Original Paper DOI: 10.5114/biolsport.2017.65995 Biol. Sport 2017;34:205-213

Training-induced changes in physical performance can be achieved without body mass reduction after eight week of strength and injury prevention oriented programme in volleyball female players

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ABSTRACT: The purpose of the study was to analyse the changes in muscle strength, power, and somatic parameters in elite volleyball players after a specific pre-season training programme aimed at improving jumping and strength performance and injury prevention. Twelve junior female volleyball players participated in an 8-week training programme. Anthropometric characteristics, isokinetic peak torque (PT) single-joint knee flexion (H) and extension (Q) at 60°/s and 180°/s, counter movement jump (CMJ), squat jump (SJ), and reactive strength index (RSI) were measured before and after intervention. Significant moderate effects were found in flexor concentric PT at 60°/s and at 180 °/s in the dominant leg (DL) (18.3±15.1%, likely; 17.8±11.2%, very likely) and in extensor concentric PT at 180°/s (7.4%±7.8%, very likely) in the DL. In the non-dominant leg (NL) significant moderate effects were found in flexor concentric PT at 60°/s and at 180°/s (13.7±11.3%, likely; 13.4±8.0%, very likely) and in extensor concentric PT at 180°/s (10.7±11.5%, very likely). Small to moderate changes were observed for H/Q_{CONV} in the DL at 60°/s and 180°/s (15.9±14.1%; 9.6±10.4%, both likely) and in the NL at 60°/s (moderate change, 9.6±11.8%, likely), and small to moderate decreases were detected for H/Q_{FUNC} at 180°/s, in both the DL and NL (-7.0±8.3%, likely; -9.5±10.0%, likely). Training-induced changes in jumping performance were trivial (for RSI) to small (for CMJ and SJ). The applied pre-season training programme induced a number of positive changes in physical performance and risk of injury, despite a lack of changes in body mass and composition.

CITATION: Lehnert M, Sigmund M, Lipinska P et al. Training-induced changes in physical performance can be achieved without body mass reduction after eight week of strength and injury prevention oriented programme in volleyball female players. Biol Sport. 2017;34(2):205-213.

Received: 2016-09-14; Reviewed: 2016-11-09; Re-submitted: 2016-11-11; Accepted: 2016-12-01; Published: 2017-02-19.

Key words:
Fitness
Body composition
Training
Isokinetics
H/Q ratios
Reactive strength index
Magnitude based inference

INTRODUCTION

In contemporary top volleyball, a high level of strength, explosive power, speed and agility are the key components of volleyball-specific physical fitness and the key preconditions for success. Strength, particularly reactive strength and explosive power, are the components of physical fitness that are not only crucial to players in terms of game performance, but also in terms of health and injury prevention [1–3]. The association between explosive power and technical-tactical level and effectiveness of a player is especially evident during the player's activities at the net, attacking from the field and spike serving [4,5]. In many sports, an important precondition for achieving high sports performance is optimum development of somatic parameters [6,7]. Their importance for elite female volleyball has been described previously [8,9]. In the context of somatic parameters, a significant performance-affecting factor is body composition. In elite sport, continuous monitoring of body composition may regulate the training process to positively affect the top form of athletes [10].

For the reasons mentioned above, an important aim of the training process during an annual training cycle is to increase or to maintain muscle strength and explosive power at a consistent level. Although during game-like training and very often during physical fitness training the strength of the knee extensors is often emphasised, it is also important to pay attention to the hamstrings. Moreover, inclusion of not only concentric but also eccentric muscle actions is important for both injury prevention and optimum performance [11].

