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Power–velocity relationship and muscular strength in female volleyball players during preparatory period and competition season

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Purpose: The aim of the study was to investigate changes of power–velocity relationship and muscular strength of female volleyball players during preparatory period and competition season. *Methods:* The study was conducted on eleven female volleyball players: age 21.6 ± 1.7 years, body height 177.9 ± 4.7 cm, body mass 71.3 ± 6.6 kg. Power–velocity relationship was determined by means of five maximal 10-second cycloergometer efforts with external loads equal to: 2.5, 5, 7.5, 10 and 12.5% of body weight (BW). The joint torque of flexors and extensors of an elbow, shoulder, hip, knee and trunk was measured using a torque meter. The measurement were taken before (I) and after (II) the preparatory period, after the first (III) and second (IV) competitive season. *Results:* The power with a load equal to 2.5, 5.0, 7.5, 10.0% BW increased significantly after first and second competitive season. The sums of joint torque for the lower and upper limb changed insignificantly. In the case of the right upper limb, sum of the joint torques was significantly reduced by 9.5% between measurement I and IV. Sum of the left upper limb was significantly decreased by 9.8% between measurement I and II. Sum of the joint torque of the trunk was significantly increased between measurements I and II, III and IV by 12.9%, 12.3% and 11.2%, respectively. *Conclusion:* Obtained results may suggest that selection of the training loads was adequate for training power output and muscle strength of lower limbs but too little emphasis was placed on development of strength in the muscles of the upper limbs.

Key words: *female, force–velocity relationship, power, strength, volleyball*

1. Introduction

Changes in the maximal joint torques and power output may reflect the results of the applied training loads. Measurements of maximal joint torques taken under static conditions [4], [6], [19], power output in vertical jumps on a force plate [4], [7], [11], [16] or/and the force–velocity relationship (F–v) obtained on cycleergometer [1], [2], [5] are routine methods used for muscle strength and power determination in laboratory testing. Muscle strength may also be expressed as a contribution of a particular muscle groups in their sum [3]. Volleyball is a sport that requires strength in upper and lower limbs [13]. The development of muscle strength is particularly important for young players, especially to female athletes [13], as priority factors to achieve success [13]. In the works of Buśko [1], [2] F–v characteristics were determined on the cycle ergometer for male volleyball players. However, in the literature, there are not many publications that describe the force–velocity or power–velocity relationship [4] and muscle torque [4], [10] in female volleyball players. There is also a paucity of research about performance characteristics of female volleyball players during an entire in-season [10], [12], [13].

The aim of the study was to investigate changes of power–velocity relationship and muscular strength in female volleyball players during preparatory period and competition season.

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2. Materials and methods

Participants

The study was approved by the Senate Ethics Committee of the Józef Piłsudski University of Physical Education in Warsaw. All participants were informed about the aim and course of the study, and about the possibility of immediate resignation without giving the cause. All subjects gave their written consent. The study was conducted on eleven second-league female volleyball players: age 21.6 ± 1.7 years, body height 177.9 ± 4.7 cm, body mass 71.3 ± 6.6 kg (I), 72.3 ± 6.2 kg (II), 72.0 ± 6.9 kg (III), 71.2 ± 6.7 kg (IV), and training experience 8.6 ± 3.3 years.

