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 were thoroughly hydrated throughout the sessions. To minimize confounders, sleep instructions were provided to all participants prior to the experiment. After arriving at the sport hall, participants were invited to sit comfortably for anthropometric measurements. The researcher received assistance from the head coach, the physiotherapist, and the co-authors during the evaluation to guarantee the accurate tests' achievement.

A 20-m sprint was performed by each participant on Day_2 **(Figure 2A)**. Each participant was informed that he 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 at exactly 0, 5 (T_5), 10 (T_{10}), and 20 (T_{20}) m 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 **(31)**. 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**(32)**.

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, 33)**. 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, 34)**. Both aforementioned tests indirectly measure jump performances **(33)**. In children, the increase in 5JT performances indicates a change in the level of neuromuscular activation (neural factors) and motor coordination in response to the specific plyometric training**(35)**. 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 (***ie***, $5JT_A$, m) can mask the results if the BM is not considered**(34)**. In order to make the diagnosis of the leg muscle power in participants reliable, two relative expressions of5JT performance(***ie***, 5JTLL 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. A dimensional scaling based on BM was used to allow direct comparisons with comparable studies**(11, 23, 34, 36)**, 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**(37)**. It was accomplished using conventional methods**(13, 14, 31)**. Participants were on both sides of the middle line in a standpoint in between the timing gate. As per the timing system set-up, 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. Timing (s) was initiated by the first movement of the hand. To start the test, the player turned and runs5 yards (***ie***, ~4.57 m) to the right side and touches the line with the right hand **(Figure 3)**. The participant then turns and runs10 yards (***ie***, ~ 9.14 m) to the left side and touched 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 a trial practice before the test to familiarize themselves with the conditions.

The laboratory test [***ie***, FVt **(Figure 2D)**] was performed twice (***ie***, 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. At 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 (***eg***, 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)**(36)**.This method allowed instantaneous power outputand 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 were 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 pedalling at 60 rpm/min against a minimal resistance (***ie***, 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'. Throughout the sprint, the pedalling rate was screened constantly on the computer, and the participant was asked to stop sprinting as soon as it was clear that velocity had reached its peak value. Most participants became breathless but not distressed or exhausted. The best absolute P_{peak} (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.

Allometric scaling of the participants

The effect of body size plays a fundamental role in physical performance variables (***ie***; power)**(38)**. 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**(39)**. An alternative is allometric scaling, which is an effective method to normalize power capacity**(40)**. 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.**(41)**. The equation $Y = a \cdot X^b$ ["*Y*" = outcome variable (***ie***, P_{peak}), "*X*" = anthropometric variable (***ie***, 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*" (***ie***, the allometric exponent) for each variable of interest. The relationship between the performance variables (***ie***, P_{peak}) and body size descriptor (***ie***, BM) was described as following log Y = log a + b·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 (***ie***, 0.67) for parameter $P_{peak,}$ was used in our study**(39)**.

Sample size and statistical analysis

An observational study was performed to estimate a correlation-coefficient (***r***) between two quantitative variables of interest: laboratory test data (***ie***; FVt) and field test data (***eg***; 5JT). The sample size was obtained by computing N= 3 + [$((Z_{\alpha/2} + Z_{1-\beta})^2)/(1/4\ (\log_e\ ((1+r)/(1-r))]$, 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)**(42)**. 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 **(43)**. 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)).

The experimental values were expressed as a mean±standard-deviation (SD) (minimum-maximum) [95% confidence interval]. Pearson "r" was performed among the variables of the FVt, 20-m sprint, pro-agility shuttle 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**(44)**. The data were analysed using Statistica 10 (Statistica 10, StatSoft, France). The threshold for the 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 2** presents the boys' anthropometric characteristics, and **Table 3** summarizes the data collected during the four applied tests.

Table 4 presents the 'r' values between $FVtP_{peak}$, and 5JT performance,20-m sprint, and pro-agility shuttle. For $FVtP_{peak}$ expressed in

i) W, the correlations were "high" with 20-m sprint (T_5, T_{10}, T_{20}) and pro-agility shuttle, "good" with $FVtP_{peak}$ ($W.kg^{-0.67}$), and "fair" with $5JT_A$;

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 pro-agility shuttle, 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 pro-agility shuttle; "good" between T_{10} and T_{20}; "fair" between T_{10} and pro-agility shuttle, and "fair" between T_{20} and pro-agility shuttle.

