Original Article

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# Validity and reliability of a repeated 5 x 20-s maximal rowing test in trained young volleyball players

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**Abstract:** Background: The purpose of this study was to evaluate the reliability and validity of a new repeated maximal rowing test (RMRT) in young volleyball players; Methods: Thirteen Polish volleyball players aged 17.98±0.51 years took part in the study. Body height was measured with an InLab S50 stadiometer, and the remaining body composition parameters were determined by bioelectrical impedance with the InBody 270 Bioelectrical Impedance Analyzer. The decrease in power generated during the 5 x 20-s RMRT was assessed on a Concept 2 PM5 rowing ergometer. Results: Power values were significantly higher ($p<0.001$) in intervals 1 and 2 (as well as in interval 3 in session II) than in intervals 4 and 5. In turn, the values of mean and maximum heart rates ($HR_{avg}$ and $HR_{max}$) were significantly higher ($p<0.001$) in intervals 4 and 5 (and partly in interval 3) than in intervals 1 and 2. In both measurement sessions, power was most significantly correlated with total body water and proteins (p = 0.050 - 0.006, respectively), minerals (p = 0.072 - 0.008), fat-free mass and basal metabolic rate (p = 0.050 - 0.005), skeletal muscle mass (p = 0.045 - 0.005), and body mass (p = 0.060 - 0.009); Conclusions: The 5 x 20-s RMRT is a valid and reliable test for assessing maximal anaerobic power in young volleyball players. The results of the 5 x 20-s RMRT revealed the presence of a linear trend indicating that power decreased in successive intervals due to the growing levels of fatigue among players.

**Keywords**: explosive strength, motor performance, male athletes, testing, body composition

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# INTRODUCTION

In the literature, volleyball has been described as an 'interval' sport with both anaerobic and aerobic elements [1]. This intermittent sport involves short and frequent bouts of high-intensity exercise, followed by periods of low-intensity activity [2]. According to Almini et al. [3], volleyball is a sport with both technical and physical characteristics [4], where precision and power are the critical success factors [5,6]. Volleyball involves short and frequent explosive activities such as jumping, diving, and ball play [7,8]. The players should have well-developed aerobic and anaerobic alactic energy systems to cope with high-intensity exercise bouts and long duration of the match (approximately 90 minutes) [9]. Their performance is also determined by other parameters, including neuro-muscular coordination [3], motor control [10], tactical attitudes, and motivation [11].

There are no official time constraints on the duration of a volleyball match. The first team to win three sets wins the match [12]. The length of a match obviously depends on its parts, including the scoring system, rally length (work time during the game), rest time (time between rallies, substitutions, sanctions, technical and team time-outs, time between sets, injuries, and other technical aspects), and the players' skill [13]. The average duration of a volleyball match is around 100 min [14]. The overall exercise time (when the ball is in play) is significantly shorter than rest time (35% vs 65%). The players are physically active for only around 30% of total match time. An average set lasts 20.44 ± 5.21 minutes, whereas the duration of the longest and the shortest set has been determined at 23.68 and 18.89 minutes, respectively. In most cases, the pause between finished points and the referee's whistle to serve the ball lasts more than 10 seconds (approx. 12 sectors), but some pauses are longer than 20 seconds. However, the number of very long pauses is kept at a reasonable level. The duration of finished points is also an important consideration. In most cases, 43.5% of finished points last 5-10 seconds, 41% of the points last 10-15 seconds, around 11% of the points last 15-20 seconds, and 3.7% of the points last 20-25 seconds [12]. Longer times were reported in a study of top-level male youth volleyball players during the finals and semi-finals of the 2008 Olympic Games (OG08) and four male matches during the finals and semi-finals of the 2009 U19 European Youth Championships (YEC09). During the OG08 and YEC09, rallies lasted 5.45±4.77 s and 5.76±4.40 s (ns), respectively; each set consisted of 45.3±5.1 and 44.0±6.7 (ns) rallies, respectively; the breaks between rallies lasted 23.54±5.55 s and 19.99±5.70 s ($p<0.001$), respectively; the sets lasted 1582±133 s and 1412±143 s ($p<0.01$), respectively; and the breaks between sets lasted 217±17 s and 213±20 s (ns), respectively [13]. The highest number of pauses between finished points and the referee's whistle for the serve lasted more than 10 seconds (approx. 12 seconds), but some pause periods lasted more than 20 seconds, and the number of long pauses was kept at a reasonable level [15].

