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B – Data Collection
C – Statistical Analysis
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E – Manuscript Preparation
F – Literature Search
G – Funds Collection

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Key words: *plyometric training, high and low-intensity, explosive power, volleyball.*

Abstract

Background: *The purpose of the present study was to determine the effects of a six-week plyometric high and low-intensity training on the explosive power of lower limbs in volleyball players.*

Material/Methods: The research was conducted on *a sample of 30 volunteers of the Sports Club at Gdansk University of Technology in Gdansk. Before the experiment, the players were divided into two homogeneous groups. After two weeks of an introductory common stage, each group followed a plyometric regime of different intensity. The results showed that the high-intensity program was more efficient than the low-intensity program in developing the explosive power in the volleyball players.*

Results: *The largest significant improvement was observed for the vertical jump with arm swing (11% in HIJG and 3.8% in LISG). The strongest correlations were registered for the maximal power and the total mechanical work obtained in the Wingate test (r=0.83), and the power of jumps during attacks and blocks (r=0.78).*

Conclusions: *The experiment confirmed high effectiveness of the training loads applied in the experiment, in particular in the high-intensity program.*

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Introduction

The physiological character of volleyball is determined by the specific offensive and defensive performance of the players such as jumps to spike, leaps in different directions or sprints to the ball at distances up to 10 m. All these techniques require strength and speed that predominantly depend on the energy generated through anaerobic alactacid pathways. During the match, a volleyball player performs over 100 jumps in either of the four elements: attack, block, serve or playing the ball. The number of jumps differs according to the player's role and his specialization. Lobletti et al. [1] found that most jumps are performed after both feet take off and fewer after a single, right or left foot take off. However, the technique of jumping strongly depends on the rules of the game, which are often changed. Nowadays, the high-power jumps, performed especially during attacks, are most preferable. Therefore, exercises developing the ability to jump high in players (for example plyometric exercises) are the crucial element of a training program. Stiff [2] claimed that the aim of the plyometric regime is to develop the ability of the muscles to generate maximal work in the shortest possible time. This occurs as an effect of the reduction in the time required for the switch from a stretch to contraction.

According to Markovic [3], the average length of a mezocycle with plyometric training takes from 8 to 9 weeks. The analysis of the data available showed that the shortest time of such a regime was 4 weeks [4, 5], and the longest one 12 weeks [6, 7]. Volunteers of different sports were involved in the studies on the effects of plyometric training. For example, Saunders [8] confirmed the influence of the plyometric intervention on the development of motor abilities in middle- and long-distance runners. However, Cherif et al. [9] examined the effectiveness of plyometric training for handball players. Moreover, Impillizzerii et al. [10] compared the influence of such a regime performed on sand and grass on football players. Furthermore, Carter et al. [11] and Dodd et al. [12] examined baseball players and the influence of plyometric training on different groups of muscles. This influence was also found in nonprofessionals and students studied by Carlson et al. [13], McBridge et al. [14] and Macaluso et al. [15]. Considering the above, the results especially of the untrained subjects support the assumption of the effectiveness of plyometric training on the vertical jumping height [3].

It is assumed that this type of training is effective only if administered regularly from 2 to 3 times a week and combined with other training means, as part of the complex specific program. There are various methods to practice plyometric regime. Intervals are preferable for volleyball players in both intensive and extensive forms. The intensity is dependent on such factors as external resistance (sports equipment or body weight), duration of the performance, or recovery breaks between the efforts. The most preferable sports equipment used in plyometric training are barbells, hurdles or other obstacles, and flexible rubber belts. The significant element of this type of training is also the way skeletal muscles work: concentric contractions (jump up) or eccentric contraction (landing). These factors of plyometric training are very important while programming the training and decide of its effectiveness. Therefore, the purpose of the study was to identify the changes in the explosive power in volleyball players that occurred after 6-week high and low-intensity plyometrc training. Moreover, it was assumed that the high intensity training has a greater influence on the improvement in the explosive power than the low-intensity training.