Procedure

The maximal joint torque of the flexors and extensors of an elbow, shoulder, hip, knee and trunk was measured using a torque meter (JBA, Zbigniew Staniak, Poland) – type LR1-P (upper extremities) and TBK2-PM (lower extremities and trunk). Technical characteristics of the torque meters were described by Buśko et al. [4]. Measurements of joint torque were performed according to the generally accepted principles. During the measurement of the joint torque for elbow flexors and extensors, the subject was sitting, with her arm bent at a proper angle and placed on the armrest, with her trunk stabilized. The joint torques of the shoulder flexors and extensors were measured in a sitting position as well. The flexion angle was set at 70° and the extension angle – at 50° during the measurement. The trunk was stabilized for the eventual presence of synergic movements to be excluded. The measurements of a joint torque taken for the knee flexors and extensors were carried out on subjects in a sitting position. The hip and knee joints were bent at 90°. The subjects were stabilized at the level of anterior superior iliac spines and thighs, with the upper extremities resting on the chest. The subjects were lying face up during the measurements of the hip flexors and extensors. The subjects were stabilized at the level of anterior superior iliac spines. The hip joint angle remained at 90° during the measurement. The maximal, physiological extension of the elbow, knee and hip joints was accepted as 0°. For the shoulder joint, the positioning of the arm along the side was taken as 0°. The joints axis of rotation during measurements corresponded to the axis of rotation of the torque meter. The joint torques of the right and left limbs were measured separately, always in the order flexion–extension. The participants performed a maximal voluntary contraction (MVC) under static conditions for flexion and extension of the elbow, shoulder, hip, knee joint and trunk lasting 3 seconds each. The measured values of maximal joint torques of the flexors and extensors of an elbow, the shoulder, the hip, and the knee and the flexors and extensors of the trunk were used to calculate the "flexors-extensors" index.

The force–velocity (F–v) and power–velocity (P–v) relationships were determined on the basis of exercises' results performed on a Monark 874 E cycloergometer (Sweden) connected to a PC, using the MCE 4.0 software package („JBA" Zb. Staniak, Poland). After adjusting the ergometer saddle and handlebars, each subject performed the tests in a stationary position, without lifting body off the saddle and with feet strapped onto pedals. Each player performed five 10-second maximal cycloergometer tests with an increasing external load amounting to 2.5, 5.0, 7.5, 10.0 and 12.5% of body weight (BW), respectively. There were 2-minute breaks between the tests. The standard procedures of exercise performance were followed, and the subjects were verbally encouraged to achieve and maintain the maximal pedaling velocity as quickly as possible. With the use of MCE, the maximal power output at a given load (P_i; i – load value) and pedalling rate (v_i) necessary to achieve P_i were determined [1].

The measurements were performed before the preparatory period (I), after the preparatory period (II), after the first (III) and second (IV) competitive season.

Statistical analysis

The results were statistically processed using analysis of variance (ANOVA) with repeated measures. The statistical significance of differences between particular mean values was analysed using post-hoc Tukey test. The level of statistical significance was set at $p = 0.05$. All statistical calculations were conducted using a Statistica™ software package.

3. Results

The obtained results power–velocity relationship are presented in Table 1. The absolute and relative power output with external load equal to 2.5, 5.0, 7.5 and 10.0% of body weight increased significantly after the first and second competitive season. The power output with external load of 12.5% BW insignificantly increased after the preparatory period.

Table 1. Pedalling rate (v), absolute (P) and relative ($P \cdot \text{mass}^{-1}$) power outputs recorded for determining force–velocity relationship (mean values ±SD) in female volleyball players during preparatory period and competition season