From the perspective of strength and power training of the lower body, the knee extensors are the prime movers involved in jumping and also running, whereas the knee flexors are involved in landing and running, where they influence stride length and stabilize the knee joint during changes of direction, acceleration and deceleration [12]. The strength of the knee flexors and extensors and their ratios have also been identified as an important parameter in resistance to the influence of stress factors and risk of knee and hamstring injuries [13]. Moreover, ipsilateral (e.g. knee flexors vs. extensors) or bilateral (e.g. right vs. left flexor) imbalances lead to an increased probability of hamstring and other soft tissue knee joint injuries [14]. In many studies, ipsilateral imbalances have been described by the conventional hamstring to quadriceps ratio (H/Q_{CONV}) [15,16]. Co-activation of the knee flexors and extensors is known to occur and takes place through opposing contraction modes, so the functional role of the hamstrings in many sports and physical activities is to decelerate the lower limb during rapid and forceful concentric contractions of the knee extensor through a protective eccentric contraction. Therefore, it is recommended to evaluate eccentric strength as well and to additionally express imbalances using the Hecc/Qcon functional ratio (H/Q_{FUNC}) [17].

As a result, examining the strength of the knee flexors and extensors and their reciprocal muscle group ratios using isokinetic dynamometry provides information on knee function, risk of injury and, more importantly, knee joint stability [18], while testing of explosive power provides information about the limiting factor of game performance. In this context, a surprising fact is the relative paucity of studies assessing the effect of pre-season training programmes in women's volleyball [19–21]. Therefore, the aim of the present study is to analyse the changes in muscle strength, power, and somatic parameters in elite junior female volleyball players after a newly introduced pre-season training programme oriented at physical performance and injury prevention.

MATERIALS AND METHODS

The present study was conducted using an intervention study design including pre- and post-testing around an 8-week pre-season training cycle. The pre-test was performed before the first training session of pre-season, and the post-test one day after the final training of pre-season.

Participants

Twelve elite junior female volleyball players (age 16.8 ± 1.3 y; stature 179.9 ± 5.3 cm; mass 69.5 ± 8.2 kg) from a Czech sports club participated in this study. The players were free of any musculoskeletal lower-limb injuries. The study was approved by the institution's ethics committee and conformed to the Declaration of Helsinki regarding the participation of human subjects. Written informed consent to the testing procedures and the use of the data for further research was obtained from the players involved. All tested players were fully informed about the aim of the study and the testing procedures. Leg dominance was verified before the testing (eleven players were right dominant, one left dominant). The day before the testing, the players were not exposed to any strenuous training load.

Training programme

The pre-season period lasted 8 weeks and the newly set up training programme consisted of pre-season conditioning and injury prevention exercises. The programme was aimed at increasing maximum strength of the lower limbs, especially the knee flexors, and injury prevention, as well as volleyball-specific abilities and game performance (Table 1). The training programme was divided into 3 blocks. The main aim of the first block (3 weeks) was to build the general (non-specific) physical fitness, the main aim of the second block (2 weeks) was to develop specific physical fitness, and the main aim of the third block (3 weeks) was to use the newly acquired level of physical fitness to increase game performance. The players performed 6-10 training sessions per week, in total 64 training sessions, and participated in 19 pre-season matches (on Saturdays and Sundays). The number of rest days was 17.

The training of non-specific fitness contained conditioning games, running, canoeing, core training, cross-fit based training and resistance training performed by the pyramid method (55%-85% 1RM). The training of "volleyball-specific" fitness was performed in the form of circuit training, which included functional strength exercises, core exercises, plyometric exercises and complex training. Additionally, during the whole pre-season period the players participated in eccentric hamstring exercises (EHE) for injury prevention, which lasted 25-30 min and consisted of the following exercises (Table 2):

- Nordic curl with the player's ankles manually secured to the floor throughout the exercise by an exercise partner [22,23],
- Nordic curl without the player's ankles manually secured to the floor throughout the exercise,
- Swiss ball hamstring curl in the supine position – from the initial position with extended legs, feet on the ball, the player slowly bends the knees while pushing the feet against the ball,
- Unilateral resistance band hamstring curl (knee flexion) in the prone position with a Theraband,

TABLE 1. Indicators of training during eight-week pre-season training.

