Original research papers

BIOMECHANICAL ASSESSMENT OF STRENGTH AND JUMPING ABILITY IN MALE VOLLEYBALL PLAYERS DURING THE ANNUAL TRAINING MACROCYCLE

ADAM CZAPLICKI[1], MARCIN ŚLIWA[2], PAULINA SZYSZKA[3], JERZY SADOWSKI[3]

Józef Piłsudski University of Physical Education in Warsaw, Faculty of Physical Education and Sport in Biała Podlaska, Department of Biomechanics and Computer Science[1], Department of Football and Volleyball[2], Department of Theory and Technology of Sports Training[3]

Mailing address: Adam Czaplicki, Józef Piłsudski University of Physical Education in Warsaw, Faculty of Physical Education and Sport in Biała Podlaska, Department of Biomechanics and Computer Science, 2 Akademicka Street, 21-500 Biała Podlaska, tel.: +48 83 3428731, fax: +48 83 3428800, e-mail: adam.czaplicki@awf-bp.edu.pl

Abstract

Introduction. The aim of the study was to determine the changes in the peak torque of the knee extensors and flexors of the dominant lower limb, the shoulder internal and external rotators of the dominant upper limb, and the shoulder extensors and flexors of the dominant upper limb as well as the changes in jump height in volleyball players during the annual training macrocycle. ***Material and methods.*** The study involved 13 volleyball players from a Polish second-league team. The measurements were performed five times: before the preparation period (T_1), at the beginning of the competitive season (T_2), in the middle (T_3) and at the end of the first competition period (T_4), and after the competitive season (T_5). The torque of the knee muscles and shoulder rotators was measured in isokinetic conditions, and the torque of the shoulder extensors and flexors was assessed in isometric conditions. Jumping ability was tested using a piezoelectric platform. ***Results.*** We observed statistically significant differences ($p < 0.05$) in jump height and relative peak torque between the measurements, except for the torque of the shoulder external rotators and flexors. The results of multiple factor analysis based on 5 sets composed of 5 strength variables revealed differences between subjects and measurement sessions. ***Conclusions.*** The results obtained indicate that strength and jumping ability should be assessed regularly during the competitive season. The findings of the study suggest that it is necessary to modify the training methods used during the preparation period and individualize the training in the final phase of the competition period.

Key words: volleyball, muscle torque, jump height, annual macrocycle

Introduction

Volleyball was introduced to the Olympic Games in Tokyo in 1964. For several years, it has been one of the most popular team sports [1, 2]. It is characterized by the changing dynamics of the movements of the players, who are required both to receive the ball accurately and perform explosive movement when spiking. Due to the status, popularity, and dynamic nature of volleyball, players are systematically assessed. One of the characteristic aspects of such assessments is the evaluation of the players' motor capacities by means of measuring their strength and jumping ability [3, 4, 5].

The biomechanical assessment of the strength of volleyball players can be performed in isokinetic and isometric conditions. In the first case, isokinetic dynamometers are typically used to measure the net torque of the knee extensors and flexors [6, 7, 8, 9] and the shoulder internal and external rotators [3, 10, 11, 12, 13, 14]. Isometric measurements, on the other hand, are not frequently applied in volleyball, despite their long tradition [15]. This stems both from a lack of standard measuring equipment and from inconsistencies in the results of such assessments. There is no evidence of strong correlations between isometric strength and the prediction of movement performance [16] or correlations between maximal voluntary isometric knee extension torque development and jump performance [17].

Due to the specificity of volleyball, jumping is regarded as a basic motor ability in this discipline. That is because this variable reflects the players' ability to perform spikes, jump serves, and blocks. A basic measurable variable which is used to assess jumping ability is jump height. The most commonly applied methods of measuring this variable include different types of vertical jumps [3, 18, 19, 20, 21, 22].

Contemporary training programmes in team sports are oriented towards ensuring that players maintain a particular level of strength and jumping ability during the entire season [23, 24]. In the first of the two studies cited above, the players were tested during the season before and after undergoing 12 weeks of resistance training, and in the second one (involving female players), the assessments were performed at the start of the season, mid-season (7th week), and at the end of the season (11th week). Other authors [22] have also studied long-term training adaptations of volleyball players at the beginning and end of the macrocycle. However, verifying the effect of training programmes requires assessing the players' physical capacities during the entire macrocycle [25], including the early and late phases of the preparation period and both parts of the season. According to our knowledge, such complex measurements of strength and jumping ability have not yet been performed on male volleyball players, although they have been carried out on female players, whose level of selected motor abilities was checked four times during a 24-week macrocycle [26].