Variable	Load [% BW]	I	II	III	IV
P [W]	2.5	283.6 ± 38.3	293.0 ± 28.0	306.3 ± 21.3[ab]	307.3 ± 29.8[ab]
P [W]	5.0	501.6 ± 55.9	527.1 ± 46.3 [a]	533.9 ± 38.9 [a]	538.3 ± 38.9[a]
P [W]	7.5	629.7 ± 54.4	639.4 ± 52.7	670.7 ± 47.3[ab]	668.4 ± 35.2[ab]
P [W]	10.0	596.3 ± 81.0	670.6 ± 69.9 [a]	682.6 ± 56.3 [a]	682.8 ± 54.1[a]
P [W]	12.5	528.0 ± 133.2	554.3 ± 90.2	585.0 ± 128.0	593.67 ± 105.8
$P \cdot \text{mass}^{-1}$ [W·kg^{-1}]	2.5	3.97 ± 0.30	4.06 ± 0.18	4.27 ± 0.22[ab]	4.28 ± 0.21[ab]
$P \cdot \text{mass}^{-1}$ [W·kg^{-1}]	5.0	7.03 ± 0.35	7.31 ± 0.22 [a]	7.44 ± 0.38 [a]	7.60 ± 0.49[ab]
$P \cdot \text{mass}^{-1}$ [W·kg^{-1}]	7.5	8.85 ± 0.48	8.99 ± 0.68	9.38 ± 0.87 [a]	9.47 ± 0.86[ab]
$P \cdot \text{mass}^{-1}$ [W·kg^{-1}]	10.0	8.40 ± 1.13	9.35 ± 1.18 [a]	9.69 ± 1.00 [a]	9.70 ± 1.27 [a]
$P \cdot \text{mass}^{-1}$ [W·kg^{-1}]	12.5	7.45 ± 1.78	7.71 ± 1.25	8.19 ± 1.89	8.48 ± 1.88
v [rpm]	2.5	161.1 ± 11.1	165.2 ± 6.7	173.0 ± 8.3[ab]	174.2 ± 7.8[ab]
v [rpm]	5.0	143.5 ± 6.8	147.9 ± 5.3	152.0 ± 7.6[ab]	154.8 ± 9.1[ab]
v [rpm]	7.5	120.3 ± 6.5	122.1 ± 9.6	127.5 ± 11.8[a]	128.8 ± 11.7[ab]
v [rpm]	10.0	85.8 ± 11.6	95.3 ± 12.2 [a]	98.9 ± 10.2[a]	98.8 ± 12.9[a]
v [rpm]	12.5	60.7 ± 14.5	62.9 ± 10.1	68.4 ± 17.4	69.2 ± 15.4

Legend: BW – body weight; I – measurements before the preparatory period, II – measurements after the preparatory period, III – measurements during after the first competitive seasons, IV – measurements during after the second competitive seasons; [a] – mean values significantly different from the I measurement ($p < 0.05$); [b] – mean values significantly different from II measurement ($p < 0.05$).

Table 2. Mean values (±SD) of sums of the maximal joint torque for the right (R) and left (L) upper extremity (SUE), lower extremity (SLE), trunk (ST) and all ten muscle groups (TOTAL) in female volleyball players during preparatory period and competition season

Variable	I	II	III	IV
SUER [N·m]	203.6 ± 25.8	198.6 ± 27.4	184.6 ± 23.457[a]	194.7 ± 24.6
SUEL [N·m]	187.9 ± 33.2	169.9 ± 16.9 [a]	183.6 ± 25.7	181.0 ± 20.7
SLER [N·m]	785.6 ± 119.6	742.73 ± 117.68	766.5 ± 134.1	818.0 ± 83.0 [b]
SLEL [N·m]	767.7 ± 114.7	724.2 ± 101.8	760.4 ± 106.1	794.8 ± 91.4 [b]
ST [N·m]	504.7 ± 86.8	571.6 ± 72.56 [a]	566.6 ± 84.8 [a]	552.3 ± 81.9 [a]
TOTAL [N·m]	2449.6 ± 314.9	2407.0 ± 292.5	2461.6 ± 322.1	2540.8 ± 271.1 [b]

Legend: I – measurements before the preparatory period, II – measurements after the preparatory period, III – measurements during after the first competitive seasons, IV – measurements during after the second competitive seasons; [a] – mean values significantly different from the I measurement ($p < 0.05$); [b] – mean values significantly different from II measurement ($p < 0.05$).