Discussion

This study identified ***i)*** "high" correlations between $FVtP_{peak}$ (W) and 20-m sprint (T_5, T_{10}, T_{20}), and pro-agility shuttle, ***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 findings of this study suggest that emphasizing leg power development in the youth volleyball population may improve sprint, horizontal approach, and agility. Moreover, our findings may be useful for youth volleyball coaches and strength conditioning coaches in determining which lower-body power tests should be prioritized when establishing an athletic testing battery for this population.

Relation between FVt and 5JT

We reported significant correlations between FVtPpeak (W, $W.kg^{-0.67}$, W.kg) and 5JTA (Table 4). The 5JT(11) was applied in a previous study to assess the leg muscular power of young male volleyball players. Ben Ayed et al.(11) highlighted that the 5JT is an appropriate measure for assessing the power of volleyball players. Given the scarcity of equipments required to evaluate youth volleyball players' lower body strength and vertical jump, the 5JT provides an interesting way to quantify power as a horizontal approach(11). Vertical and horizontal leg hops, which are commonly considered as separate tasks with differing leg strength/power properties, are commonly compared, while authors have identified some similarities between them in previous studies (11, 45) (***ie;*** short and maximum characteristic achievement).

The correlation involving muscle strength and performance assessment was acknowledged by Meylan et al.(45). The single-leg vertical and horizontal jump tests have a high correlation (r = 0.64) and a consistent variation of approximately 45%, **(45)**. Spike jumps, jump setting, and blocking are only a few of the jumping techniques used in volleyball. Sprinting represents for a significantly larger proportion (i.e. 30%) of all movement distance in volleyball, especially in linear sprinting**(1)**. Previous studies showed that the 5JT's explosive strength training might improve neuromuscular properties to increase muscular strength **(23, 33, 34)**. It seems that the 5JT is an appropriate field test for determining soccer players' stride power **(23, 33, 34)**. In fact, the power variables of jumps are associated with the $5JT_A$ and $5JT_{LL}$ **(11)**. These findings appear to demonstrate that the 5JT provides adequate estimations of the lower limb muscular power **(11, 23, 34, 43)**. The similarity of the bio-energetic and bio-mechanical parameters across $FVtP_{peak}$ and 5JT contributes to the relationship between the two tests.. The 5JT is a performance of five alternating bounds that demands high neuromuscular coordination and technical ability **(33)**,), while the FVt is an assessment of pedaling with the legs in which one of the two legs is active while the other is passive (back pedal)**(23)**. Additionally, various parameters, such as the ability to cycle, the pedaling velocity, motivation, and coordination between and within the muscle fiber

contractions, can have an impact on the association between a field test (***eg***, 5JT) and the FVt **(23)**. Furthermore, Diallo et al.**(35)** showed that the 5JT requires particular neuromuscular adaptations (motor coordination). Nevertheless, it is worth to notice that many factors can influence the different tests' performances. Our cycle ergometer protocol might be closer to the dynamics of muscle contraction and the times connected to the 5JT.

Potential mechanisms for improving jump performance in volleyball players involve more effective movements because the alterations in the temporal sequencing of muscle activation, the preferential recruitment of rapid motor units, and the enhanced nerve conduction velocity are characterized by stochastic, acyclic, and intermittent movement bouts, which are characterized by highly varied and unexpected movement patterns Adenosine triphosphate-phosphocreatine reserves, which are strongly tied to muscle volume, are actually what determines how well the Ppeak performs(21).Volleyball players must demonstrate a high level of speed, agility, upper and lower body muscle (2), power, as well as maximum aerobic power due to the physical demands of the activity and the length of a volleyball match, which may last up to 90 minute. (10, 20, 23).