The aim of the study was to perform a biomechanical assessment of the strength and jumping ability of second-league male volleyball players during the annual macrocycle. We assumed that this analysis would reveal differences between subjects and measurement sessions, as well as indicating which biomechanical variables are superior in quantifying these changes during the macrocycle. We also believe that analyzing the motor abilities of non-elite players is equally important as examining those of elite players, as the former group clearly dominate among volleyball players, and many champions start their careers by taking part in lower-level tournaments.

Material and methods

The study included 13 players (age = 21.7 ± 3.8 years; height = 186 ± 5.7 cm; weight = 89.1 ± 9.9 kg). All the players were examined by a sports doctor and were qualified for the study. Both the coach and the players were provided with information on the research procedure and the possible risks and benefits related to participating in the study. The study was approved by the Senate Research Ethics Committee of the University of Physical Education in Warsaw.

The participants of the study were players of a second-league team, who competed to be promoted to the first league during the play-offs of the season which was investigated in the current study. Figure 1 shows an outline of the volleyball players' annual training macrocycle. It consisted of two preparation periods, two competition periods, and a transition period. The first competition period ended in a play-off phase, during which four of the best teams competed to participate in the semi-finals of the tournament that decided promotion to the first league. During the macrocycle, the team played 46 matches, including 25 league matches (three in the semi-finals of the first-league promotion tournament) and 21 additional matches in friendly tournaments and the semi-finals and finals of the Polish University Championship.

The measurements were performed at the following five points of the annual training macrocycle: before the first preparation period (T_1); at the beginning of the competitive season (at the start of the first competition period) (T_2); in the middle (16th microcycle) of the first competition period (T_3); at the end (27th microcycle) of this period (T_4); and after the competitive season (after the second competition period) (T_5).

Before undergoing the tests, the subjects performed a standard warm-up lasting 15 minutes. The measurements were taken on the testing stations in a random order by the same persons, following an identical procedure. Before the tests, the subjects performed three submaximal attempts so that they could familiarize themselves with the measuring devices. The best results obtained at each of the stations were included in the biomechanical analysis.

The torque of the knee extensors and flexors was measured in isokinetic conditions using Biodex System Pro 4 (Biodex Medical Systems Inc., USA). The subjects assumed the position of the body recommended by the manufacturer. Then standard measurement protocols were implemented, which consisted in performing 5 and 10 cycles of extension and flexion of the dominant limb at the angular velocities of 60 deg/s and 180 deg/s [6, 27, 28, 29]. The torque values of the flexors at both angular velocities were corrected for gravitation using an original algorithm developed in MATLAB (MathWorks, Natick, MA).

