

THE EFFECTS OF A SIX-WEEK PLYOMETRIC TRAINING PROGRAM ON THE STIFFNESS OF ANTERIOR AND POSTERIOR MUSCLES OF THE LOWER LEG IN MALE VOLLEYBALL PLAYERS

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Abstract The study assesses the effects of a six-week plyometric training program (PT) on muscle stiffness in the dominant and non-dominant leg in male collegiate volleyball players. The study group comprised 16 volleyball players who had played collegiate volleyball for at least four years. For six consecutive weeks, twice a week, the players undertook a plyometric program of 60-min training sessions, each preceded with a specialist warm-up. The analysis of the anterior muscles of the right and the left lower leg revealed a significant increase in stiffness in the muscles of the right leg and the left leg. No significant differences were found between the anterior muscles of the left lower leg and the right lower leg in particular weeks of the training program. The analysis of the posterior lower leg muscles revealed no significant differences, either in the consecutive weekly training microcycles or between the left leg and the right leg. The measurement of muscle tone and biomechanical properties of muscles can be used as a fast and direct assessment of plyometric training-related muscle fatigue. A similar level of muscle stiffness in both lower legs (symmetry) is a reflection of the appropriate selection of plyometric training loads.

Key words plyometric training, muscle stiffness, volleyball

Introduction

Modern training of elite volleyball players must prepare them to face huge match demands for high-level competitions that comprise two or more matches a week, or more than ten matches during the European

Championship, World Cup, or Olympic Games. Incremental fatigue during competition make the players successfully cope with those demands, only if their training and competitive loads as well as active regeneration and supplementation are properly adjusted.

Our novel research into muscle stiffness is aimed at determining predictors of athletes' fatigue due to overtraining. An early identification of such predictors can prevent muscle microinjuries, which then can lead to serious injuries. Masi (Masi, Nair, Evans, Ghandour, 2010) confirmed that objective measurements of the muscle tone, tension level, and such biomechanical properties as muscle elasticity and stiffness can be effectively used for detection of overloads and for injury prevention.

From the biomechanical standpoint muscle stiffness is a response to an emitted stimulus, which results from muscle resistance to mechanical lengthening (Rack, Westbury, 1969). According to Wilson, Wood, Elliott (1991) optimal muscle stiffness is significantly correlated with augmentation of muscle training loads.

Laboratory measurements of muscle tone and biomechanical properties are performed with the use of different measurement devices and methods (Chen, Wu, Huang, Lee, Wang, 2005; Gavronski, Veraksits, Vasar, Maaros, 2007; Gennison, Cornu, Catheline, Fink, Portero, 2005; Leonard, Brown, Price, Queen, Mikhailenok, 2004; Tous-Fajardo et al., 2010; Viir, Laiho, Kramarenko, Mikkelsen, 2006), which stimulate muscles mechanically or electrically and analyze muscle response. The MyotonPRO measurement tool (Estonia) implements a state-of-the-art technology used in vivo for muscle stiffness, tension and elasticity assessment both in patients in clinical conditions and in healthy athletes during sport competition. MyotonPRO measurements can be conveniently and reliably carried out in extra-laboratory conditions, e.g. to determine the post-exercise status parameters in healthy athletes. MyotonPRO induces – in a non-invasive way – the oscillation of muscle tissue and then computes the parameters of muscle tone (oscillation frequency), elasticity, and dynamic stiffness.

Material and Methods

Subjects

The study involved 16 male collegiate volleyball players from AZ'S Opole University of Technology Sports Club (age, 21.12 ± 1.67 years; body mass, 86.30 ± 6.66 kg; height, 191.60 ± 5.74 cm; Vuma, 52.88 ± 4.408) with experience (minimum, 4–5 years) performing regular volleyball training participated in this experiment (Table 1). None of the players had any physical or physiological limitations (injuries) that could have affected the training. All layers were healthy and there was an official certified medical advisor for those competing in the Division II league.