The differences between young adults and youths may be partially explained by the significant recruitment of motor units from the neuromuscular system during diverse jumps (***eg***, attack against the net in volleyball) and intense brief repeated actions during a volleyball match**(20)**, According to the latter, the increase in high velocity during the takeoff of a vertical jump associated with a force variable during the stretch-shortening cycle could explain for such muscular strength of the lower limbs **(20)**. It is related to the volleyball player's attack movement **(11, 46)**. In our investigation, the 5JT accurately reflects the lower limbs' "explosive" force.

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, 47)**. 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 (***eg***, T_5, $T_{10,}$ and T_{20}). In line with all the cited findings about the importance of SSC, the current study identified “high” 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 (***ie***, side-out phase or break phase).

In volleyball, as a complex sport that relies on technical, tactical, and physical abilities, the periods of maximal bouts last only few seconds and are interrupted by rest or lower-intensity activity**(2, 8, 19, 31, 48)**. 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 (***ie***, 3-9 s), high-intensity activities, interspersed with relatively long periods (***ie***, 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, 49)**. The energy requirements of volleyball are complex and difficult to quantify. Although previous research has shown that a strength and conditioning training programme improves jump performance in volleyball players, there is a significant gap in the literature regarding correlations between indicators of performance, specifically speed, horizontal jump approach, and P_{peak} output in youth volleyball players**(7, 13, 14, 48, 50)**.

Relation between the FVt and pro-agility shuttle

Previous studies revealed that a successful COD needs enhanced physical capacities of lower body strength and power**(4, 7, 13, 15, 18, 21, 25, 32, 37, 45, 47)**. 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” 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**(51)**. Generally, exercises involving muscle power, linear sprint, agility, and COD speed benefit from the mechanical properties of the SSC**(52)**. It has been highlighted that these types of exercises enhanced neuromuscular (***eg***, improved neural drive to agonist’s muscles) and/or mechanical/structural properties (***eg***, 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**(52)**. These positive effects on neuromuscular and structural properties should have potential results in sports such as volleyball, which involves 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. As significant procedures in volleyball competition, a suggested training modality included power, acceleration, and explosiveness (vertical and horizontal). The most common type of movement is linear sprint ability over short distances, which serves as the foundation for most speed training programs**(7, 14)**.

The horizontal jump approach (***ie***, defensive and offensive volleyball skills) and speed tests impose great demands on the stretching and shortening abilities of the leg muscles. The relations between intrinsic muscle components (***ie***, 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, 46, 47)**, given the fact that some studies shared a good variance between horizontal and vertical jumps**(45)**. In fact, the relationships between assessment of leg power to linear sprint speed were investigated in previous studies**(7, 13-15, 32)**. 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 an important implications 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 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 4). Several reasons can explain these correlations. For example, concentric power, as opposed to reactive power, may be more important for speed over short distances(53), and also small yet impactful difference in distance between the two tests. Future studies should investigate into how youth volleyball players optimise power qualities with shorter sprint acceleration distances and concentric power activity.

Study limitations

Our study has some limitations. The first has to do with the fact that it is observational. For example, as the number of recorded factors increases, the probability increases. Thus, at least one of the factors recorded was coincidentally strongly correlated with data output (54). Furthermore, observational studies must meet several criteria in order for their results to be more understandable and generalizable (54). Observational studies have been reported to provide information about 'real world' use and practice and help formulate hypotheses to be tested in follow-up experiments (54). A second limitation is related to possible sex and age differences in agile shuttle and coordination in 5JT. Ritzer et al.(55), indicated that female athletes had a higher rate of overuse injury than males, while male athletes had a higher rate of acute injury. In this study, overuse injuries were more likely to be frequent injuries than acute injuries, while acute injuries were more often new injuries. Attention to these differences between acute and overuse injuries can help inform improved athlete preparation (such as conditioning and strength training), treatment, rehabilitation, and schedules allowing for adequate rest time, which may reduce injuries and improve injury outcomes in high school athletics. A third limitation is that research on children can be disturbing for ethical reasons. As a result, underlying mechanisms are often proposed but not always proven. Fourth, our study focused primarily on the relationship between lower body strength in field and laboratory tests, not strength. Future studies of youth volleyball players may include examining strength/force protocol to investigate lower-body power. Finally, since we only study players from professional sports club 'youth division' teams, the sample is likely to be very homogeneous. Future studies should also consider testing multiple teams to increase the sample size of youth volleyball players and make the findings more replicable to a wider range of players.