Agility is an essential requirement in most team sports [16], in particular volleyball. In the traditional approach, agility was defined as speed with directional changes [17]. According to Young et al. [18], agility is a skill that is composed of two main sub-components: the ability to rapidly change body direction, and cognitive skills. More recently, agility has been defined as the rapid movement of the entire body, where velocity or direction of movement change in response to a stimulus [19]. Due to rapid changes in momentum in a volleyball game, the players are expected to have relatively high levels of reactive agility (RA) and repeated sprint ability (RSA), which are the key skills in most field and team sports [16, 20]. Both RA and RSA are closely linked with open skills that cannot be planned and involve two components: cognitive skills and the ability to rapidly change body direction [19]. Reactive ability is somewhat different from RSA in terms of its spatial character. Repeated spring ability has been defined as the ability to produce repeated, short, maximal efforts with brief recovery periods, where most efforts are focused on generating maximum running power across long distances, which is particularly important in training programs for soccer, hockey, rugby, football, and basketball players [20].

The motor performance of volleyball players has to be measured with the use of valid and reliable tests that accurately simulate real-life playing conditions. Such measurements are controversial because the players' ability to generate maximum power is practically impossible to determine with the use of such tools under conditions that closely approximate real-life volleyball matches. Validity and reliability are among the key adequacy criteria for evaluating motor ability tests and their relevance in motor fitness (MF) evaluations [21-24]. A test is valid when it accurately measures the analyzed parameters. Therefore, to ensure the validity of a test, the parameters or functions to be measured by the test should be strictly defined. Reliability is defined as the overall consistency of a standard measure or the error of measurement. The reliability of a test provides information about the magnitude of measurement error; therefore, the extent to which a measurement is reliable is determined by the consistency of the results scored by an individual or a group in a motor test during repeated measurements [23,24]. A reliable test should generate identical or very similar results if it is repeated at least twice by the same individuals and under the same conditions. The consistency of a measurement can be determined by calculating the reliability coefficient when a given motor task is performed several times by a random group of participants. In most cases, reliability is determined by calculating the coefficient of correlation between two repeated measurements [25, 26]. The validity and reliability of speed tests have been less frequently examined in the literature. Such assessments have been made in the Slalom test (speed) and the Hurdle test (agility) administered to 11-year-old girls and boys [27], in the 4×10 m Shuttle Run test involving 13- and 14-year-old girls and boys [28], and in the 8-s SHC test [26]. These tests are effective mostly in the training stage and the players' overall development, but they are not highly useful for measuring volleyball players' motor performance. Repeated performance tests are administered mainly to identify genuine changes in the analyzed parameters. Above all, RA/RSA measurements should reflect changes in performance that are attributable to the intervention. In the absence of intervention, a test should yield consistent and reliable results that do not fluctuate to an unacceptable degree across trials. Some of the most widely used RSA tests have been evaluated for reproducibility [29-32]. The reliability of a 6 x 6-s cycling test was evaluated by Fitzsimons et al. [29], but test-retest reliability was analyzed only in two trials. The reliability of power output was assessed in a repeated sprint test involving 10 x 7-s cycle sprints, each separated by 30-s rest intervals [33]. In the traditional approach, agility was assessed in zig-zag running speed tests [34]. The first study to evaluate RA was conducted on Australian football players, and it consisted of a 10 m straight sprint (10 m SS) and an 8-9 m change of direction speed test [16].

Very few reliability assessments were conducted for the multiple sprint rowing test, where performance is examined in two trials, and the protocol is specific to the demands of volleyball-related team sports. Therefore, the aim of this study was to evaluate the validity and reliability of the 5 x 20 s repeated maximal rowing test on a Concept 2 rowing ergometer (5 x 20-s RMRT). The anthropometric and physiological parameters that are significantly correlated with the generated power were also examined.

# MATERIALS AND METHODS

*Participants*

The study involved 13 right-handed male volleyball players of the AZS UWM Olsztyn club. The mean age of the players was 17.98±0.51 years (range 17.61 - 18.62 yrs), and they competed in the tournaments of the third national league of the Warmia and Mazury Volleyball Union. The analyzed athletes were born in 2004 and 2005 (junior league). The following inclusion criteria were applied in the targeted sampling procedure: volleyball players held a valid competition license and had participated in national third league competitions for at least one year. All players had valid medical certificates. They trained regularly, and their physical activity levels were not limited (for whatever reason) to the extent that could significantly affect their motor fitness. During a four-week period preceding the first trial, the participants were allowed to miss one training session per week, and none of the participants had been dismissed from training due to illness or injury for more than one week in the previous two months. During the macrocycles, the players trained 12–13 h per week on average.

*Ethics statement*

The research was performed in compliance with the guidelines and policies of the Health Science Council and the Declaration of Helsinki. The study was approved by the Ethics Committee of the University of Warmia and Mazury (37/2011). Each participant was provided with detailed information about the purpose of the study, potential risks, and the research protocol. The research protocol contained detailed information about measurement methods and motor test techniques that could be practiced during training sessions directly before the study. All volleyball players gave voluntary informed consent to participate in the study by signing consent forms.