Initially, the plyometric intervention program was started by the whole team ($n = 16$); however, only 8 players completed the entire six weeks. The experimental team was composed of 11 hitters (3 middle blockers, 5 service receivers, 3 opposite attacker), 3 setters, and 2 liberos. All players were healthy and were counseled by an official medical advisor for competing in league matches, in accordance with the university sports law. The protocol of research on human subjects was approved by the university ethical committee. Before the commencement of the plyometric intervention program (PIP) the players were informed about the research aim and methods. A written informed consent to participate was obtained from the participants before any plyometric training and testing.

It was assumed that the homogeneity of the tested group was evident from the standard deviation of the BMI measure (Ward, Johnson, Stager, 1984), which did not exceed 10% of the arithmetic mean for all subjects – 23.47 BMI (± 1.68).

Table 1. Mean \pm SD for body height, body mass, and body mass index

Group	Age (years)	Body height (m)	Body mass (kg)	BMI (%)
All players (n = 16)	21.12 \pm 1.67	191.6 \pm 5.74	86.3 \pm 6.66	23.47 \pm 1.68
Attacker (n = 3)	21.00 \pm 0	193.33 \pm 2.52	88.33 \pm 7.64	23.65 \pm 2.29
Service receiver (n = 5)	21.20 \pm 2.68	190.20 \pm 3.49	82.60 \pm 5.55	22.83 \pm 1.33
Middle blocker (n = 3)	20.67 \pm 0.58	199.33 \pm 1.16	91.0 \pm 1.00	22.90 \pm 0.14
Setter (n = 3)	20.67 \pm 1.15	190.00 \pm 4.00	87.67 \pm 10.97	24.23 \pm 2.04
Libero (n = 2)	22.50 \pm 2.12	183.50 \pm 7.78	83.00 \pm 2.83	24.76 \pm 2.93

Procedures

The study was carried out five weeks before the commencement of the Polish volleyball league season: at the start of the direct pre-competitive preparation period (Week 0), mid preparation period (Week 3), and two weeks at the start of competitive preparation period (Week 6). The team under study practiced 5–6 times a week, in 80–90 min training sessions which included sparring matches and league matches at the beginning of the season. In Week 0 the measurements of stiffness of anterior and posterior muscles of the lower leg in the lying position were carried out in all 16 players before the training units.

For six consecutive weeks, twice a week – on Mondays and Wednesdays - the players undertook a plyometric training program of 60-min sessions (Table 1), each preceded with a specialist warm-up. The training sessions consisted of multiple types of vertical and horizontal jumps and hops performed at different intensities, paces, and directions (Table 2). On the remaining week days the players undertook a specialist volleyball training program prepared by the team's coaches, and played a few sparring matches. In the competitive period the players played regular league matches (Thursday, Saturday). All studied volleyball players also performed regular activities of daily living; however, due to their low and sporadic intensity they did not affect the training process. A single plyometric training unit lasted from 70 to 90 min and consisted of a 10-min specialist warm-up, 60-min main part, and 10-min recovery.

Table 2. Summary of strength exercises and plyometric training program

Weeks	Workout 1		Sets	Reps	Load % of 1 RM	Workout 2	
	Exercise					Exercise	
1	2	3	4	5	6		
1/2	Bench press	2	10	70	Incline bench press		
	Squat	2	10	70	Leg presses		
	Power clean	3	6	60	Power snatch		
1/4	Double leg squat jump	2	8	–	Double legs vertical back kicks		
	Combination: standing long jump and “spiking” jump	2	5	–	Combination: standing long jump and “spiking” jump		
	Double leg hops over hurdles	2	8	–	Double leg horizontal speed hops		
	Horizontal scissors jumps in place	2	20	–	Alternate leg vertical box step-ups		
	Alternate vertical high knee jumps	2	6	–	Double leg vertical knee-tuck jumps		
Total number of foot contacts				116			
3/4	Bench press	2	10	75	Incline bench press		
	Squat	2	10	75	Leg presses		
	Power clean	3	6	60	Power snatch		