To conclude, 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, concerning different sports games and 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.

Abbreviations

BM: body-mass

COD: change of direction

FVt: force-velocity test

LL: leg-length

P_{peak}: peak leg power

r: correlation-coefficient

SD: standard-deviation

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

Declarations

Ethics approval and consent to participate

Approval for this study was granted from the Farhat HACHED Hospital Ethics Committee (approval number: FHHEC19032018), and the study was 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 of the participants, as well as 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.

Authors' contributions. KBA, MAH, IL, and HBS analyzed the data and wrote the manuscript. KBA, MAH, IL, and HBS contributed to the study design, data collection, and critical review of draft manuscript. IL and HBS assisted with the statistical analysis and interpretation of data. All the authors read and approved the final manuscript. All authors read and approved the final manuscript.

Competing interests. The authors declare that they have no competing interests.

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Consent for publication. Our manuscript does not contain data from any individual person. Therefore, a consent for publication is “not applicable”. Written informed consent to publish individual images was obtained from parents/legal representatives.

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Tables

Table 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

Scrotum: male reproductive structure

Table 2 Anthropometric data of participants (n=31).				
		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 3 Data measured during the force-velocity test (FVt), 5-jump test (5JT), 20-m sprint (T_5, T_{10}, T_{20}), and pro-agility shuttle (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
Pro-agility shuttle	-	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 4

Correlation matrix (r) between force-velocity test (FVt), 5-jump test (5JT), 20-m sprint, and pro-agility shuttle (n=31).

Data			FVt				5JT			20-m sprint			Pro-agility shuttle
	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	I										
		$W.kg^{-0.67}$	0.505[*b]	I									
		W.kg	0.103[d]	0.466[*c]	I								
		W.l	0.300[d]	0.203[d]	I0.060	I							
5JT	$5JT_A$	m	0.499[*c]	0.489[*c]	0.531[*b]	0.310[d]	I						
	$5JT_{BM}$	m.l	-0.065[d]	-0.019[d]	0.052[d]	0.023[d]	0.099[d]	I					
	$5JT_{LL}$	m.kg	0.056[d]	0.150[d]	0.174[d]	0.006[d]	0.306[d]	-0.432[*c]	I				
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]	I			
	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]	I		
	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]	I	
Pro-agility shuttle	-	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]	I

$5JT_A$: 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.

Box

Box 1 is available in the Supplementary Files section.