Table 3. Mean values (±SD) of sums of the maximal relative joint torque for the right (R) and left (L) upper extremity (SUE), lower extremity (SLE), trunk (ST) and all ten muscle groups (TOTAL) in female volleyball players during preparatory period and competition season

Variable	I	II	III	IV
SUER [N·m·kg^{-1}]	2.86 ± 0.33	2.75 ± 0.32	2.59 ± 0.40 [a]	2.75 ± 0.41
SUEL [N·m·kg^{-1}]	2.64 ± 0.38	2.36 ± 0.22 [a]	2.57 ± 0.39 [b]	2.56 ± 0.35
SLER [N·m·kg^{-1}]	11.11 ± 1.95	10.33 ± 1.76	10.73 ± 2.09	11.57 ± 1.47 [bc]
SLEL [N·m·kg^{-1}]	10.87 ± 1.92	10.09 ± 1.65 [a]	10.65 ± 1.71	11.23 ± 1.43 [b]
ST [N·m·kg^{-1}]	7.09 ± 1.10	7.93 ± 0.97 [a]	7.92 ± 1.23 [a]	7.81 ± 1.29 [a]
TOTAL [N·m·kg^{-1}]	34.57 ± 4.85	33.46 ± 4.42	34.46 ± 5.18	35.92 ± 4.59 [b]

Legend: I – measurements before the preparatory period, II – measurements after the preparatory period, III – measurements during after the first competitive seasons, IV – measurements during after the second competitive seasons; [a] – mean values significantly different from the I measurement ($p < 0.05$); [b] – mean values significantly different from II measurement ($p < 0.05$), [c] – mean values significantly different from III measurement ($p < 0.05$).

Table 4. Changes in the mean values (±SD) of the "flexors-extensors" index [–] (FEI) in female volleyball players during preparatory period and competition season

Index	I	II	III	IV
FEI_{ER} [–]	1.69 ± 0.32	1.56 ± 0.29 [a]	1.62 ± 0.24	1.57 ± 0.23 [a]
FEI_{EL} [–]	1.67 ± 0.29	1.62 ± 0.22	1.70 ± 0.17	1.61 ± 0.20
FEI_{SR} [–]	0.77 ± 0.14	0.68 ± 0.11	0.73 ± 0.13	0.78 ± 0.25
FEI_{SL} [–]	0.88 ± 0.11	0.81 ± 0.10	0.83 ± 0.13	0.90 ± 0.20
FEI_{KR} [–]	0.61 ± 0.11	0.62 ± 0.15	0.56 ± 0.17	0.55 ± 0.11 [b]
FEI_{KL} [–]	0.58 ± 0.10	0.60 ± 0.12	0.57 ± 0.12	0.55 ± 0.08
FEI_{HR} [–]	0.32 ± 0.11	0.32 ± 0.09	0.32 ± 0.08	0.30 ± 0.08
FEI_{HL} [–]	0.33 ± 0.09	0.36 ± 0.13	0.33 ± 0.09	0.31 ± 0.09
FEI_{T} [–]	0.64 ± 0.11	0.68 ± 0.33	0.58 ± 0.08	0.61 ± 0.14

Legend: E – elbow, S – shoulder, H – hip, K – knee, T – trunk, R – right, L – left; I – measurements before the preparatory period, II – measurements after the preparatory period, III – measurements during after the first competitive seasons, IV – measurements during after the second competitive seasons; [a] – mean values significantly different from the I measurement ($p < 0.05$); [b] – mean values significantly different from II measurement ($p < 0.05$).

Maximal joint torques (MT) and relative maximal joint torques estimated for tested female volleyball players are shown in Tables 2 and 3, respectively. The sums of maximal joint torques of the lower and upper limb changed insignificantly. The sum of the maximal joint torques for right upper limb decreased significantly by 9.5% between measurement I and IV. The sum of the maximal joint torques for left upper limb decreased too, by 9.8% between measurement I and II. However, the sum of the maximal joint torque for trunk muscles increased significantly between measurements I and II, III and IV by 12.9%, 12.3% and 11.2%, respectively.

The calculated values of the "flexors–extensors" index for an elbow, shoulder, hip, knee, and trunk remained unchanged during the one-year training cycle, except of "flexors–extensors" index for the right elbow after the preparatory period and after the second competitive seasons (Table 4).