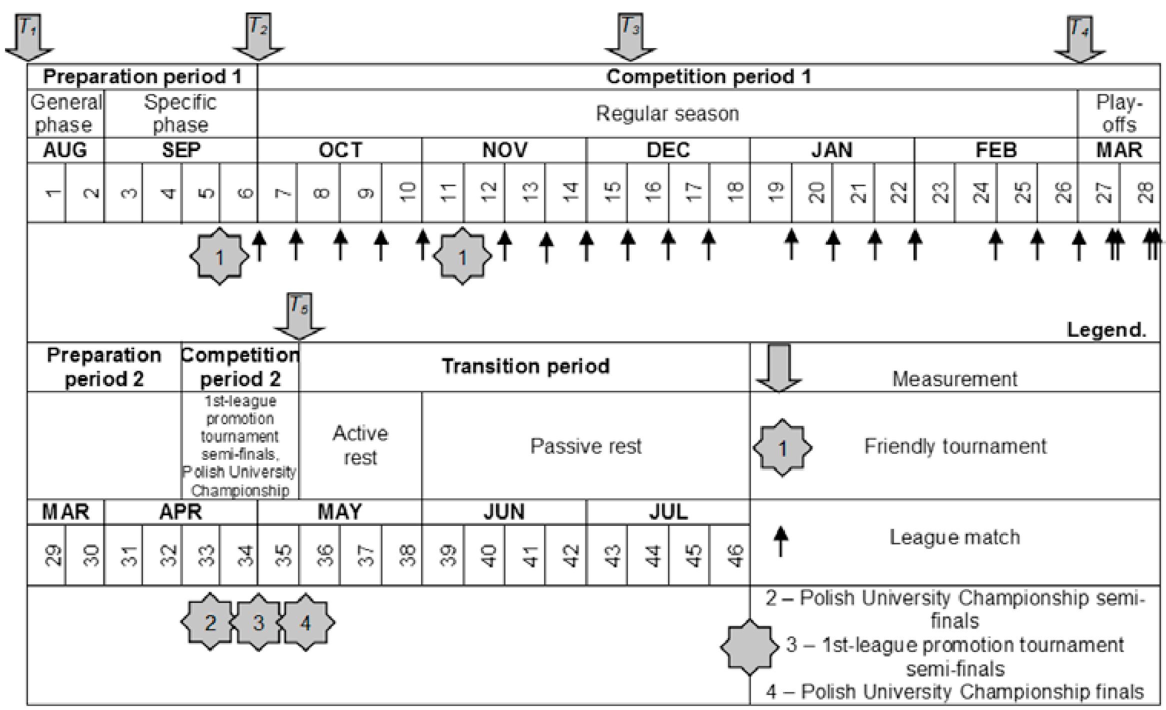

Figure 1. Annual training macrocycle

The torque values of the shoulder internal and external rotators of the dominant limb were measured taking into account the gravity correction. The subjects were tested in a sitting position with 45° of shoulder abduction in the scapular plane [11, 12]. The range of motion (ROM) was 70°. The subjects performed 5 repetitions of shoulder internal and external rotation.

The torque of the muscles acting on the shoulder joint was measured in static conditions on the measuring station LR2-P (JBA Zb. Staniak, Poland). During the test, the subjects performed 3 repetitions of flexion and extension in a sitting position with the upper limb placed along the body (Fig. 2).

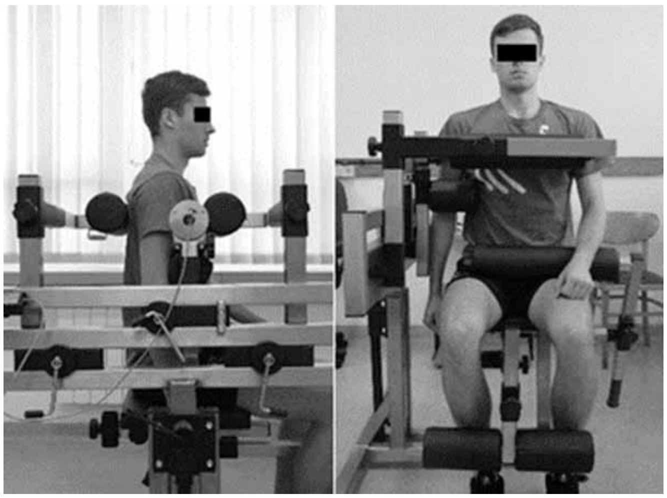

Figure 2. Measurement of shoulder extensor and flexor torque in isometric conditions

Jump height was measured using a 9281CA force plate (Kistler Group, Switzerland). The players performed 4 countermovement jumps (CMJ) with arm swing.

It is worth emphasizing that measurements of torque taken using isokinetic dynamometers and those of jump height performed on force plates are characterized by high reliability. Test-retest intraclass correlation coefficients (ICCs) exceed 0.9 in the case of the assessments of knee extensor and flexor torque [30], shoulder rotator torque [11, 12, 31], and the height of the centre of gravity after the CMJ [22, 23]. The test-retest which was performed before the first measurement in the current study confirmed these results, since the ICC values ranged from 0.91 (for the external rotators at a velocity of 60 deg/s) to 0.98 (for jump height). As for the assessment of the torque of the shoulder muscles in static conditions, the ICCs were 0.93 for the flexors and 0.91 for the extensors.