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*Procedures, data collection, and equipment*

The first (16 August 2023) and the second (23 August 2023) measurement sessions were conducted over a weekly interval. Both sessions took place between 9 a.m. and 11 a.m. under similar environmental conditions. The measurements were performed in the Human Wellness Research Laboratory and in an indoor sports hall on the campus of the University of Warmia and Mazury in Olsztyn. The players were instructed to eat a light meal (800–1200 kcal) consisting mainly of carbohydrates (60%–70%) not later than 3–4 h before the trial [35]. On day 1, anthropometric measurements were performed before motor tests, and the athletes participated in motor tests on days 1 and 2. The players were asked not to engage in any strenuous training on the day before the trial, and they assisted the authors in performing the measurements. The athletes performed the 5 x 20-s RMRT on a Concept 2 PM5 rowing ergometer directly after anthropometric measurements.

*Anthropometric measurements and body composition analysis*

There is scientific evidence to indicate that anthropometric characteristics can be used to predict athletes' performance and select young female volleyball players for a junior national team [36]. The performance of volleyball players is assessed with the use of multidimensional measures [37], and successful players are leaner, taller, and have greater motor abilities than lower-level players [38].

Body height was measured to the nearest 1 mm with a calibrated InLab S50 stadiometer (InBody Co, Seoul, South Korea) in accordance with the relevant guidelines. Body mass (measured to the nearest 0.1 kg), the body mass index (BMI), and body composition parameters, including percent body fat (PBF) and skeletal muscle mass (SMM), were determined by bioelectrical impedance with the InBody 270 Bioelectrical Impedance Analyzer (BIA) (Biospace Co. Inc., Seoul, South Korea). This foot-to-foot, hand-to-hand, and hand-to-foot contact device features two stainless steel foot pad electrodes mounted on a platform scale and a tetrapolar 8-point tactile electrode system with two stainless steel handles. The reliability of bioelectrical-impedance analysis relative to other body composition measurement methods, such as DXA, has been successfully demonstrated [39, 40]. The platform scale uses a single load cell to measure body mass (and stature) and calculate the BMI. The PBF is calculated by summing the results of the segmental lean analysis to determine total lean body mass, fat mass, and the proportion of fat mass to total body mass. Muscle mass percentage (M%) is calculated by evaluating water content in the segmental regions with the use of the provided equations. Visceral fat level (VFL) is estimated with the use of regression equations (provided) which, according to the manufacturer, were derived by comparing visceral fat in computerized tomography scans and impedance in the torso region in a segmental lean analysis.

*5 x 20-s repeated maximal rowing test (5 x 20-s RMRT)*

The 5 x 20-s RMRT was performed on a Concept 2 PM5 standardized rowing ergometer (PH Markus, Szczecin, Poland) which is widely used to measure strength endurance in athletes [41]. The performance of young volleyball players was evaluated with the use of a rowing ergometer. In professional sports, endurance is often assessed in a laboratory, but laboratory tests do not account for movements that are specific to a given sports discipline. One of such examples is the Wingate anaerobic test on a cycle ergometer which is also administered to volleyball players [42].

The purpose of the rowing ergometer test was to imitate interval exercise corresponding to physical effort during a volleyball game. The results of the 5 x 20-s RMRT were assessed to determine whether a rowing ergometer can be effectively applied in research to evaluate volleyball players' ability to generate maximum power during repeated efforts that roughly correspond to the duration of a single volleyball action. According to Sánchez-Moreno et al. [15], the average length of a rally is around 5.0 ± 4.3 seconds, which is why the interval adopted for the needs of the study (20 s) relates mainly to long rallies that account for only around 10.5% of all rallies during a game. Some volleyball matches involve long rallies, which is why the corresponding time intervals were applied in this study.

The power generated by all parts of the body was assessed in five rowing intervals of 20 s each, separated by 20-s rest periods. This approach was adopted because most studies assessing the reliability of repeated sprint protocols involved five to seven 4-6 m or 30-40 m sprints, interspersed with 19-25 s of passive or light recovery [29, 30, 32, 43, 44]. The rowing interval represented a moment in the game when the ball remains in play, whereas the rest interval denoted the end of the playing action and preparation for a serve. The following parameters were measured during the rowing ergometer test: maximum, average, and minimum heart rate [$HR_{max,\ avg,\ min}$]; total distance covered during five 20-s intervals; power generated during the entire test [W]; average rowing time over a distance of 500 m; energy expenditure [kcal] per hour; strokes per minute – SPM [s/m]. Each participant wore a Polar H10 heart rate sensor (Polar Electro Oy, Kempele, Finland) on a chest strap. The ergometer was programmed and paired with the ErgData application and the HR sensor. The test was initiated upon a verbal start cue. After each rowing interval of 20 s, the participant rested for 20 s in a sitting position, holding the bar in his hands. The fifth rowing interval was also followed by a 20-s resting period. The data from the ErgData application were recorded in an Excel spreadsheet.