Material and method

The research was conducted on a sample of 20 volleyball players, all of whom were members of the AZS Sports Club of Gdansk University of Technology. The sample was divided into two homogenous groups: HIJG (High-Intensity Jumping Group) and LIJG (Low-Intensity Jumping Group). The division was based on the mean power values counted for the 10 jumps performed on a tensometric mat (Smart Jump Mat 120 x 120 cm – Fusion Sport, Cooper Plains, Australia). The results ranked the players from the best to the worst. Then the athletes from the list were allocated to either group alternately, starting from the best player. The division was conducted so that no statistically significant differences were found between the results for both groups: High-Intensity Jumping Group (HIJG 51.4±4.44 W/kg) and Low-Intensity Jumping Group (LIJG 51.4±4.24 W/kg) (Table1).

Table 1. Anthropometric profiles of volleyball players (mean values with standard deviation)

Group	Age (years)	Height (cm)	Body mass (kg)	BMI (kg/m²)	Training experience (years)
HIJG	21.2 ± 1.36	187.3 ± 5.89	80.2 ± 5.27	22.9 ± 2.09	7.5±2.85
LIJG	20.7 ± 1.52	189.3 ± 5.92	81.0 ± 8.54	22.6 ± 2.31	7.2±2.63

Each week, the subjects participated in three training sessions, 2 hours each. Moreover, they took part in the College League tournaments. Prior to the experiment, the subjects were provided with detailed information about the research procedures and gave their written consent. The study protocols received ethical approval from the institution.

In order to prepare the subjects for the 6-week experiment that included high-intensity plyometric exercises and to prevent injuries, the players were subjected to six preparatory training sessions (initial stage). The first week of this phase included 4 sessions (Monday, Tuesday, Wednesday, and Thursday) that developed aerobic power and general fitness (drills without the external resistance). In the second week, the subjects underwent two training sessions (Monday and Tuesday) including general fitness drills and low or moderate-intensity plyometric exercises (Table 2.).

Table 2. Training loads applied during the initial stage

Drills	Total time of performance (min)		Number of repetitions		Sum (min. or rep.)	
	1st week	2nd week	1st week	2nd week	1st week	2nd week
Run at 30% [KP1]HR_{max}	5	4	1	1	5 min	4 min
Skip A, B, C	-	-	3 x 20	3 x 20	4 min	4 min
Single-leg skipping on right and left leg	-	-	2 x 30	2 x 20	60	40
Ground bounces	-	-	40	30	40	30
Tip toes raises at wall bars	-	-	2 x 30	2 x 30	60	60
Run at 40 %[KP2] HR_{max}	4	2	-	-	4 min	2 min
Stretching	6	6	-	-	6 min	6 min
Single-leg jumps with arm swing	-	-	-	40	-	40
Double-legs jumps over the hurdles (0.3 m)	-	-	-	50	-	50
Double-legs skipping the rope	-	6	-	-	-	6 min

After completing the initial phase, the players rested for two days. Then, on Thursday, the subjects performed the tests in a sports hall with a wooden surface. During the tests, the explosive power measurements were taken. The air temperature was 19˚C and the atmospheric pressure was 1010hPa. The players used standard footwear designed for volleyball practice. The tests started with 25 min of warming up: 3 min of low-intensity running (40% of HR_{max}), 3 min of running at 60% of HR_{max}, 3 min of static stretching, 7 min of general strength and explosive power drills (A and C skips, single-leg skips, ground bounces, jumps up with raising knees and feet), and 3 min of static stretching. This part was followed by individual practice of jumps to attack or block at the net (2 x 4 repetitions). Then the subjects marched for 1 min and performed two sprints at 10 m.

After completing the warm-up, the players were provided with detailed information on the research procedures. The tests involved explosive power measurements taken during double-leg jumps:

- from the squat starting position, with arms supported on the hips (one vertical jump)
- 3 min of break

- from the squat starting position with the arm swing (one vertical jump)
- 3 min of break
- a series of 10 vertical jumps with arm swing with the shortest possible time of contact of the feet with the surface.