Training indicators	Non-specific fitness	Specific fitness	Technical-tactical training	Friendly matches	Total
Time (min)	1385	2425	1860	1620	6490

TABLE 2. Description of hamstring exercise programme

Exercise	Weeks 1-2 Reps/sets	Weeks 3-5 Reps/sets	Weeks 6-7 Reps/sets	Week 8 Reps/sets
Nordic curl*	15/2	15/2	15/3	15/3
Nordic curl without ankles secured*	15/2	15/2	15/3	15/3
Swiss ball hamstring curl	10/2	12/2	15/3	20/3
Unilateral band hamstring curl	10/2	12/2	15/3	20/3
Bilateral hamstring curl	10/2	12/2	15/3	20/3
Sessions per week	1	3	2	1

* Load was increased by attempting to withstand the fall for longer

– Bilateral hamstring curl (knee flexion) in the prone position throwing a medicine ball.

Procedure
The measurement of body composition was performed first, then physical tests were performed in the following order: counter movement jump free arms (CMJ), squat jump (SJ), and drop jump (DJ) to cover different aspects of take-off power determinants, and isokinetic knee flexion and extension to measure maximum strength. Prior to the testing procedure, the participants completed a supervised warm-up, which included cycling on a stationary bicycle ergometer for 6 minutes at 1.5 W/kg, dynamic stretching exercises targeting the main muscle groups involved during the testing, individual warm-up for two minutes and finally ten bodyweight squats and ten vertical jumps with subjectively progressive increasing jump height.

Somatic measurements
Body height was measured by the Tanita HR-001 anthropometer (Tanita, Japan) with a permissible error of measurement of 5 mm. Body weight was measured using the InBody 230 instrument (Biospace, South Korea). Measurement accuracy for the determination of body weight was 100 g. The anthropometric measurements were made in accordance with international standards [24]. To determine the proportion of body fat (BF; kg, %), fat free mass (FFM; kg, %) and to perform a segmental analysis the authors used a non-invasive method of multifrequency tetrapolar bioelectrical impedance (BIA) using the InBody 230 instrument (Biospace, South Korea). During the BIA examination the conditions of the recommended measurement procedure were adhered to [25].

Vertical jump tests
Counter movement jump free arms (CMJ). To familiarise the players with the testing procedure two trials were performed. The rest period between individual trials was 30 s. The result of the test was the best performance (cm) out of three successful attempts.

Squat jump with *hands on the hips (SJ)*
The participants squatted down with hands placed on the hips until the knees were bent at 90 degrees (slightly higher than parallel with the floor), keeping the trunk straight, and sustained this position for approximately 1 second. Then they jumped vertically as high as possible. To familiarise the players with the testing procedure two trials were performed. The rest period between individual trials was 30 s. The result of the test was the best performance (cm) out of three successful attempts.

Drop jump with hands on the hips. The participants stepped off a 30 cm high box with an erect standing position and upon ground contact attempted to minimise ground contact and maximise jump height [26]. To familiarise the players with the testing procedure two trials were performed followed by three measured attempts. The rest period between individual trials was 30 s. The trial with the highest jump height was used for further analysis. The reactive strength index (RSI) was calculated on the basis of the contact time on the mat and the flight time and was shown to have high test-retest reliability [27]. All jump test parameters were determined using an optical measurement system (Optojump-next, Microgate, Bolzano, Italy).

Isokinetic test
The bilateral strength of the concentric action of the knee flexors and extensors was measured using an IsoMed 2000 isokinetic dynamometer (D. & R. Ferstl GmbH, Hemau, Germany). The reproducibility for the IsoMed 2000 dynamometer in measuring concentric and eccentric knee extension has been reported as being high [28]. The players were tested in a sitting position with a hip angle of 100° of extension. For fixation of the pelvis and thigh of the tested leg, fixed straps were used; shoulders were fixed by shoulder pads in the ventral-dorsal and cranial-caudal direction. The axis of rotation of the dynamometer was aligned with the lateral femoral epicondyle (axis of rotation). The arm of the dynamometer lever was fixed to the distal part of the shin with a pad placed 2.5 cm over the medial apex malleolus. Individual seat settings were stored before measuring the

right leg and automatically activated in the process of measuring the left leg and follow-up testing. At the beginning of the follow-up testing, individual settings were rechecked and adjusted if necessary.