Figures

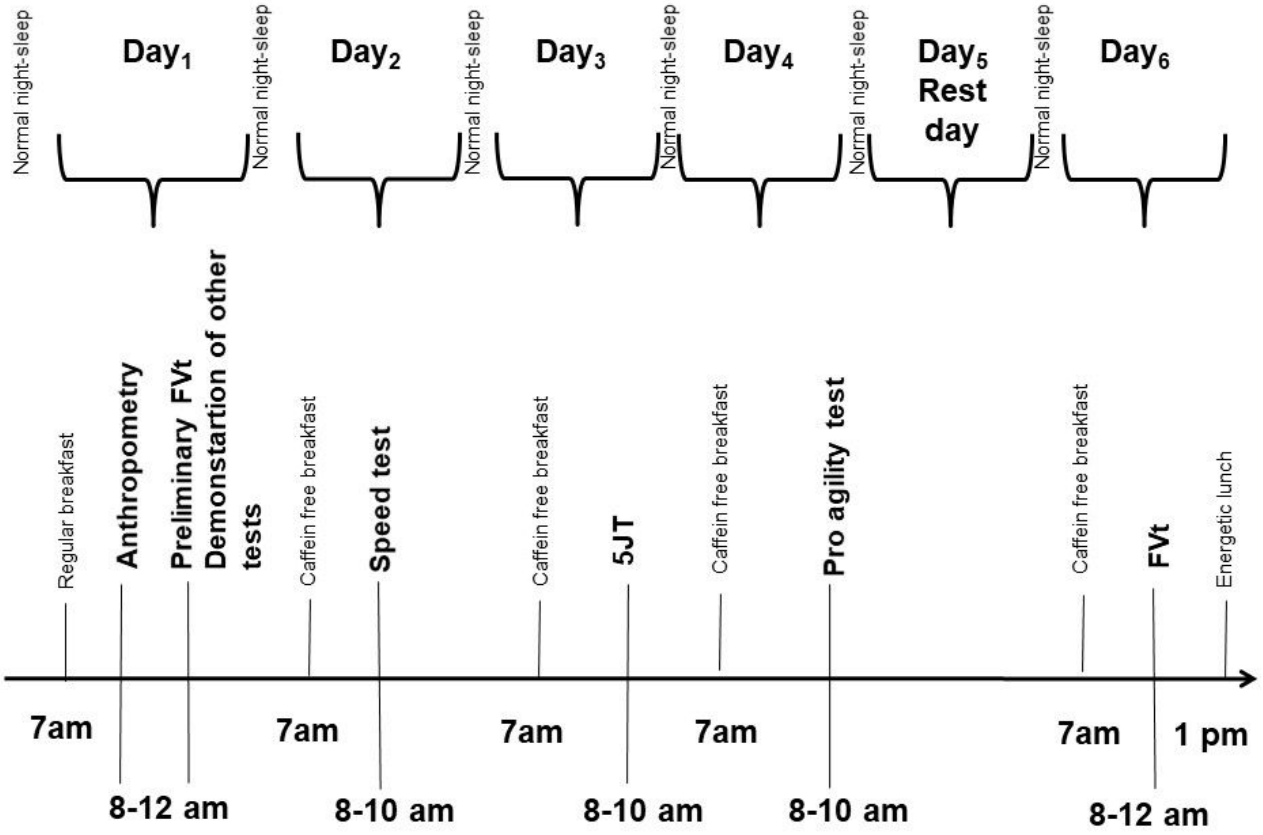

Figure 1

Study flowchart.

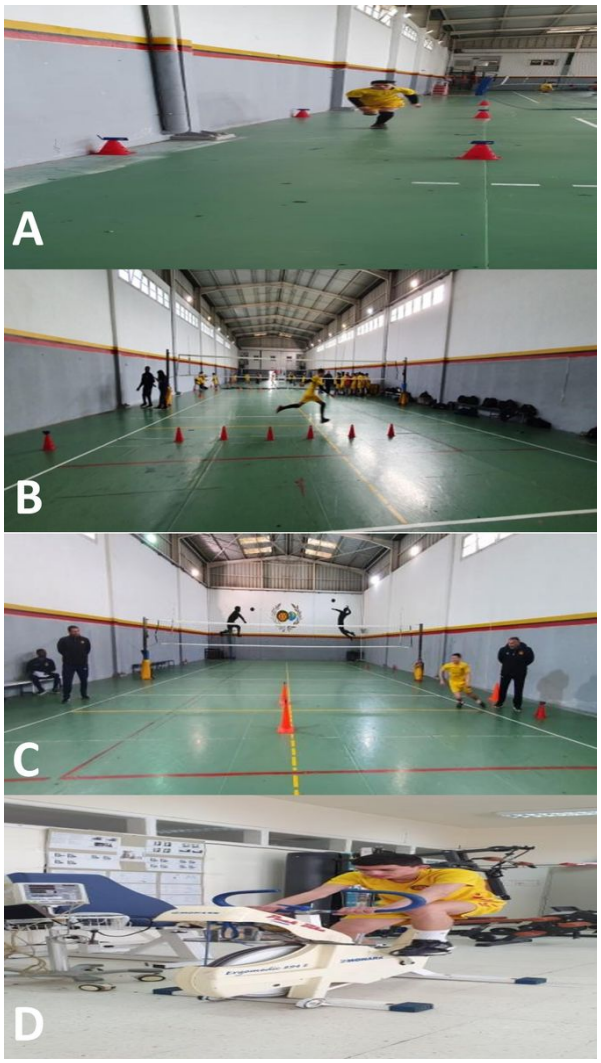

Figure 2

Applied tests.