Statistical analysis

The statistical analysis was carried out using STATISTICA 12 (StatSoft, Poland). First, the data were tested for normality of distribution and homogeneity of variances using the Shapiro-Wilk test and Bartlett's test. The results (with a $p = 0.05$ level of statistical significance) showed that the data were normally distributed and that the variances were homogeneous. Then one-way ANOVA with repeated measures was performed, and the assumption of sphericity was verified using Mauchly's test. If the results of Mauchly's test were negative, the correctness of the calculations was also verified by means of multivariate analysis, which is not sensitive to violations of the sphericity assumption, considering the value of Wilks's λ. In the final stage of the statistical analysis, we applied Bonferroni's test, which allowed for a detailed interpretation of significant differences between the mean values of the variables, and we estimated effect size using partial eta squared (η^2), which was interpreted as follows: $\eta^2 > 0.01$ – small effect size, $\eta^2 > 0.09$ – medium effect size, and $\eta^2 > 0.25$ – large effect size [32].

We used multiple factor analysis (MFA) followed by hierarchical clustering, in order to discriminate the players and the measurement sessions during the macrocycle. This approach can handle experimental data consisting of several sets of variables [33, 34]. In the case at hand, 13 subjects were assessed 5 times at different dates, and each set of variables was measured at each date. The computations were performed in the R environment (R Foundation for Statistical Computing, Austria) using the FactoMineR package [35].

Results

The first four rows of Table 1 contain the mean relative peak torque values of the knee extensors and flexors measured in isokinetic conditions at the angular velocities of 60 deg/s and 180 deg/s. At the lower velocity, statistically significant differences were observed between T_1 and T_2 ($p \approx 0.0$), T_3 ($p \approx 0.0$), T_4 ($p \approx 0.00$), and T_5 ($p < 0.0$) for the extensors ($\eta^2 = 0.42$) and between T_1 and T_3 ($p < 0.01$), T_4 ($p < 0.04$), and T_5 ($p \approx 0.0$) for the flexors ($\eta^2 = 0.31$). At the higher velocity, significant differences were found between T_1 and the remaining measurements ($p \approx 0.0$) for the extensors ($\eta^2 = 0.57$) as well as between T_1 and T_3 ($p < 0.046$), T_4 ($p < 0.048$), and T_5 ($p < 0.001$) for the flexors ($\eta^2 = 0.28$).

Table 1. Mean and SD values of the variables in consecutive measurements. Superscript indicates measurement with significantly different mean value of the variable

Variable	Measurement 1	Measurement 2	Measurement 3	Measurement 4	Measurement 5
Ex_60 (Nm/kg)	$2.88 \pm 0.28^{2, 3, 4, 5}$	3.44 ± 0.38^{1}	3.39 ± 0.33^{1}	3.36 ± 0.58^{1}	3.25 ± 0.32^{1}
Fl_60 (Nm/kg)	$-1.30 \pm 0.17^{3, 4, 5}$	-1.44 ± 0.12	-1.48 ± 0.20^{1}	-1.47 ± 0.26^{1}	-1.53 ± 0.19^{1}
Ex_180 (Nm/kg)	$1.95 \pm 0.22^{2, 3, 4, 5}$	2.38 ± 0.33^{1}	2.43 ± 0.24^{1}	2.24 ± 0.38^{1}	2.54 ± 0.29^{1}
Fl_180 (Nm/kg)	$-1.05 \pm 0.13^{3, 4, 5}$	-1.22 ± 0.30	-1.25 ± 0.20^{1}	-1.25 ± 0.21^{1}	-1.34 ± 0.25^{1}
IR (Nm/kg)	-0.64 ± 0.07^{5}	$-0.69 \pm 0.08^{4, 5}$	-0.64 ± 0.09^{5}	-0.56 ± 0.17^{2}	$-0.48 \pm 0.09^{1, 2, 3}$
ER (Nm/kg)	0.38 ± 0.06	0.39 ± 0.07	0.37 ± 0.07	0.37 ± 0.12	0.33 ± 0.08
Ex_s (Nm/kg)	-0.80 ± 0.14	-0.79 ± 0.16^{5}	-0.84 ± 0.19	-0.89 ± 0.17	-0.90 ± 0.18^{2}
Fl_s (Nm/kg)	0.89 ± 0.19	0.91 ± 0.22	0.96 ± 0.23	1.00 ± 0.21	1.02 ± 0.19
H (m)	0.48 ± 0.05^{3}	0.49 ± 0.05	0.51 ± 0.06^{1}	0.50 ± 0.07	0.49 ± 0.06