The participants were instructed to hold the handgrips located at the side of the seat during all testing efforts. Angular velocities of 60º/s and 180º/s were used for the measurement from the lowest to the highest velocity. A static gravitational correction was applied according to the manufacturer's instructions. The testing range of motion was 80° and was set from 10–90° of knee flexion (with 0° = full voluntary extension). The testing protocol consisted of two contraction sets of concentric (quadriceps and hamstrings) and two contraction sets of eccentric muscle actions (only hamstrings) at both velocities. The concentric muscle action preceded the eccentric muscle action. In the first warm-up set the players performed five reciprocal actions (with flexion movements performed first) with a progressive increase in the muscle action until a maximum action was performed. After a 30s rest the players performed a set of six maximum repetitions. The rest interval between the sets of different velocities and between the sets of concentric muscle action and eccentric muscle action was 1 minute. There was a two min rest interval between the right and left lower limb testing. During the testing procedure the players were provided with concurrent visual feedback in the form of an isokinetic strength curve displayed on the dynamometer monitor. For the assessment of changes in isokinetic strength, absolute peak torque (PT; N·m) was monitored and further used to calculate the hamstring concentric-to-quadriceps concentric conventional ratio (H/Q_{CONV}) and the hamstring eccentric-to-quadriceps concentric functional ratio (H/Q_{FUNC}).

Statistical analysis

Descriptive statistics (mean ± SD) were calculated for all variables. All measurements were analysed using a spreadsheet for a post-only crossover trial [29]. Raw data were log-transformed to reduce bias arising from the non-uniformity of error. Effects (differences in the changes of the means and their confidence limits) were back transformed to percentage units. To improve the precision of estimates the mean changes were adjusted to the log-transformed baseline mean. Magnitudes of the effects were also evaluated with the log-transformed data by standardizing with the standard deviation of the baseline values. The magnitudes of the standardized effects were interpreted with a modification [30,31] of Cohen's scale [32] for such effects: trivial <0.20; small 0.20-0.59; moderate 0.60-1.19. Uncertainty in each effect was expressed as a 90% confidence limit as well as a probability of the true effect being substantially positive (increase) or negative (decrease). These probabilities were used to make a qualitative, probabilistic, nonclinical inference about the true effect: if the probability of the effect being a substantial increase or a substantial decrease was >5% in both cases (equivalent of 90% confidence interval overlapping thresholds for a substantial increase and decrease), the effect was reported as unclear; otherwise, it was considered clear and assigned the relevant magnitude value, with the qualitative probability of the true effect being a substantial increase,

Table 3. Simple statistics for PT on baseline and after training programme, and magnitude-based inferences for the change of the means.

	Baseline (n=12) Mean ± SD	After programme (n=12) Mean ± SD	Effect	
			Mean; ±90%CL	Inference [a]
Dominant Leg				
H Con60	93 ± 18	109 ± 13	18.3%; ± 15.1%	moderate ↑**
Q Con60	184 ± 26	190 ± 32	2.8%; ± 11.0%	trivial ↑
H Con180	111 ± 16	130 ± 17	17.8%; ± 11.2%	moderate ↑***
Q Con180	139 ± 14	149 ± 13	7.4%; ± 7.8%	moderate ↑**
H Ecc60	113 ± 15	118 ± 16	4.4%; ± 11.2%	small ↑
H Ecc180	155 ± 17	155 ± 19	0.0%; ± 8.8%	none
Non-dominant Leg				
H Con60	94 ± 15	107 ± 17	13.7%; ± 11.3%	moderate ↑**
Q Con60	180 ± 22	187 ± 25	3.7%; ± 11.0%	small unclear
H Con180	117 ± 13	133 ± 20	13.4%; ± 8.0%	moderate ↑***
Q Con180	129 ± 13	143 ± 14	10.7%; ± 11.5%	moderate ↑**
H Ecc60	111 ± 14	116 ± 17	4.4%; ± 11.1%	small ↑
H Ecc180	154 ± 16	156 ± 17	1.1%; ± 8.6%	trivial ↑