1	2	3	4	5	6
	Double leg squat jump	3	8	–	Double legs vertical back kicks
	Combination: standing long jump and "spiking" jump	3	5	–	Combination: standing long jump and "spiking" jump
2	Double leg hops over hurdles	3	8	–	Double leg horizontal speed hops
	Horizontal scissors jumps in place	3	20	–	Alternate leg vertical box step-ups
	Alternate vertical high knee jumps	3	6	–	Double leg vertical knee-tuck jumps
Total number of foot contacts				174	
5	Bench press	2	10	80	Incline bench press
	Squat	2	10	80	Leg presses
	Power clean	3	6	70	Power snatch
3/5	Double leg squat jump	4	6	–	Double legs vertical back kicks
	Combination: standing long jump and "spiking" jump	4	5	–	Combination: standing long jump and "spiking" jump
	Double leg hops over hurdles	4	8	–	Double leg horizontal speed hops
	Horizontal scissors jumps in place	4	20	–	Alternate leg vertical box step-ups
	Alternate vertical high knee jumps	4	6	–	Double leg vertical knee-tuck jumps
Total number of foot contacts				224	
6	Bench press	2	–	85	Incline bench press
	Squat	2	10	85	Leg presses
	Power clean	3	10	75	Power snatch
6	Double leg squat jump	5	6	–	Double legs vertical back kicks
	Combination: standing long jump and "spiking" jump	4	5	–	Combination: standing long jump and "spiking" jump
	Double leg hops over hurdles	5	8	–	Double leg horizontal speed hops
	Horizontal scissors jumps in place	4	20	–	Alternate leg vertical box step-ups
	Alternate vertical high knee jumps	5	5	–	Double leg vertical knee-tuck jumps
Total number of foot contacts				240	

Measurement procedure using MyotonPRO

The measurements were performed with the MyotonPRO Digital Palpation Device (MyotonPRO, Myoton Ltd, Estonia). The procedure consisted of inducing and recording damped natural oscillation of muscle in the form of an acceleration signal and the subsequent simultaneous computation of the parameters of state of tension (frequency in Hz), elasticity, and dynamic stiffness (N/m). The measurement was performed under constant pre-load (0.18N) through compression of the skin surface by a mechanical impulse (15 ms) of low force of 0.4 N followed by quick release (<http://www.myoton.com/en/technology>).

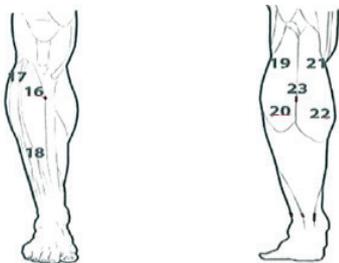


Figure 1. Positioning of the MyotonPRO device on selected muscles during muscles stiffness measurement

Each week, before the start of the procedure measurement spots were marked on the skin surface of particular muscle bellies and attachments (Figure 1) of anterior muscles of the lower leg (tibialis anterior muscle – spot 16, peroneus longus muscle – spot 17, peroneus brevis muscle – spot 18) and posterior muscles of the lower leg (lateral head of the gastrocnemius muscle mm – spots 19 and 20, medial head of the gastrocnemius muscle – spots 21 and 22, mid-part of the gastrocnemius muscle – spot 23). Following the manufacturer's instructions the probe of the MyotonPRO device was placed on the spots marked on the skin, in numerical order in Figure 1. Muscle stiffness was measured before exercise (before warm-up) for all marked muscles.

Statistical analysis

Descriptive statistics (means and \pm SD) were calculated. The Shapiro-Wilk test indicated a normal distribution for all variables. Comparisons between the jumping exercises were examined with unpaired Student's *t* tests, and the effect size was calculated using Cohen's *d* (Thalheimer, Cook, 2002). Effect sizes were interpreted as negligible ($d \geq 0.2$), small ($0.2 < d \leq 0.5$), medium ($0.5 < d \leq 0.8$), or large ($0.8 < d$). Spearman's correlation coefficients were used to examine the relationships between the load (volume - number of foot contacts, and intensity – HR) of PT and jumping performance. The level of significance was set at $p \leq 0.05$ or $p \leq 0.01$. Data were statistically analysed with the use of SPSS for Windows 15.0 (Chicago, IL, USA).