Next, there were 15 min of rest during which the players individually performed marching and static or dynamic stretching that were followed by another course of tests. The players performed a forward leap and a jump up simulating attack (spike), and the side leap followed by the jump simulating a block at the net 243 cm high. All of the jumps were performed on a tensometric mat (Smart Jump Mat 120 x 120 cm - Fusion Sport, Cooper Plains, Australia).

After completing the explosive power tests, there was one day of recovery (Friday). Next day (on Saturday) in the morning (10:00 – 12:00 am.), the subjects performed the Wingate test in 30 s version for lower limbs on a cycloergometer (Monark Ergomedic 894 E, Monark, Sweden) [16]. After two days of recovery (on Monday), the subjects were subjected to a 6-week plyometric training program. Each week the players practiced three times, every second day (Mondays, Wednesdays, and Fridays). In order to adjust the height of the hurdles or the external resistance (barbells, dumb-bells or leg weights), the players were subdivided into groups based on the body height (above or below 188 cm) and the body mass (above or below 81 kg) (Table 3).

Table 3. Parameters of the tools used for plyometric training for each set of volleyball players

Subdivision of players	Hurdle height (cm)			Bench height (cm)		
Body height (cm)	Week 1-2	Week 3-4	Week 5-6	Week 1-2	Week 3-4	Week 5-6
>188	76	76	81	25	25	30
<188	71	71	76	20	20	25
	Barbell weight (kg)			Dumb-bells weight (kg)		
Body weight (kg)	Week 1-2	Week 3-4	Week 5-6	Week 1-2	Week 3-4	Week 5-6
>81	20	20	25	7.5	7.5	10
<81	25	25	30	5	5	7.5

The high-intensity training program for HIJG differed from the low-intensity program, in particular in the type of exercises and the manner they were performed. For example, the HIJG used barbells and hurdles that forced the athletes to generate larger explosive power. The LIJG performed the exercises during which they had to overcome the resistance of their own bodies or the leg weights or dumb-bells that had the lighter absolute weight (Tables 5 and 6). Hurdle jumps and drops from the gymnastic box were performed on hard mattresses. No injuries occurred to the subjects during the experiment.

The intensity of the exercise can be expressed as a metabolic index (the heart rate or lactate concentration in the blood) or the power counted as the work volume generated in the time unit.

Analyzing plyometric exercises performed for sport, it is extremely difficult or even impossible to determine the time of the performance without the use of a tensometric mat. This device can register the time of a separate stage of a jump, for example the action in the air. Therefore, in this study the volume of work performed by volleyball players (Table 4) during plyometric exercises (Tables 4 and 5) was counted in order to differentiate the training loads for the HIJG and LIJG. The analysis showed that the total work rate for the volleyball players from the HIJG in 1-2 weeks exceeded the value for the LIJG by 66%. Then, in weeks 3 and 4, these values increased by 14% for both groups (178 single or double-legs jumps). However, the intensity for the LIJG decreased by 11% (as leaps were excluded from the program), and for the HIJG increased by 13.5% (the number of repetitions of jumps increased by 22). During the next two weeks (the 5th and 6th), the training loads increased in both groups: by 28.5% for the HIJG in comparison to the first two

weeks, and by 13.6% for the LIJG. The comparison of the training load values for both groups revealed that the workload for the HIJG was higher than for the LIJG by 71% in the 5th and 6th week, and the difference in the total work was 107 kJ.

Table 4. Total work values for the HIJG and LIJG performed during plyometric exercises

Group	Week		
	1-2	3-4	5-6
HISG	200 kJ	227 kJ	257 kJ
LISG	132 kJ	118 kJ	150 kJ

Table 5. High-intensity plyometric training program for the HISG

Exercise volume / Type of exercise	Week								
	1-2			3-4			5-6		
	rep. x series	sum of jumps	height (cm)	rep. x series	sum of jumps	height (cm)	rep. x series	sum of jumps	height (cm)
Drop from the height of the platform to the squat position followed by a single-leg maximal vertical jump	12x4	48	30	12/4	48	30	12/4	48	40
Double-leg jump over a hurdle	8x6	48	74	8/7	56	74	8/7	56	81
Double-leg drop jump	8x3	24	60	7/4	28	60	7/4	28	80
Double-legs drop jump with a barbell	6x2	12	20*	6/3	18	20*	6/3	18	30**
Double-legs drop jump over a hurdle	8x3	24	40***	7/4	28	40***	7/4	28	50****
Total	-	156	-	-	178		-	178	-