[a] Magnitude thresholds (for change in means divided by baseline SD): <0.20, trivial; 0.20-0.59, small; 0.60-1.19, moderate. Asterisks indicate effects clear at the 5% level and likelihood that the true effect is substantial or trivial, as follows: *possible, **likely, ***very likely. Effects in bold are also clear at 0.5%.

substantial decrease, or a trivial difference (whichever outcome had the highest probability). The following scale for interpreting the probabilities was used: 25–75%, possible; 75–95%, likely; 95–99.5%, very likely; >99.5%, most likely. This study involved the assessment of substantial changes in 26 measures. To maintain an overall error rate of <5% for declaring one or more changes to have opposite magnitudes (a substantial decrease instead of an increase, and vice versa), the effects were also evaluated as clear or unclear with a threshold of 5%/5 (1%), equivalent to consideration of overlap of substantial values with a 98% confidence interval (CI).

RESULTS

The PT values of flexors and extensors of the dominant leg (DL) and non-dominant leg (NL) for the group of elite junior female volleyball players are reported in Table 3. Significant increases in flexor PT values were found at a velocity of 60°/s and at 180°/s in concentric action both in DL and in NL, significant effects were also detected in extensors PT at 180°/s in concentric action, also in DL and in NL. Relevant changes were also observed in the H/Q ratio, particularly in H/Q_{CONV} (Table 4). The same applies to the changes in CMJ, SJ, and RSI (Table 5).

TABLE 4. Simple statistics for hamstring-to-quadriceps ratios on baseline and after training programme, and magnitude-based inferences for the change of the means.

	Baseline (n=12) Mean ± SD	After programme (n=12) Mean ± SD	Effect	
			Mean; ±90%CL	Inference [a]
H/Q_{CONV}				
DL 60	0.51 ± 0.08	0.59 ± 0.12	15.9%; ± 14.1%	moderate ↑**
DL 180	0.80 ± 0.12	0.88 ± 0.11	9.6%; ± 10.4%	small/moderate ↑**
NL 60	0.52 ± 0.08	0.58 ± 0.10	9.6%; ± 11.8%	moderate ↑**
NL 180	0.91 ± 0.10	0.93 ± 0.15	1.5%; ± 10.4%	trivial ↑
H/Q_{FUNC}				
DL 60	0.62 ± 0.05	0.63 ± 0.07	1.6%; ± 6.0%	trivial ↑
DL 180	1.12 ± 0.14	1.04 ± 0.14	-7.0%; ± 8,3%	small ↓**
NL 60	0.63 ± 0.07	0.63 ± 0.09	-0.4%; ± 8.2%	trivial ↓
NL 180	1.21 ± 0.19	1.09 ± 0.13	-9.5%; ± 10.0%	moderate ↓**

[a] Magnitude thresholds (for change in means divided by baseline SD): <0.20, trivial; 0.20-0.59, small; 0.60-1.19, moderate.
Asterisks indicate effects clear at the 5% level and likelihood that the true effect is substantial or trivial, as follows: *possible, **likely, ***very likely.

TABLE 5. Simple statistics for anthropometric characteristics and vertical jump parameters at baseline and after training programme, and magnitude-based inferences for the change of the means.