4. Discussion

Training of motor skills in volleyball players has its principal place during the preparatory period. In the competitive period the main emphasis is placed on improving the technique and tactics, and training of motor skills is reduced [10]. Thus, a training for volleyball players should concentrate on developing power of legs and should improve strength and/or velocity during preparatory period. The present study revealed a significant increase in maximal power and sum of joint torques of trunk. Additionally, non-significant changes of the joint torques for upper and lower extremities were observed during whole season. Increase of the power output ranged from 6 to 8% with external load ranging from 2.5% to 7.5% BW. For external loads equal to 10 and 12.5% BW, the power output increased by 16.5 and 18.0%, respectively. Our results confirm the thesis that the value of the players' power output measured on a cycloergometer depends on the amount of external loading [5]. A number of studies have investigated effects of different training methods applied to a subject [14], [15] during the competitive season in volleyball [2], [13], [15], [18]. In the competitive season, strength increased significantly by 15% and jump height in CMJ was significantly improved by 3.8% [13]. Height of the squat jump (SJ) and CMJ increased significantly by 7.6% and 4.6%, respectively, and the muscle strength increased by 6.01% in the second competitive season [8]. The results presented by Stanganell et al. [18] show that the training-induced adaptations of the SJ (3.9%) and CMJ (2.3%) were not statistically significant during second competitive season while the attack height and block height changed significantly during an annual training cycle (3.0% and 3.5%, respectively). In our research, volleyball training improved the power output developed with external load equal to 5 and 10% BW during the preparatory period and power output developed with external load equal to 2.5%, 5.0%, 7.5% and 10.0% BW after first and second competitive season. There were no changes of power output between the III and IV measurements, while in article of Häkkinen [10] all measured parameters were reduced. Buśko [2] described similar changes of the power–velocity relationship in male volleyball players who were affected by training after the first competitive season, in comparison to initial (before preparatory) values.

The aim of a preparation period is to raise the strength of an athlete to the highest possible level, whereas during a competition period the attained strength should remain unchanged as long as possible. Hence, the physical features of players should change together with a training stage. There are several methods for assessing muscle strength, and different studies use different methodologies. Hence, it is difficult to compare results among studies [11]. In the present study, increases in the maximal joint torques were observed only for the trunk. The joint torques of upper extremities were insignificantly reduced. Strength of the lower limbs increased insignificantly during the season. Observed changes, expressed as a percentage growth of a particular parameter in relation to the first measurement, were similar to those reported by Häkkinen et al. [9] for the muscle strength of lower limbs (3.5%) after one year of the strength training of weightlifters. They were also similar to those reported by Valadés et al. [21] (7.3%) for Spanish female volleyball team throughout the season. Our results are not in accordance with paper in which the six-month training period (volleyball players) led to a significant increases in strength of the main muscle groups and upper extremities (by 4.8% and by 13.9%, respectively), but changes in the muscle strength of lower extremities (by 3.4%) and trunk (by 1.3%) were not significant [20].

Based on the measurements of the maximal muscle torques under static conditions, the authors of some reports calculate a strength index defined as the ratio of the maximal torques of flexors to the maximal torques of extensors (FEI) [3], [19]. The values of this index obtained in the present study for knee, hip and trunk are compatible with the results reported by Buśko [3], who investigated female basketball players, and correspond to work of Szpala et al. [19], who presented that FEI index of trunk in female students from the Faculty of Physical Education equals to 0.59. Moreover, in contrast to the results reported by Shealy et al. [17], who demonstrated alterations in the "flexors–extensors" ratio after eight weeks of sprint training, no significant changes in this index were recorded in the present investigation for all the analyzed joints, except of FEI of right elbow.

5. Conclusions

During whole one-year study, the power output, the sum of maximal joint torques of lower limbs and trunk increased, while the sum of maximal joint torques of upper limbs decreased. Obtained results may suggest that selection of the training loads was adequate for training power output and muscle strength of lower limbs but too little emphasis was placed on development of strength in the muscles of the upper limbs.

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