A. Speed test (20-m sprint).

B. 5-jump test.

C. Pro-agility shuttle.

D. Force-velocity test

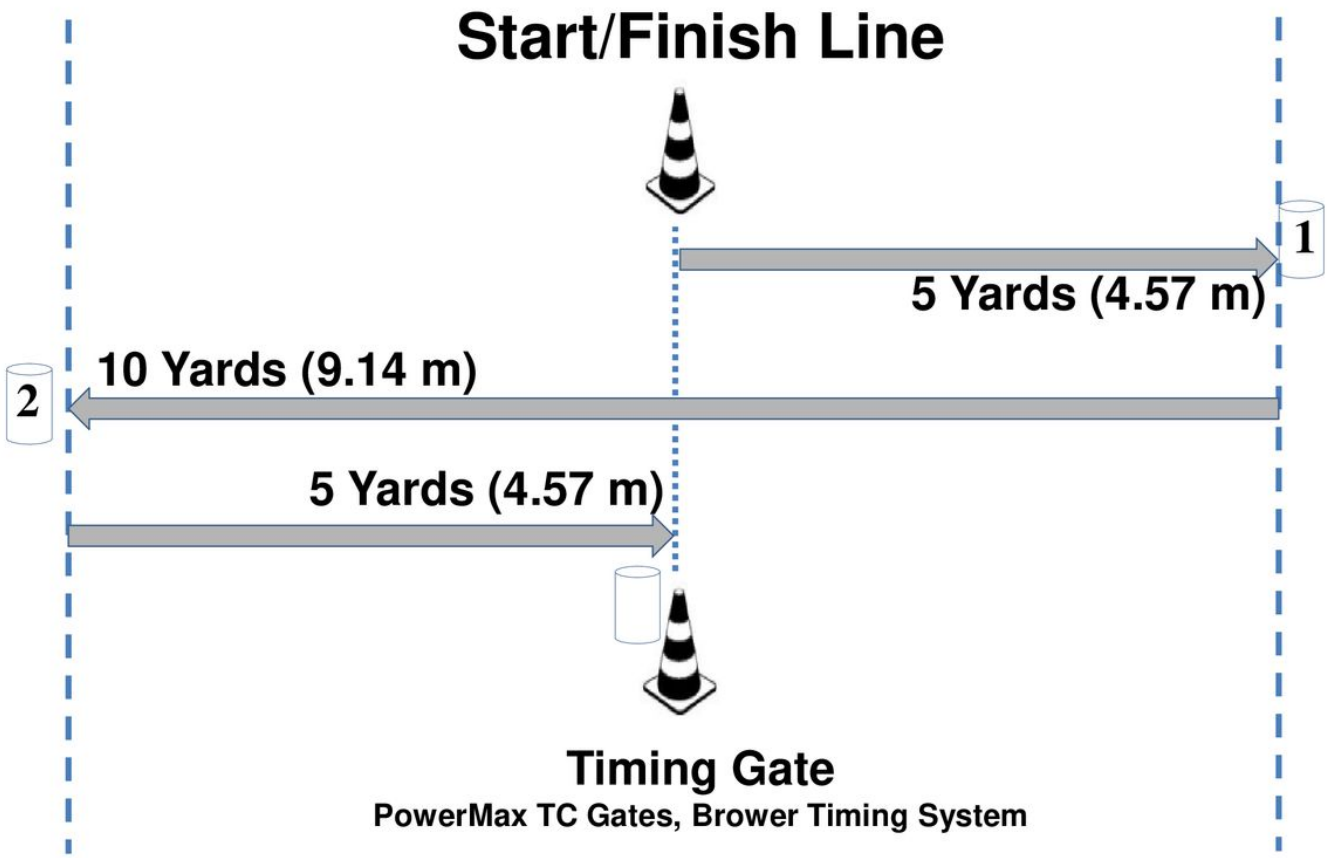

Figure 3

The pro-agility shuttle procedure

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Box1.docx