	Baseline (n=12) Mean ± SD	After programme (n=12) Mean ± SD	Effect	
			Mean; ±90%CL	Inference [a]
Anthropometric characteristics				
Body weight	69.5 ± 8.2	69.4 ± 9.3	-0.2% ± 1.6%	trivial ↓***
BMI (kg/m^2)	21.7 ± 2.0	21.5 ± 2.1	-1.3%; ± 3.4%	trivial
Fat mass (%)	18.5 ± 3.9	18.1 ± 3.9	-2.1%; ± 9.8%	trivial ↓
Vertical jump parameters				
CMJ (cm)	34.2± 4.4	35.8 ± 5.2	4.4%; ± 5.6%	small ↑*
SJ (cm)	32.9 ± 4.4	34.1 ± 4.7	3.7%; ± 3.7%	small ↑*
RSI (m/s)	1.45 ± 0.24	1.41 ± 0.27	-3.0%; ± 4.6%	trivial ↓*

[a] Magnitude thresholds (for change in means divided by baseline SD): <0.20, trivial; 0.20-0.59, small.
Asterisks indicate effects clear at the 5% level and likelihood that the true effect is substantial or trivial, as follows: *possible, **likely, ***very likely. Effects in bold are also clear at 0.5%.

DISCUSSION

The main finding of this study indicates that the strength of the hamstrings of both lower limbs in the case of both velocities in concentric action and the strength of the quadriceps at a velocity of 180°.s^{-1} in concentric action changed significantly after the pre-season training programme. Furthermore, different tendencies in the case of both ratios were observed: H/Q_{CONV} ratio increased significantly (except H/Q_{CONV} 180°/s of NL); conversely, H/Q_{FUNC} decreased significantly at a velocity of 180°/s in both the DL and NL. These results indicate changes in muscular control of the knee joint in the observed group of players.

The maximum strength is a significant functional quality of skeletal muscles, as shown by the significant correlation between the maximum strength of the lower limb muscles and explosive power, in particular the rate of force development, and the correlation between maximum strength and speed [33,34]. Increased PT of the hamstrings in concentric action is probably attributed to strength and conditioning during pre-season, especially to the EHE training programme with a special focus on eccentric hamstring strength. Increased PT of the quadriceps (180°.s^{-1}) might be the result of the whole conditioning programme or the antagonist excitation resulting from increased hamstring PT. The post-test values of the strength of the hamstrings and quadriceps in both legs in concentric action indicated a positive effect on muscle balance in the knee joint and a decreased risk of injury due to an increase in PT values [13] (H Con60 DL by 18.3%, H Con180 DL by 17.8%, Q Con180 DL by 7.4%, H Con60 NL by 13.7%, H Con180 NL by 13.4%, and Q Con180 NL by 10.7%). However, it should be noted that the strength of the quadriceps at a velocity of 60°/s, which is considered to be the best indicator of strength deficits [35], did not change significantly after the pre-season training programme.

The effect size values of the training-related changes in PT of the hamstrings pointed to a moderate effect at a velocity of 60°/s and at a velocity of 180°/s. From this point of view it is surprising that unlike the strength of the hamstrings in concentric action the strength of the hamstrings in eccentric action did not change significantly in either the DL or the NL. The difference in PT results in different isokinetic velocities for the quadriceps, and the absence of improvement at 60°/s could be explained by the principle of specificity [36], referring to missing training stimuli for the development of the quadriceps maximal strength at a slow velocity. The presented changes are only partially consistent with the results of a study by Gonzáles-Ravé et al. [19], who after eight-week general strength and power training in the pre-season observed a significant increase in muscle strength in the lower limbs and jumping ability in Spanish female volleyball players in the top league.

Muscle strength of the knee flexors and extensors should be well balanced in players throughout the season to reduce the risk of lower limb injury. Therefore, the increase in H/Q_{CONV} ratio might be considered a desired aim of EHE, while on the other hand the H/Q value remained below the recommended minimum value of 0.6 at a velocity of 60°/s. In this case the knee musculature may not be able to optimally position the knee joint during movements, which increases the stress placed on the intra-articular structures, possibly resulting in biomechanical changes and soft tissue injury [14,37]. Although there is no absolute consensus about a normative value, it is generally accepted that if the H/Q_{CONV} ratio does not exceed this value, the probability of hamstring and ACL injury increases [38]. Generally, these results suggest a higher risk of lower limb injury due to muscle imbalance in the knee joint in the observed group of volleyball players both before and after the conditioning programme.