Results

The analysis of stiffness of the anterior muscles of the right and the left lower leg did not reveal any significant changes in stiffness between the measurement before the start of the plyometric training program (right leg 545.92 ± 75.97 ; left leg 548.50 ± 74.39) and the measurement in the third week of the program (right leg 525.15 ± 67.81 ; left leg 524.29 ± 69.50). In the sixth week of the program significant increases in the muscle stiffness of the right leg (for 61.41) and the left leg (for 76.77) ($p < 0.001$) were noted.

No significant differences were found between the anterior muscles of the right and the left lower legs in particular weeks of the plyometric training program (Figure 2).

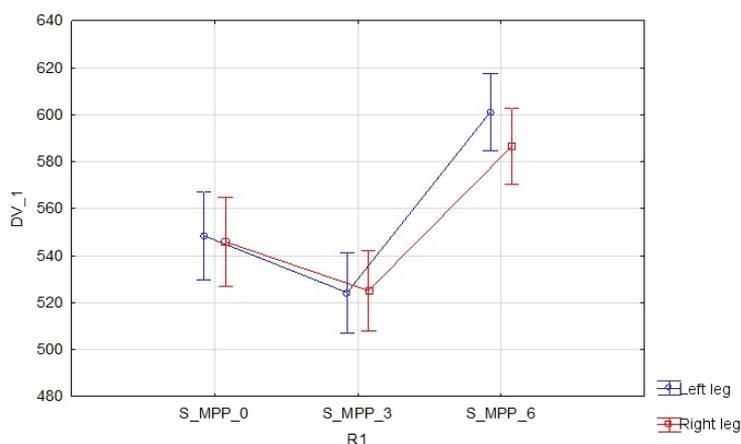


Figure 2. Changes in stiffness of lower leg muscles within a six-week plyometric training program

The analysis of stiffness of posterior muscles of the lower leg revealed no differences between particular weekly training microcycles or between muscles of the right and the left lower leg (Figure 3).

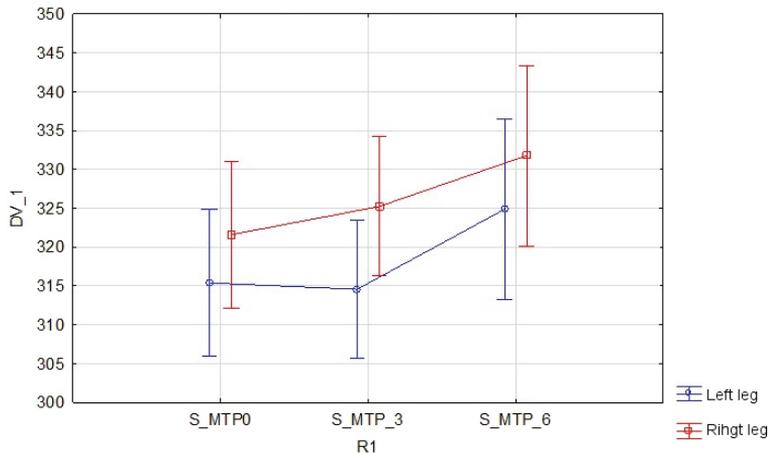


Figure 3. Changes in stiffness of lower leg muscles within a six-week plyometric training program

Discussion

The examination of stiffness of anterior and posterior muscles of the lower leg revealed initially a greater tone of the anterior than the posterior muscles. The analysis also showed that with the increased tone the level of stiffness of anterior muscles of the lower leg was significantly higher after six weeks of plyometric training than at rest (Week 0). On the one hand, the increased muscle tone can be explained by the activity of the central nervous system in regulating muscles stiffness and elasticity through muscle spindles within the body of muscles (Aura, Komi, 1986). While performing jumping exercises, it appears to be particularly significant in the sudden shock absorption phase during landing and the rapid take off after a brief floor contact.