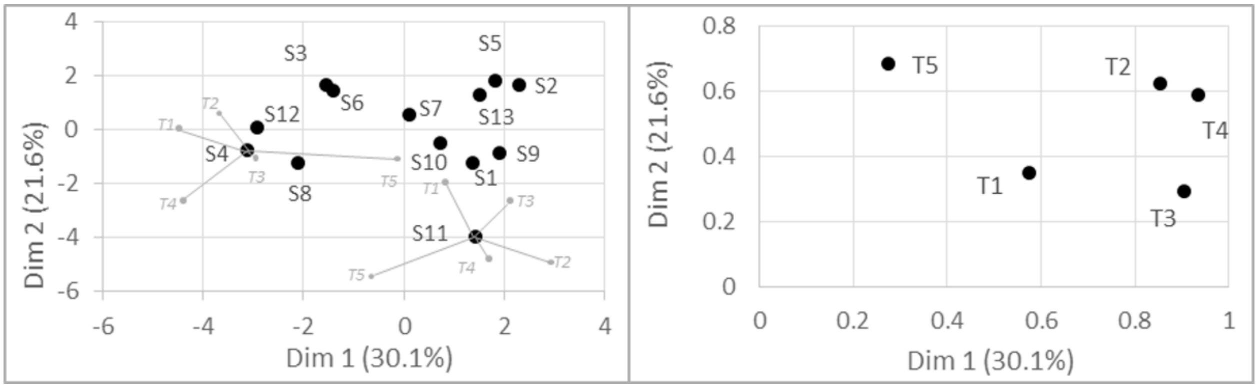

Figure 3. Subjects (left) and measurements (right) in the space of the first two global principal components

The mean relative peak torque values of the shoulder internal and external rotators measured in isokinetic conditions at the angular velocity of 60 deg/s are shown in the 5th and 6th rows of Table 1. Statistically significant differences ($\eta^2 = 0.53$; $p \approx 0.0$) were noted between T_2 and T_4 as well as between T_5 and T_1, T_2, and T_3 for the internal rotators. No significant changes were observed for the external rotators.

The mean relative peak torque values of the shoulder extensors and flexors measured in isometric conditions are presented in the 7th and 8th rows of Table 1. Only the differences between T_2 and T_5 for the extensors ($p < 0.04$) were found to be statistically significant ($\eta^2 = 0.24$).

The bottom row of Table 1 shows the changes in jump height recorded for the players during the annual macrocycle. The only statistically significant difference which was observed was that between the first and third measurement ($\eta^2 = 0.17$; $p < 0.04$).

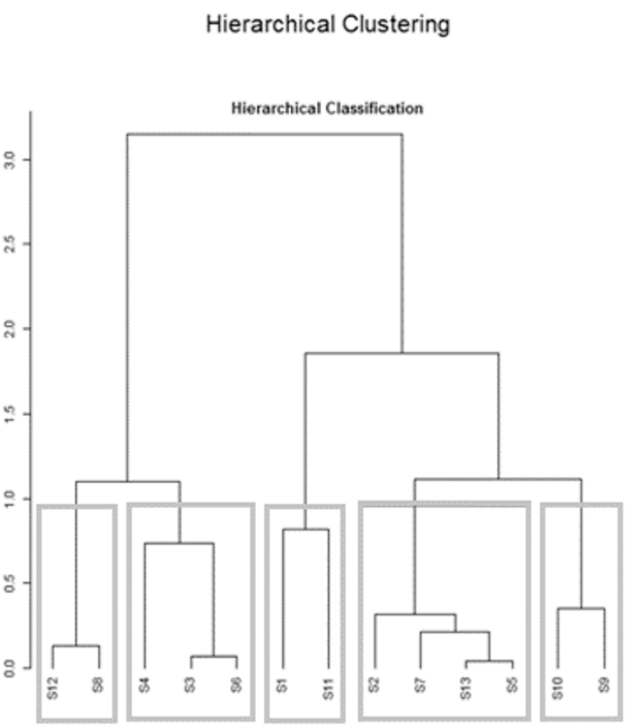

Figure 4. Hierarchical clustering of subjects' strength abilities during the annual training macrocycle