* *barbell weight in weeks 1-4: 20 kg for subjects <81 kg and 25 kg for subjects >81 kg*
** *barbell weight in weeks 5-6: 25 kg for subjects <81 kg and 30 kg for subjects >81 kg*
*** *hurdle height: 71 cm for subjects <188 cm and 76 cm for subjects >188 cm*
**** *hurdle height: 76 cm for subjects <188 cm and 81 cm for subjects >188 cm*

Table 6. High-intensity plyometric training program for the LISG

Exercise volume / Type of exercise	Week								
	1-2			3-4			5-6		
	rep. x series	sum of jumps	height (cm)	rep. x series	sum of jumps	height (cm)	rep. x series	sum of jumps	height (cm)
Double-legs leaps on the spot	10 x 2	20	-	-	-	-	-	-	-
Forward single-leg leap	10 x 4	40	-	-	-	-	-	-	-
Double-leg vertical jump on the spot	10 x 4	40	-	12 x 4	48	-	12 x 4	48	-
Double-leg jump over a hurdle	10 x 4	40	20	12 x 4	48	20	12 x 4	48	30
Squat leap (frog leap)	4 x 4	16	-	7 x 4	28	-	7 x 4	28	*
Double-leg vertical jump from the squat position – squat jumps	-	-	-	6 x 5	30	**	6 x 5	30	***
Approach run followed by a single-leg take-off from a stable platform and a vertical jump	-	-	-	6 x 4	24	20	6 x 4	24	30
Total	-	156	-	-	178		-	178	-

* *exercise with leg weights 2 x 1 kg for subjects < 81 kg and 2 x 1.5 kg for subjects > 81kg*

** *exercise with the dumb-bells 5 kg for subjects < 81 kg and 7.5 kg for subjects > 81 kg*

*** *exercise with dumb-bells with the weight increased by 2.5 kg*

Apart from the experimental practice, the participants played three control matches (on Saturdays), that is after the first, third, and fifth week of the experiment. After completing the whole program, the athletes rested for two days (Saturday and Sunday). On the next two consecutive days they performed the following tests: the explosive power was measured on Monday and the Wingate test on Tuesday. The time of the days (9:00 – 12:00) and the sequence of the tests were identical with the initial course.

The results are presented as the mean and standard deviation (M ±SD). All of the statistical analyses were conducted using StatSoft, Inc. STATISTICA software version 9.0. The level of significance was set at $p < 0.05$. All of the data sets were assessed using the Shapiro-Wilk test for normal distributions. A two-way repeated measures ANOVA was applied to analyze the between-group (HIJG and LIJG) and within-group (pre- and post-training) effects. Additionally, the effect size (eta squared, η^2) for analysis of variance was calculated. If interaction effects were significant, post-hoc analyses using the HSD Tukey test were applied.

Results

The results of the study demonstrate that plyometric training applied to volleyball players improved their explosive power with reference to the time (all the parameters involved in the two-way analysis of variance) and also within each group (arm swing vertical jump in a one-way analysis of variance). The values for the height of the vertical jump as well as the power generated during the performance were significantly higher after the 6-week experiment. The HIJG showed considerable differences ($p \leq 0.01$, $p \leq 0.001$) in three of the five tests, and the LIJG in two tests at $p \leq 0.05$. Although the program improved the players' abilities, no statistically significant differences were found in both groups for the explosive power generated during the jump to attack or block before and after the experiment (Table 7). The training programs applied to both groups during the experiment have proved to be effective in the development of the maximal power and the total work rate measured by the Wingate test; however, the HIJG showed a greater improvement (Fig. 1 and 2). The analyses of the relationships between the explosive power, the maximal power, and the total work revealed strong or extremely strong correlations between these indices (Table 8).