What the authors consider more important is the absence of a training effect on the strength of the hamstrings in eccentric action and consequently the negative changes in H/Q_{FUNC} at 180°.s^{-1}. The reason is that increased antagonistic activation of the hamstrings helps produce efficient muscular control to provide compression and consequently knee joint stability. It reduces redundant tension of the anterior cruciate ligament (ACL), and helps avoid overextension by decelerating the leg prior to full extension and by stabilizing the knee joint throughout the range of motions, which reduces the risk of injury [18,39]. It has been suggested that at an angular velocity of 60°.s^{-1} the value of H/Q_{FUNC} of 1.0 indicates adequate joint stability [17]. Regarding this border, both the pre-training and post-training values of the H/Q_{FUNC} in our group may indicate a higher risk of lower limb injury. The values of H/Q_{FUNC} at an angular velocity of 60°/s are similar to the results of a previous study of female junior and senior handball players [40], where the authors observed similar low values for both groups at the beginning of the preparatory period, specifically 0.66 (DL) and 0.62 (NL) in junior players. The results of both studies underpin the importance of the assessment of both H/Q_{CONV} and H/Q_{FUNC} in young players during the season.

We do not suppose that the decrease in H/Q_{FUNC} at 180°.s^{-1} was caused by a low volume or intensity of hamstring exercises, but conversely by a high volume of EHE and accumulation of fatigue throughout the whole pre-season programme, especially during weeks 3-7. This could, together with the large amount of non-specific and specific strength and conditioning exercises, and technical-tactical and game-like exercises, cause insufficient recovery and result in an interference effect, and consequently attenuated strength gains from simultaneous eccentric strength training of the hamstrings [11,41]. This fatigue-related effect has also been suggested in a previous study [42], where the hamstring strength increased more after the rest period than during the periods with a physical fitness training programme. Moreover, the number of repetitions in the sets exceeded the previously recommended guidelines for eccentric hamstring training consisting of 3 sets of 6-12 repetitions [22,23]. When interpreting the changes in PT and its ratios, it is also important to consider the measurement error of isokinetic single-joint maximum knee strength measurements. Although the reproducibility of the obtained measurement scores is high [43,44], which was also confirmed for the IsoMed 2000 dynamometer [28], it is necessary to consider that the reliability of eccentric measurements is lower in comparison with concentric measurements [28].

We also observed changes in the RSI, which is a method used to explore the ability to move from eccentric to concentric actions [45]. The data from our study suggest that the values of the RSI decreased following the pre-season training, even though the decrease was not significant. This finding is surprising because the pre-season training programme included resistance training, plyometric training and also volleyball-specific training, which, as one would expect, should have a positive effect on reactive strength. Considering the method of RSI calculation (contact time on the mat divided by flight time) and also the high correlation between maximum strength of the leg muscles and vertical jump performance [33,46], this result could be to some extent explained by the finding that the quadriceps PT did not increase significantly after the pre-season training. Our finding is not consistent with the requirements of game performance in volleyball, because a high level of reactive strength is an important factor for volleyball players in many specific movements, particularly in jumping and changes of direction after landing. Also from a health perspective our finding indicates increased stress exerted on the muscle-tendon complex during the plyometric exercise in the observed group [47]. Moreover, it was suggested that a low RSI was one of eight significant predictors of ACL injury [48].