The MFA was based on the 5 sets of data, each containing 5 observable variables (Ex_60, Fl_60, Ex_180, Fl_180, IR). These variables were chosen as they changed most significantly during the annual macrocycle. Figure 3 (left) shows the subjects in the space of the first two principal components of the global space. The components have the eigenvalues of $\lambda_1 = 3.54$ and $\lambda_2 = 2.54$, and they explain 51.7% of the inertia of the transformed data. The first principal component clearly splits the subjects into two groups. It should be noted that the global position of each subject is the barycentre of its positions for the measurement sessions (small grey dots). The grey lines, for clarity reasons drawn for subjects S_4 and S_{11} only, indicate that the position of both subjects is determined by the results achieved in the 5th measurement session, T_5. The relationship between the measurements can also be identified by their positions in the global space (Fig. 3, right). The first component, for example, clearly discriminates between measurement T_1, measurement T_5, and measurements T_2, T_3, and T_4.

Figure 4 shows the results of the hierarchical clustering analysis, which was performed in the global space resulting from the MFA. The clustering was performed in the first 5 dimensions of MFA. Three pairs of clusters are visible on the lowest level of the dendrogram: (S_8, S_{12}), (S_3, S_6), and (S_5, S_{13}). At the relatively low height of approximately 0.8, five other clusters can be additionally identified; these clusters do not contain individual elements.

Discussion

The aim of the study was to assess the strength and jumping ability of volleyball players over the course of the annual macrocycle. We analyzed 7 variables which are commonly examined in biomechanical assessments.

The first group of variables included the torque of the knee extensors and flexors measured in isokinetic conditions. The torque of the knee extensors increased significantly after the preparation period, and the strength of these muscles did not change until the last measurement. This was confirmed by the results of all tests performed at both angular velocities (Tab. 1). On the other hand, we recorded a lower increase in the torque of the flexors, which was not found to be statistically significant between measurements T_1 and T_2. The possibility of a smaller improvement in the strength of the hamstrings after intense quadriceps exercise has long been noted in the literature [36] and our results confirmed these findings.

When the results of the current study are compared to those of other studies, it can be observed that the mean relative peak torque values of the knee extensors assessed in isokinetic conditions approximately correspond with the values of this variable measured in the Under-21 Brazilian National Volleyball Team [7], and they are higher than those recorded for elite players from Greek national volleyball divisions [8]. The values obtained in the studies cited above were equal to 3.57 Nm/kg and 2.72 Nm/kg, respectively, at the angular velocity of 60 deg/s, compared to 3.39 Nm/kg recorded for the volleyball players in this study at the beginning of the competitive season (T_2). The absolute values of the mean relative peak torque of this muscle group obtained at T_3 are, on the other hand, much higher than those obtained for volleyball players from the Turkish second league [6]. As far as the flexors are concerned, both the players from the Under-21 Brazilian National Team and the Greek players mentioned above had clearly higher values of mean relative peak torque at the velocity of 60 deg/s, amounting to 1.88 Nm/kg [7] and 1.82 Nm/kg [8], respectively, the value recorded for our volleyball players being 1.55 Nm/kg (in T_2). However, the absolute values of Turkish second-league players [6] were lower than the values obtained in the current study at T_2.

The second group of variables included the torque of the shoulder extensors and flexors assessed in isometric conditions. There were no statistically significant changes in the torque values of the shoulder internal or external rotators in the first part of the training macrocycle. The first symptoms of a decrease in internal rotator torque values were found only at the end of the first competition period (T_4), which was when the players started competing to be promoted to a higher league. Not only did both of these torque values decline at this time, but T_4 was also the measurement during which the greatest variability in the results obtained by the players was noted. The decreasing tendency in the torque values could be observed until the end of the competitive season, which was corroborated by the results of measurement T_5, performed immediately after the final matches.