Table 7. Results for volleyball players of HIJG and LIJG from the explosive power tests before and after the 6-week experiment

Test	Parameter	HIJG		LIJG		Interactions	ES
		PRE	POST	PRE	POST		
Vertical jump with hands on hips	Height [cm]	38.6±5.28	43.9±5.49**	40.5±4.20	44.1±5.53*	time	0.45
	Power [W]	48.8±3.87	51.7±4.10	49.6±3.89	53.0±4.16	time	0.29
Arm swing vertical jump	Height [cm]	47.0±5.19	52.8±4.57***	50.1±5.29	52.1±6.49	time group x time	0.53 0.15
	Power [W]	54.7±3.19	59.7±3.43***	57.0±5.01	58.8±5.10*	time group x time	0.61 0.34
10 arm swing vertical jumps	Height [cm]	41.3±6.00	46.05±4.27***	42.2±5.64	45.0±5.73	time	0.43
	Power [W]	51.0±4.55	54.5±3.11**	51.6±4.17	53.3±4.03	time	0.36
Jump to attack	Height [cm]	57.7±6.36	60.9±7.16	59.0±4.84	62.3±5.92	time	0.31
	Power [W]	63.3±4.55	65.9±5.83	64.2±4.51	66.6±4.83	time	0.30
Jump to block	Height [cm]	48.1±6.76	49.7±5.54	46.9±5.84	49.9±6.13	time	0.25
	Power [W]	56.3±5.06	57.4±4.20	55.5±4.41	57.3±4.85	time	0.20

*Differences statistically significant at *p≤0.05, **p≤0.01, ***p≤0.001*

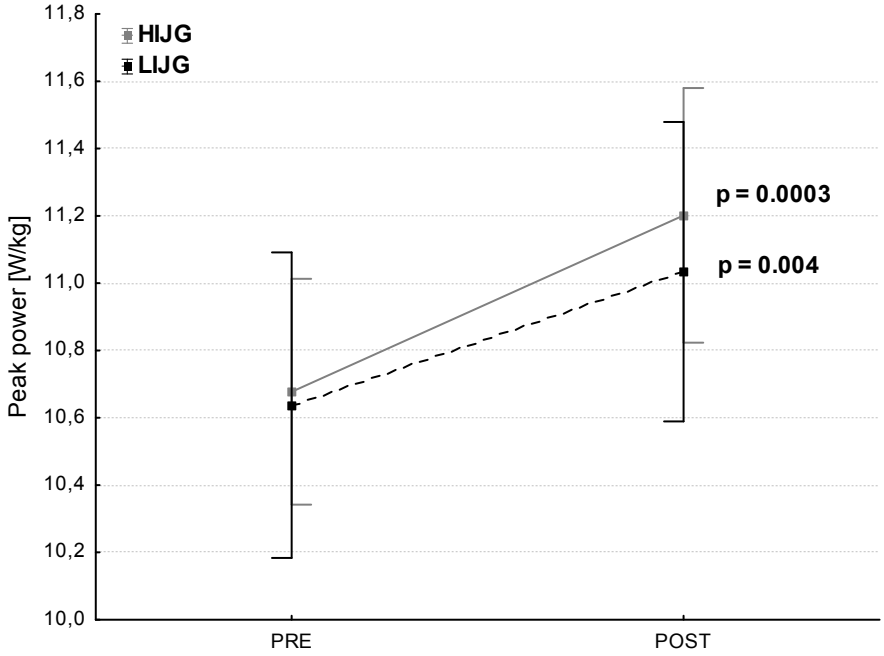

Fig. 1. Changes in the mean maximal power values in volleyball players of HIJG and LIJG before and after the 6-week experiment.