After the pre-season the values of the jump tests did not change significantly. We only recorded a positive tendency in CMJ by 1.60 cm (4.62%) and SJ by 1.22 cm (3.74%). This finding suggests that the pre-season training did not result in a significant increase in explosive strength of the lower limbs and that the effect of the training programme is low in terms of specific fitness and game performance. The result of our group in the CMJ test is similar to the result of the group of top Polish female basketball and volleyball players (age 21.5±1.4 years) [49]. However, if we compare the average results of CMJ in our group after the pre-season (M=35 cm) with the best female junior players (M=41 cm) [50], it is evident that an increase in jumping abilities should be one of the priorities in the observed players.

Due to time restrictions of the team the players were tested one day after finishing the pre-season. Therefore the stagnation in the explosive strength of the lower limbs could have been caused by fatigue due to the pre-season training programme. However, in the above-mentioned study by Gonzáles-Ravé et al. [19] involving elite Spanish female players, after completion of the 8-week pre-season training programme the authors reported significant ($p<0.01$) performance changes in vertical jumps (11% squat jump, 10% CMJ) and a significant ($p<0.01$) increase in muscle strength in the lower limbs measured by means of 2RM back squat (11%).

Regarding the duration of the pre-season and the actual load, the assessment of basic somatic characteristics in the monitored female volleyball players suggested relatively stable values. The differences were insignificant in all cases ($p>0.05$), which corresponds with the results of a study by Gonzáles-Ravé et al. [19] aimed at elite Spanish female players. The values are also consistent with the data reported by other authors dealing with elite women's volleyball [6,10]. A positive result was found in the proportion of fat fraction, which is at the lower limit with respect to age, gender and sports specialization. The actual body composition in the monitored junior volleyball players can be regarded as optimum and thus provides suitable space for further sports development and the use of individual potential in women's volleyball. In terms of comparing body composition values, which represent a significant factor of sports performance, it is necessary to take into account the actual method applied. Some authors assess the proportion of body fat by means of caliper measurements, which might eventually decrease the overall values because the method does not directly include the proportion of visceral fat [51]. However, this may not be the rule, as confirmed by other studies [10]. In the present study the whole-body BIA method was used, which appears appropriate in diagnostic practice provided that the main BIA examination recommendations are observed [25].

Limitations

It should be considered that the post-testing was performed immediately after the pre-season. The present study refers to the H/Q_{CONV} and H/Q_{FUNC} ratios, but muscle co-activation in the knee area also depends on the ratio of thigh muscle strength to gluteus medius strength [52,53], which was not calculated in the present analysis. The test results of the pre- and post-test could also be affected by the phases of the menstrual cycle; however, in the present study this information was not obtained from the participants.

CONCLUSIONS

The results of the present study indicate that maximum strength of the knee flexors and extensors measured by means of isokinetic PT differed across the 8-week pre-season training in elite junior volleyball players and that only the concentric PT of the knee flexors in both lower limbs at a velocity of $60°.s^{-1}$ and $180°.s^{-1}$ and PT of the knee extensors at a velocity of $180°.s^{-1}$ significantly increased after the pre-season with an included EHE programme. However, eccentric isokinetic hamstring strength did not significantly improve or decreased in the players and H/Q_{FUNC} decreased significantly at a velocity of 180°/s in both the DL and NL as well. From the perspective of injury prevention, these results indicate negative changes in muscular control of the knee joint in the observed group of players. Both the H/Q_{FUNC} ratio and H/Q_{CONV} ratio were below the recommended values at the beginning of the pre-season and at the end of the pre-season training programme. Similarly, the reactive strength index and power of the lower limbs did not change significantly; the same applies to the monitored somatic parameters. Collectively, the results indicate that the newly applied pre-season training programme induced a number of changes in the observed parameters, which points to the importance of systematic planning of training programmes in team sports and the assessment of muscle strength and power in specific periods of the annual training cycle in terms of both performance and risk of injury. The suggestion that the hamstrings appear to have residual fatigue after the pre-season has implications for pre-season and early in-season training and recovery processes to avoid an increased risk of injury and to optimise performance.

Acknowledgement

This work was supported by Palacký University Olomouc under Grant FTK_2015_005 and the Czech Science Foundation NO. 16-13750S.

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