*Statistical analysis*

Basic descriptive statistics (mean, SD, and range) were calculated for each parameter. The normality of data distribution was checked with the Shapiro-Wilk test. The values of the asymmetry (skewness) coefficient *As* were also given. All parameters were normally distributed, and the Student’s t-test for dependent samples was used to assess the significance of differences between the arithmetic means of the examined parameters in two consecutive sessions. Pearson's correlation coefficient $r$ and the coefficient of determination $R^2$ were also calculated to determine differences in the values of physiological parameters between the corresponding intervals (based on the order in which they were performed) in sessions I and II. In addition, the significance of differences between the arithmetic means of the parameters examined in five subsequent intervals was estimated with the use of repeated measures ANOVA and Tukey’s Honest Significant Difference (HSD) post-hoc test. The results were processed in the Statistica 13 program at a significance level of $\alpha = 0.05$.

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# RESULTS

No significant differences (p>0.05) in distance, pace $_{avg}$/500 m, power, energy expenditure, and SPM were observed between the first and the second session (Table 1). The values of HR $_{avg}$ and HR $_{max}$ were significantly higher in session I than in session II. The highest power (505 W) was generated during the 5 x 20-s RMRT in session II (Table 1).

Table 1. The values of physiological parameters in sessions I and II

| Parameter | Session | Mean | SD | Min-Max | *As* | *t* | *p* |
|---|---|---|---|---|---|---|---|
| Distance [m] | I | 510.52 | 33.74 | 466-555 | -0.11 | 1.81 | 0.095 |
| | II | 522.58 | 31.01 | 466-565 | -0.21 | | |
| Pace$_{avg}$ / 500 m [s] | I | 98.33 | 6.65 | 90.0-107.2 | 0.23 | 1.82 | 0.096 |
| | II | 96.04 | 5.86 | 88.4-107.2 | 0.38 | | |
| Power [W] | I | 377.05 | 73.63 | 238-479 | 0.01 | 1.80 | 0.097 |
| | II | 403.21 | 70.58 | 283-505 | -0.02 | | |
| Energy expenditure [kcal/h] | I | 1596.74 | 252.87 | 1275-1947 | 0.01 | 1.80 | 0.096 |
| | II | 1687.15 | 242.92 | 1275-2038 | -0.02 | | |
| SPM [strokes/minute] | I | 42.22 | 5.79 | 34-56 | 0.89 | 1.96 | 0.069* |
| | II | 44.38 | 3.45 | 39-51 | 0.67 | | |
| HR$_{avg}$ [bpm] | I | 165.75 | 9.53 | 156-189 | 1.01 | **7.09** | **<0.001** |
| | II | 155.73 | 8.50 | 142-177 | 1.02 | | |
| HR$_{max}$ [bpm] | I | 170.95 | 8.52 | 161-190 | 1.03 | **6.05** | **<0.001** |
| | II | 161.82 | 9.26 | 147-182 | 0.64 | | |

I and II – first and second session, respectively; pace $_{avg}$ / 500 m - average pace per 500 m [s]; SPM – strokes per minute [s/m], As – asymmetry (skewness) coefficient, bold faced – significant differences, * - near significant differences