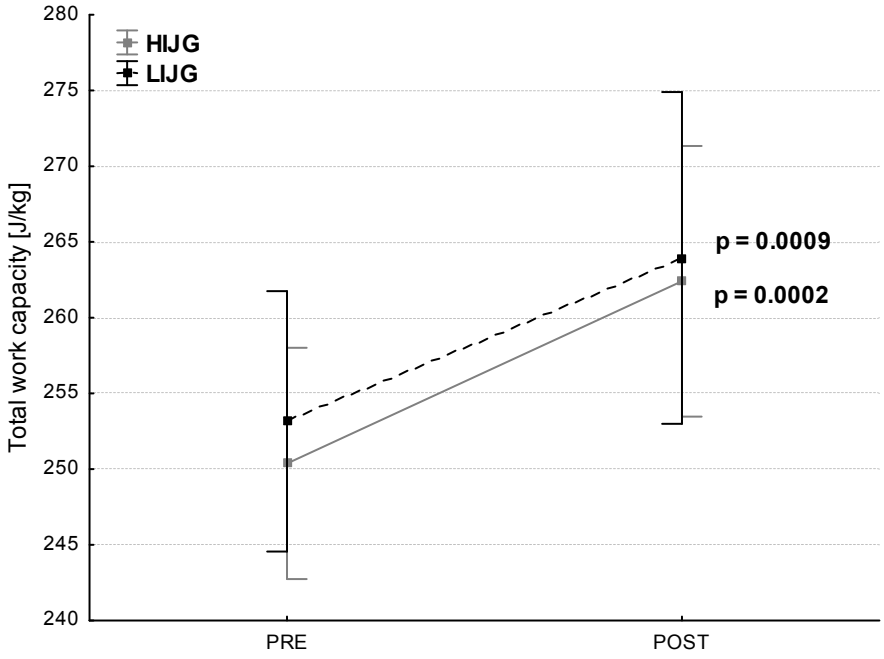

Fig. 2. Changes in the mean total work values in volleyball players of HIJG and LIJG before and after the 6-week experiment.

Table 8. Correlations between the indices of explosive power [W] and maximal power [W/kg], and total work [J/kg] obtained during the Wingate test in volleyball players before and after the 6-week experiment

p/r	Vertical jump with hands on hips	Arm swing vertical jump	10 arm swing vertical jumps	Jump to attack	Jump to block	W/kg	J/kg
Vertical jump with hands on hips		**r=.6757***	**r=.5205***	**r=.5500***	**r=.5335***	r=.2384	**r=.2956***
Arm swing vertical jump	**p=.000**		**r=.6624***	**r=.7433***	**r=.6752***	**r=.3773***	**r=.4388***
10 arm swing verti-cal jumps	**p=.000**	**p=.000**		**r=.5731***	**r=.6903***	**r=.3805***	**r=.3988***
Jump to attack	**p=.000**	**p=.000**	**p=.000**		**r=.7776***	**r=.2955***	**r=.4892***
Jump to block	**p=.000**	**p=.000**	**p=.000**	**p=.000**		**r=.3515***	**r=.4617***
W/kg	p=.067	**p=.003**	**p=.003**	**p=.022**	**p=.006**		**r=.8280***
J/kg	**p=.022**	**p=.000**	**p=.002**	**p=.000**	**p=.000**	**p=.000**	

Discussion

The aim of the study was to identify the effectiveness of 6-week high and low-intensity plyometric training on the explosive power of the lower limbs in volleyball players. The results of the experiment validated this assumption, thus the training program that was applied in the experiment can be included in the training process of volleyball players. After completing both training programs, the subjects from both groups: the HIJG and LIJG, enhanced their jumping height while jumping with hands on hips or with arm swing, attacking or blocking. However, the HIJG showed a greater improvement. The results of the laboratory Wingate test indicated the effectiveness of the training drills. Moreover, strong correlations between the measured variables demonstrated the accuracy of the choice of the tests.

A similar experiment was conducted by Adams et al. [17], who administered 7-week plyometric training to volleyball players. The improvement in jumping height occurred in both studied groups by 3.81 cm and 10.67 cm. The results of Milic et al. [18] for volleyball players were consistent with the above. After 6-week plyometric training, the vertical jumping height increased by 3.44 cm to 5.39 cm. Similarly, Sheppard et al. [19] found the values of vertical jump for volleyball players that were enhanced by 4.3% (from 48.4 to 50.5 cm) after an even shorter, 5-week plyometric training intervention.