A comparison of our findings with the results obtained by other authors revealed that the mean relative peak torque values of the shoulder internal and external rotators recorded in some of the phases of the macrocycle were similar to the data presented in the works of several other authors [8, 10, 13]. In the first publication mentioned above, the values which were recorded were 0.64 Nm/kg for the internal rotators and 0.40 Nm/kg for the external rotators. These results approximately correspond to the ones obtained in the current study in measurements T_1 to T_3 for the internal rotators and T_1 to T_4 for the external rotators. In the two remaining articles which are cited above, these values amounted to 0.67 Nm/kg and 0.45 Nm/kg, respectively. When comparing our findings with those reported in these three publications, one should note that in the studies cited, the volleyball players were tested in a supine position, and not a sitting one as was the case in our study. On the other hand, both of the torque values of the shoulder rotators assessed in our study were higher compared to the referential data for untrained persons tested in a sitting position [37].

The analysis of the strength of the shoulder extensors and flexors in isometric conditions indicated a lack of statistically significant differences during the annual training macrocycle, except for the difference between T_2 and T_4 for the extensors. This means that out of all of the methods of measuring strength in the annual macrocycle which were applied in the study, isometric tests had the lowest diagnostic value. On the other hand, since the mean relative peak torque values of the shoulder extensors and flexors were approximately the same during the entire macrocycle, the mean torque values measured in the entire macrocycle, which amounted to 0.95 ± 0.21 Nm/kg and 0.84 ± 0.17 Nm/kg, respectively, can be used as referential values in similar future studies.

The results of our study indicate a statistically significant increase in jump height between the measurement before the first preparation period (T_1) and the one carried out in the middle of the first competition period (T_3), but not the one performed after the first preparation period (T_2). Minor changes in jump height during the training macrocycle also point to the fact that athletes playing at this level exhibit a constant level of jumping ability, acquired during several years of training. It is worth emphasizing that statistically non-significant increases in jump height between two measurements carried out in May and July 2007 (amounting to 3 cm) were found in players of the Spanish National Team [18].

Due to the importance of jumping ability in volleyball, investigations concerning this motor ability are particularly well documented. Examining other studies conducted in this respect, it can be stated that the height of the countermovement vertical jump with arm swing recorded in our study corresponds with the results of the volleyball players an Italian regional league [3]. It is, at the same time, lower that the height achieved by selected first-league players from Belgium [20] and those from the Spanish National Team in the years 2007 and 2008 [18]. In the latter study, the first measurement was performed during the season, whereas the second one was conducted after it was finished.

The results of the MFA made it possible to discriminate the players and the measurement sessions during the annual training macrocycle. Due to the large dimension of the global data matrix, which has 12 eigenvalues, the first two components explain 51.7% and the first five components account for approximately 85% of the inertia of the transformed data. These values increase considerably when a smaller number of subjects is examined: for example, the first two components of the MFA performed for the seven main players in the team (the starting six players and libero) explain 68.8% and the first three components account for 85.8% of the inertia of the data. We believe that the results obtained in the study, apart from having a cognitive value, can also be of practical use to coaches, as they can, for example, facilitate selecting players for paired exercise implemented during the macrocycle.

Conclusions

The purpose of the current study was to examine the changes in selected biomechanical parameters in second-league volleyball players in the annual training macrocycle. The results of the study have revealed the nature of the changes in the players' strength and jumping ability during the macrocycle. As for the variables related to strength, it was found that the peak torque values of the knee extensors and flexors increased after the first preparation period and remained at a similar level until the end of the competitive season, the peak torque values of the shoulder internal rotators decreased towards the end of the season, whereas those of the shoulder external rotators and the static torque values of the shoulder extensors and flexors remained constant. As far as maximal jump height with arm swing is concerned, it was achieved during the first competition period.

Regular assessment of the strength and jumping ability of volleyball players during the annual training macrocycle makes it possible to introduce modifications in the periodization of training at an appropriate time and make individual adjustments in the second part of the season. The need to individualize training in this part of the season has been clearly confirmed by our results, which showed that the end of the first competition period (T_4) was the time when there was greatest variability in the torque of the knee extensors, the knee flexors at the higher angular velocity, and the shoulder internal rotators.

The measurements of the torque of the knee muscles performed in isokinetic conditions and those of the shoulder internal rotators were demonstrated to have significant diagnostic value due to the variability in the results depending on the time of measurement. The results obtained for these variables were used to classify the subjects in the entire macrocycle and analyze the structure of particular measurements.

Acknowledgements

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