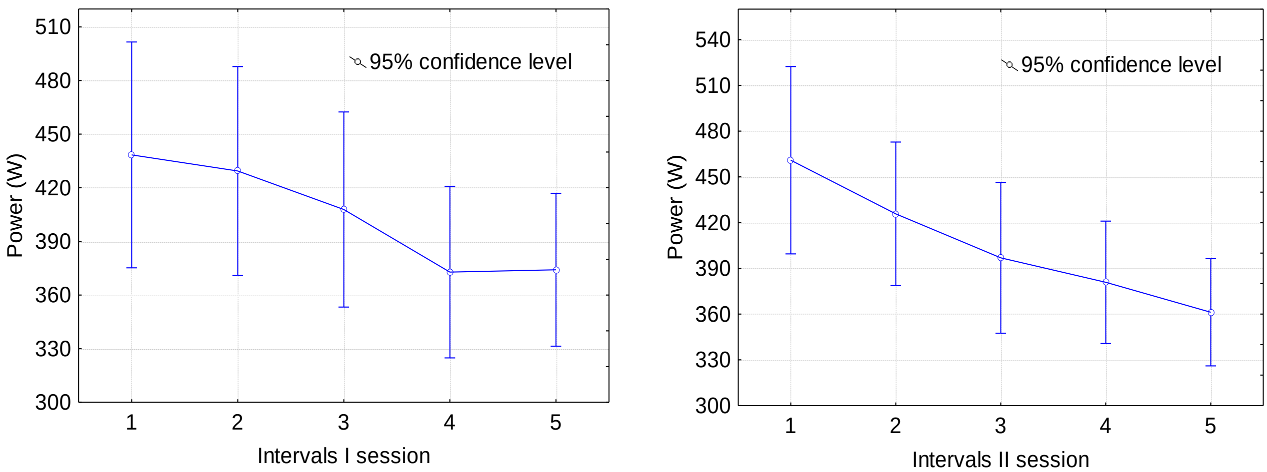


Figure 1. Power generated in subsequent intervals in session I (r=0.96, regression equation: Watts= 460.02 – 18.5 * interval number) and in session II (r=0.99, regression equation: Watts = 478.44 – 24.44 * interval number).

The players' physiological parameters in each interval are presented in Table 2. The values of covered distance, pace $_{avg}$ / 500 m, power, energy expenditure, and SPM were significantly higher (p<0.001) in intervals 1 and 2 (and, excluding SPM, also in interval 3 in session II) than in intervals 4 and 5. In turn, the values of $HR_{avg}$ and $HR_{max}$ were significantly higher (p<0.001) in intervals 4 and 5 (and partly in interval 3) than in intervals 1 and 2. The values of SPM in intervals 1 and 2 were significantly higher in session II than in session I [difference in interval 1 – 3.7 s/min, t(p) = 3.25 (0.007); difference in interval 2 – 2.7 s/min, t(p) = 2.80 (0.016)]. No significant differences in the remaining parameters were noted between the sessions (Table 2). Power decreased gradually and significantly in successive intervals in both sessions, in particular in session II (Table 2, Fig. 1). The regression analysis revealed that the changes in volleyball players' power were bound by a linear relationship.

The correlation coefficients describing the relationships between physiological parameters during the corresponding intervals in both sessions (based on the order in which they were performed) are presented in Table 3. Between the first and the second session, the correlation coefficients for distance, pace $_{avg}$ / 500 m, power, energy expenditure, and SPM (range of *r* values: 0.60 – 0.92) were significantly higher than the correlation coefficients for $HR_{avg}$ and $HR_{max}$, where significant differences were noted only in the values of $HR_{avg}$ in interval 1 (range of *r* values: -0.30 – 0.50).