Our studies of volleyball players provide similar results indicating the positive effect of plyometric training, and the highest values of the vertical jumping index were found in the HIJG. The improvements by 12.1% (from 38.6 cm to 43.9 cm) and 11% (from 47.0 cm to 52.8 cm) were reported for the jumping height performed in the vertical jump with hands on hips and swing arm jump, respectively. Nevertheless, for the LIJG the increase in the results for the vertical jumping height in these trials was smaller and reached 8.2% (from 40.5 cm to 44.1 cm).

Our experimental results are consistent with those of Shepard et al. [19], who examined elite volleyball players subjected to a 5-week plyometric intervention. That study showed an improvement in the explosive power of lower limbs by 9.4% (from 46.6 W to 50.9W). The authors

reported the increase in the power values for the vertical jump with hands on hips by 5.6% (from 48.8 W to 51.7 W), and for arm swing jump by 8.4% (from 54.7 W to 59.7 W) in HIJG.

Some authors have noticed that the technique of arm swing has a beneficial influence on the vertical jumping height results, thus the jumping power. For example, Brown et al. [20] studied the effect of 5-week plyometric training in basketball players. They found that 57% of the improvement in the vertical jumping height was dependent on the technique (enhancement of arm swing coordination). The results of our study supported this conclusion, as the difference between the jumping heights with and without the arm swing was 8.7 cm. The effectiveness of the volleyball players is highly dependant on their range of action when attacking or blocking, and the key factors for this range are body structure and vertical jumping height. The results of our study confirmed the positive effect of plyometric training on the jumping height, although the observed correlations do not particularly favor high-intensity training, as players from the LIJG attained higher results for vertical jumping height and power. It might result partly from the players' stature that was higher by 2 cm in the LIJG than in the HIJG. The results of studies by Brown et al. [20] support this conclusion. The authors proved the significant role of arm swing (jumping technique, coordination) in attacking and blocking. The improvement in jumping height by 5.3% and 3.2% was observed in the current studies for attacking and blocking respectively in the HIJG and by 6.0% in the LIJG. The results of Soundara [21] were consistent with the above. The author administered a similar training regime to volleyball players and found that the 6-week plyometric intervention had a statistically significant influence on the increment in the explosive power of lower limbs thus the increase in the jumping height while attacking or blocking.

Specific tests that were used to assess the explosive power appeared to be important for the training control. However, the application of laboratory tests proved equally substantial. Kasabalis et al. [22] found a strong correlation ($r = .86$) between the vertical jumping height and the maximal power obtained by volleyball players of various age in the Wingate test. Similarly, the results from our study revealed significant correlations between the results of vertical jumps and W/kg or J/kg obtained in the Wingate test. However, the strongest association was found between the specific tests (Table 8).

The current results align with previous studies and support the conclusion that high and low-intensity plyometric training has a beneficial effect on the explosive power of lower limbs in volleyball players. Moreover, the assumption that the 6-week high-intensity plyometric regime develops the explosive power more effectively than the low-intensity intervention has been proved. Although this assumption seems to be obvious, our intention was to focus rather on the type of the applied training loads and the included particular exercises.

Conclusions

Practical application

The two types of training programs (and workloads) occurred to be effective for the development of volleyball players' performance. The proper choice of exercises for the program seems a problem for coaches as they do not fully realize the effect of the applied training means on the players. Therefore, we suggest that each coach should precisely determine the volume and intensity of the applied exercises, also involving individualization. In the present study, the training loads were determined according to the players' mass and height. Moreover, the total work rate counted for each of the groups performed throughout the experiment showed differences in the effectiveness of the programs. Because such an attitude to the training process is sparse, the experiments of this type help the coaches to understand the effect of the applied regimes on the players' performance. The training programs presented in our study can be successfully applied for both amateur and professional volleyball players because the involved plyometric exercises are standard and easy to perform in various training conditions.

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