The goal of used plyometric exercises is to increase the power of subsequent movements by using the natural and elastic components of the muscle, tendon, and stretch reflex. Plyometric training causes muscular and neural changes that facilitate and enhance the development of rapid and powerful movements (Fatahi, Sadeghi, 2014). Muscles are prestretched prior to jumping, and the stretch shortening cycle is involved. Prestretching causes the muscles to store potential elastic energy (Ishikawa, Komi, Grey, Lepola, Bruggemann, 2005; Potach, Chu, 2000) and then recoil during take-off, thus allowing more power while jumping (Ishikawa et al., 2005). Plyometric exercises train and activate the fast muscle fibers and nerves and activate the reflexes (Harmandeep, Satinder, Amita, Anupriya, 2015). Therefore, plyometric training is one primary tool that enhances both explosive power and speed, especially in volleyball. The plyometric method is ranked among the most frequently used methods for conditioning in volleyball (Lehnert, Lamrova, Elfmark, 2009).

The analysis of posterior lower leg muscles showed that while the level of initial muscles stiffness was significantly lower, its increase after the 3rd and the 6th week of plyometric training was statistically non-significant,

but also respectively lower than in the anterior muscles. In this case a great role in regulation of muscles stiffness is played by Golgi tendon organs in the Achilles tendon at the origins of skeletal muscle fibers (Cameron-Tucker, 1983). This tendon-muscle complex is particularly protected by the central nervous system during dynamic eccentric-concentric muscle performance.

The significant increase in the stiffness of anterior muscles of the thigh can also be impacted by plyometric training, especially while performing jumps different from jumps exercised by volleyball players to which they were adapted during the sport-specific training. The applied training program comprised dynamic exercises with higher loads (because of the preparatory training period of the volleyball players) which significantly shorten the ground contact time of the foot and improve jumping quality. During swinging movements, as Maćkała (Mackala, Stodolka, Siemiński, Coh, 2013) claim, the most active are the rectus femoris muscle and the tibialis anterior muscle.

The applied plyometric training was a new and non-specific stimulus to the volleyball players and thus their system of locomotion could respond to the program with increased activity and greater fatigue manifested by muscle stiffness. During training particular attention was paid to the jumping technique that emphasized brief ground contact time and prolonged time of the flight stage. In consequence, the volleyball players performed the new jumping exercises differently than the jumps during matches and, therefore, loaded the locomotor system in a different way. Plyometric exercises (jumping, hopping, modified bounding, and some type of skipping) executed bilaterally and unilaterally can strongly increase muscle stiffness (Behrens, Mau-Moeller, Bruhn, 2014; Behrens et al., 2016), thereby enhancing the dynamic muscular performance (Impellizzeri et al., 2008) of activities related to the vertical jumping ability (King, Cipriani, 2010; Kotzamanidis, 2006; Mackala, Fostiak, 2015; Sozbir, 2016) which are very demanding and required in volleyball.

The analysis did not show any significant differences in stiffness between anterior and posterior muscles of both lower legs. This can be explained by similar training loads (number of jumps) for both legs. The plyometric training program was performed during the preparatory training period, during which general exercises, including jumping exercises, dominate over volleyball-specific loads. However, a full explanation of the observed changes would be possible with a future comprehensive analysis of kinematic chains of anterior and posterior muscles of the lower leg. In the present study, for example, data on the ankle joint activity was not collected and analysed.

Conclusion

The measurement of muscle tone and biomechanical properties of muscles can be used as a method of quick and direct assessment of plyometric training-related muscle fatigue. The volleyball player represented an intermediate level of sport performance and had a minimum of five years of training /match experience. This allowed to performed a 6 weeks of plyometric training without injury. The use of plyometric training in younger athletes representing lower level of sport experience needs a lot of care and methodical attention.

A similar level of muscle stiffness of different muscle groups in both lower legs (symmetry) is a reflection of the appropriate selection of plyometric training loads. Different levels of muscle stiffness for both legs indicate the necessity of adjustment of training loads to ensure the balanced development of muscles and to prevent and reduce the risk of injuries.

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