Table 2. Significance of differences between intervals in sessions I and II

| Parameter | Session | Interval numbers between which there are significant differences Mean (SD) | | | | | Differences | |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | *F* | *p* |
| Distance [m] | I | 107.2 (8.6) [4,5] | 106.5 (8.3) [4,5] | 104.5 (8.1) | 101.6 (7.5) [1,2] | 101.8 (6.6) [1,2] | **9.40** | **<0.001** |
| | II | 109.1 (8.0) [3,4,5] | 106.4 (6.5) [4,5] | 103.8 (7.6) [1] | 102.5 (5.9) [1,2] | 100.8 (5.6) [1,2] | **14.58** | **<0.001** |
| | *t (p)* | 1.37 (0.195) | 0.07 (0.945) | 0.67 (0.514) | 0.59 (0.569) | 0.92 (0.375) | | |
| Pace $_{avg}$ / 500 m [s] | I | 93.7 (7.6) [4,5] | 94.5 (7.6) [4,5] | 96.2 (7.6) | 98.8 (7.7) [1,2] | 98.5 (6.6) [1,2] | **8.54** | **<0.001** |
| | II | 91.9 (6.8) [3,4,5] | 94.2 (5.9) [4,5] | 96.7 (7.7) [1] | 97.8 (5.6) [1,2] | 99.5 (5.8) [1,2] | **13.76** | **<0.001** |
| | *t (p)* | 1.52 (0.153) | 0.23 (0.823) | 0.39 (0.706) | 0.74 (0.474) | 0.88 (0.378) | | |
| Power [W] | I | 438.4 (104.5) [4,5] | 429.4 (96.7) [4,5] | 407.8 (90.3) | 372.8 (79.4) [1,2] | 374.2 (70.8) [1,2] | **9.34** | **<0.001** |
| | II | 460.9 (101.6) [3,4,5] | 425.8 (77.9) [4,5] | 396.9 (81.9) [1] | 380.8 (66.4) [1,2] | 361.2 (58.2) [1,2] | **14.32** | **<0.001** |
| | *t (p)* | 1.27 (0.227) | 0.27 (0.791) | 0.86 (0.408) | 0.44 (0.672) | 0.96 (0.354) | | |
| Energy expenditure [kcal/h] | I | 1808 (360) [4,5] | 1777 (333) [4,5] | 1706 (314) | 1582 (274) [1,2] | 1587 (244) [1,2] | **9.43** | **<0.001** |
| | II | 1886 (349) [3,4,5] | 1766 (267) [4,5] | 1665 (282) [1] | 1610 (229) [1,2] | 1543 (201) [1,2] | **14.43** | **<0.001** |
| | *t (p)* | 1.28 (0.225) | 0.25 (0.808) | 0.90 (0.383) | 0.44 (0.668) | 0.96 (0.356) | | |
| SPM [strokes/ minute] | I | 43.4 (7.2) | 43.2 (5.6) | 43.5 (5.9) | 43.4 (7.0) | 43.4 (7.2) | 0.03 | 0.999 |
| | II | 47.1 (4.6) [4,5] | 45.9 (4.5) | 44.1 (3.3) | 43.2 (4.0) [1] | 43.3 (5.1) [1] | **4.59** | **0.003** |
| | *t (p)* | **3.25 (0.007)** | **2.80 (0.016)** | 0.36 (0.725) | 0.15 (0.883) | 0.01 (0.999) | | |
| $HR_{avg}$ [bpm] | I | 127.8 (22.8) [2,3,4,5] | 159.4 (14.0) [4,5] | 168.7 (13.1) [1] | 173.4 (12.4) [1,2] | 177.1 (10.9) [1,2] | **48.67** | **<0.001** |
| | II | 117.2 (14.0) [2,3,4,5] | 146.6 (12.4) [3,4,5] | 156.8 (15.2) [1,2] | 161.0 (16.8) [1,2] | 164.2 (18.0) [1,2] | **63.17** | **<0.001** |
| | *t (p)* | 1.99 (0.069) * | **2.20 (0.049)** | 1.96 (0.071) * | 1.93 (0.077) * | 2.03 (0.065) * | | |
| $HR_{max}$ [bpm] | I | 142.7 (19.4) [2,3,4,5] | 164.5 (14.4) [4,5] | 172.3 (13.8) [1] | 177.0 (11.3) [1,2] | 179.9 (10.0) [1,2] | **39.15** | **<0.001** |
| | II | 131.7 (16.8) [2,3,4,5] | 152.6 (13.6) [4,5] | 160.4 (15.8) [1] | 163.8 (17.5) [1,2] | 166.8 (18.6) [1,2] | **44.48** | **<0.001** |
| | *t (p)* | 1.72 (0.112) | 0.61 (0.554) | 1.93 (0.077) * | 2.10 (0.057) * | 2.06 (0.061) * | | |

bold faced – significant differences; * - near significant differences

The correlation coefficients (r) denoting the strength of the relationship between the average power generated in five intervals and selected body composition parameters in sessions I and II are presented in Table 4. In sessions I and II, power was bound by the most significant (and near-significant) correlations with TBW and proteins (for both parameters, $r$ = 0.55 - 0.72 and p = 0.050 - 0.006, respectively), minerals ($r$ = 0.51 - 0.70 and p = 0.072* - 0.008), FFM and BMR (for both parameters, $r$ = 0.55 - 0.72 and p = 0.050 - 0.005, respectively), SSM ($r$ = 0.56 - 0.72 and p = 0.045 - 0.005), and body mass ($r$ = 0.53 - 0.69 and p = 0.060* - 0.009). In session II, power was significantly correlated with body height and BMI, ($r$ = 0.52 – 54 and p = 0.0.55* - 0.067*). In turn, BFM, PBF, WHR, and VFL were not significantly correlated with power in either session. A higher number of significant correlations was noted in session II (Table 4).

Table 3. Correlation coefficients ($r$), coefficients of determination ($R^2$) between physiological parameters during the corresponding intervals in both sessions, and the significance levels of the parameters measured in sessions I and II

| Parameter | Interval<br>$r$ ($R^2$); $p$-value | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | Total |
| Distance [m] | **0.82 (0.67) p=0.001** | **0.88 (0.77) p<0.001** | **0.86 (0.74) p<0.001** | **0.66 (0.44) p=0.013** | **0.77 (0.59) p=0.002** | **0.91 (0.83) p<0.001** |
| Pace $_{avg}$ / 500 m [s] | **0.84 (0.71) p<0.001** | **0.89 (0.79) p<0.001** | **0.84 (.71) p<0.001** | **0.73 (0.53) p=0.005** | **0.82 (0.67) p=0.001** | **0.92 (0.85) p<0.001** |
| Power [W] | **0.81 (0.66) p<0.001** | **0.87 (0.76) p<0.001** | **0.86 (0.74) p<0.001** | **0.60 (0.36) p=0.030** | **0.74 (0.55) p=0.004** | **0.89 (0.79) p<0.001** |
| Energy expenditure [kcal/h] | **0.81 (0.66) p<0.001** | **0.87 (0.76) p<0.001** | **0.86 (0.74) p<0.001** | **0.60 (0.36) p=0.030** | **0.74 (0.55) p=0.004** | **0.89 (0.79) p<0.001** |
| SPM [strokes/minute] | **0.85 (0.72) p<0.001** | **0.77 (0.59) p=0.002** | 0.21 (0.04) p=0.485 | **0.61 (0.37) p=0.026** | **0.69 (0.48) p=0.009** | **0.76 (0.58) p=0.003** |
| $HR_{avg}$ [bpm] | 0.54 (0.29) p=0.054 * | -0.27 (0.07) p=0.381 | -0.18 (0.03) p=0.550 | -0.23 (0.05) p=0.451 | -0.22 (0.05) p=0.464 | -0.16 (0.03) p=0.592 |
| $HR_{max}$ [bpm] | 0.19 (0.04) p=0.532 | -0.22 (0.05) p=0.463 | -0.14 (0.02) p=0.657 | -0.20 (0.04) p=0.522 | -0.21 (0.04) p=0.501 | -0.19 (0.04) p=0.532 |

bold faced – significant differences, * - near significant differences

Table 4. Correlation coefficients ($r$), coefficients of determination ($R^2$), and the significance levels of anthropometric parameters and power (W) in sessions I and II

| Body composition characteristics | Session<br>$r$ ($R^2$); $p$-value | |
|---|---|---|
| | I | II |
| Body height [cm] | 0.37 (0.14); p=0.219 | 0.54 (0.29); p=0.055 * |
| Body mass [kg] | 0.53 (0.28); p=0.060 * | **0.69 (0.48); p=0.009** |
| BMI [kg/m²] | 0.46 (0.21); p=0.219 | 0.52 (0.27); p=0.067 * |
| TBW [kg] | **0.55 (0.30); p=0.050** | **0.72 (0.52); p=0.005** |
| Proteins [kg] | **0.55 (0.30); p=0.049** | **0.72 (0.52); p=0.005** |
| Minerals [kg] | 0.51 (0.26); p=0.072 * | **0.70 (0.49); p=0.008** |
| BFM [kg] | 0.33 (0.11); p=0.271 | 0.29 (0.08); p=0.343 |
| FFM [kg] | **0.55 (0.30); p=0.050** | **0.72 (0.52); p=0.005** |
| SSM | **0.56 (0.31); p=0.045** | **0.72 (0.52); p=0.005** |
| PBF | 0.22 (0.05); p=0.470 | 0.09 (0.01); p=0.770 |
| BMR | **0.55 (0.30); p=0.050** | **0.72 (0.52); p=0.005** |
| WHR | 0.03 (<0.01); p=0.918 | 0.07 (0.01); p=0.809 |
| VFL | 0.28 (0.08); p=0.350 | 0.30 (0.09); p=0.320 |

bold faced–significant differences, * - near significant differences

# DISCUSSION

The study demonstrated significant differences in average power generated in successive intervals. An analysis of these values revealed the presence of a linear trend, which implies that the power generated by players decreased gradually in successive intervals. A gradual decline was also noted in distance, pace $_{avg}$ /500 m, and energy expenditure. In turn, a significant increase in the mean values of $HR_{avg}$ and $HR_{max}$ points to the growing levels of fatigue in successive intervals. During repeated maximal power interval performance, fatigue can be attributed to a number of factors, where the depletion of phosphocreatine stores and the accumulation of hydrogen ions in muscle cells appear to play the key role [44 – 46]. The number of type IIA and IIX fast twitch (FT) fibers is also important in this type of performance [47] because the force exerted by a muscle during a voluntary contraction depends mainly on the number of motor units recruited for the action and the rate at which these units discharge action potentials (rate coding). In turn, the difference in power generated by all motor units is determined mainly by the number and proportions of different muscle fibers [48]. In the 5 x 20-s RMRT, maximum power has to be generated within the shortest possible time and maintained for 20 s. Therefore, the test measures explosive strength, namely the ability to increase force or torque as quickly as possible during a rapid voluntary contraction starting from a low or resting level [49].

The mechanisms that contribute to fatigue during repeated-maximal power interval exercise have to be explored in greater detail to improve the RA/RSA of athletes participating in team sports. Field RA/RSA tests are reliable [31,32] and specific to the exercise demands of team players [29], but they are not highly practical for obtaining physiological and metabolic data that are needed to improve our understanding of the mechanisms underpinning fatigue during repeated maximal power exercises. Therefore, recovery intervals with the same duration as the intervals in the 5 x 20-s RMRT play an equally important role from the physiological point of view. Numerous studies have shown that short intervals during the recovery phase also contribute to greater residual fatigue between stimuli [50,51]. This effect has been associated with both PCr and ATP concentrations which stimulate glycolytic metabolism and increase blood lactate levels in the recovery phase [52,53].

The observed decrease in power in successive intervals contradicts the results reported by Denisiuk [54] and Podstawski et al. [23,26], and these discrepancies can be directly attributed to differences in the research methodology. In the present study, differences between intervals were examined during a single test, whereas in the cited studies, successive trials were performed at weekly intervals, which led to a significant improvement in the results of repeated motor tests up to a certain point. This phenomenon is referred to as the "learning trend", and it affects an athlete's/participant's ability to correctly perform a motor test. According to Podstawski et al. [23,26], a participant is ready to perform a test (i.e. the participant has mastered the technique and developed sufficient endurance capacity) when no significant differences are noted between trials. In turn, high coefficients of correlation in the values of power and power components (covered distance, pace $_{avg}$ / 500 m, and energy expenditure) between intervals could indicate that the test is reliable.

Treadmill or ergocyclometer tests do not engage all muscle groups that are required to assess motor performance in volleyball players. This study was undertaken to explore the reliability of a motor test that meets the above requirement. A rowing ergometer was used to evaluate the power generated by volleyball players because this instrument engages muscles throughout the entire body to a greater extent than an ergocyclometer or running tests. Therefore, the rowing ergometer test is a more valid and reliable tool for assessing volleyball players' motor performance. The results of the 5 x 20-s RMRT indicate that a rowing ergometer can be reliably used to assess the decline in maximum power during exercise intervals corresponding to the average duration of the longest rallies that account for 10.5% of all rallies during a game [15]. However, the test does not account for the spatio-temporal character of the players' performance which, according to research, is difficult to measure because volleyball is a highly dynamic sport with a complex playing environment [3,55]. The motor performance (physical fitness) of athletes is often evaluated in laboratory tests which do not account for movements that are specific to a given sports discipline, such as the Wingate anaerobic test on a cycle ergometer which is administered to assess the performance of volleyball players [42,56,57]. Other examples include running tests, such as the TW 20 meter test which was effectively used to assess the explosive strength of the lower limbs (vertical jump) [58]. Volleyball players are also evaluated in the volleyball intermittent endurance test (VIET) and the treadmill graded exercise test (GXT) which measures gas exchange parameters (GXT) [59].

From the practical point of view, the 5 x 20-s RMRT could be useful for evaluating substitute players' ability to generate and maintain maximum power (substitute players enter the court to play several tactical games and score a point for the team). Therefore, players who remain in the court for most of the game should be assessed in a test containing a higher number of repetitions (for example, ten repeated intervals). It can be assumed that better players will be able to generate more power and maintain that power over longer periods of time. Short, repeated-interval protocols are not only useful for evaluating RA/RSA, but they are also effective training tools for improving muscle oxidative potential and increasing endurance capacity [60]. The 5 x 20-s RMRT can be used in volleyball training as an alternative approach to maintaining or improving motor fitness, and it can be helpful during functional training to prevent injury caused by repeated movement patterns [61]. Cross-training is also a popular preventive approach, and it is used to structure training programs and improve competitive performance in a given sport by training in a variety of sports [62]. The main purpose of a repeated performance test is to determine genuine changes in performance [44]. Above all, RA/RSA measurements should reflect changes in performance that are attributable to the intervention. The extent to which the results of motor tests are linked with the players' actual performance during volleyball games is also an important consideration [3]. Research has shown that athletes who score high results in motor tests often underperform during games [63]. In other words, test results are not always a reliable indicator of athletes' real-world performance [64,65].

*Strengths and Limitations*

The main strength of the study was that the motor performance of volleyball players was evaluated in a novel test (5 x 20-s RMRT) involving the Concept 2 rowing ergometer. The minimum number of two repetitions in the test-retest method was a limitation, but this approach is often used in research studies of the type. A higher number of measurement sessions could not be organized due to time constraints (a homogeneous sample of volleyball players capable of participating in successive weekly trials could not be obtained). Therefore, future research should involve more measurement sessions to determine the minimum number of repetitions for eliminating significant differences in results between sessions ("learning trend"). Blood chemistry tests could also be included in the research protocol to examine the impact of physical effort during the 5 x 20-s RMRT on the human body and the participants' physiological responses. Classification standards for age and gender groups should be also developed based on the results of large-scale population studies.

# CONCLUSION

The study demonstrated that the 5 x 20-s RMRT is a valid and reliable test for assessing maximal anaerobic power generated by young volleyball players. According to the authors, the test is best suited for evaluating maximum power that is generated and maintained by volleyball players during several tactical actions in a game. The results of the 5 x 20-s RMRT revealed the presence of a linear trend indicating that power decreased in successive intervals due to the growing levels of fatigue among players.

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