PRODUCTION AND DEVELOPMENT OF MUSCLE FORCE IN ELITE MALE VOLLEYBALL PLAYERS' SPIKE

Predrag Nemec[1], Miloš Milošević[2], Vesna Nemec[3] and Milenko Milošević[1]

[1]*Faculty of Management in Sport, Alpha BK University, Belgrade, Serbia*
[2]*Faculty of Sport, University Union-Nikola Tesla, Belgrade, Serbia,*
[3]*Faculty of Physical Education and Sports Management, University Singidunum, Belgrade, Serbia*

Original scientific paper

Abstract
The aim of this study is to discover the mechanisms of muscle force generation in spike and to determine the methodology of its development in the training course of the elite volleyball players. For this purpose the biomechanical and functional analyses of muscle force generation were performed and the methodology of its development was proposed. Eccentric contraction is used to generate muscle force in spike in landing, however, in all other cases one uses a reversible contraction. To achieve good results in spike one must have developed muscle force generation of all muscle groups involved in the realization of spike, then a well developed motor units recruitment velocity and a good synchronization of their work, the maximum force of certain groups of motor units, muscle force generation change velocity, inter and intramuscular coordination. The maximum values of the specified parameters in the elite volleyball players are achieved in the time interval ranging from 0.005 s to 0.082 s. The maximum muscle force production velocities in the elite volleyball players are ranging from 3440.00 daN$\cdot$s^{-1} to 14988.69daN$\cdot$s^{-1} at the motor units recruitment velocity ranging from 22.00 IU to 95.0 IU. The force of certain groups of motor units of the knee extensors in elite volleyball players ranges from 1.09 daN to 105.14 daN. During the vertical-landing jumps the elite volleyball players synchronize up to 94.7% of the leg extensors motor units. The greatest impact on the enormous increase in muscle force along with the shortening time of its generation in reversible contractions in service is attributed to the disinhibition process at all levels. In accordance with the results of the analysis a muscle force development methodology is suggested in which, in addition to mastering the disinhibition process, the whole set of required parameters is devised, on which the level and muscle force generation velocity depend, on a daily, weekly, monthly and annual basis, applying the appropriate resources and methods for each particular parameter.

Key words: *volleyball, force, velocity, motor units, synchronization*

Introduction

Successful performance in volleyball often depends on the ability of the individuals to perform high enough high jumps, a good spike and a good landing. High jump precedes service, block and spike. Each jump ends up in a good landing. Good landing eliminates the risk of injury (Milosevic, Blagojevic, Tosic, Pilipovic, 2000b) and provides a good preparation for the generation of muscle force for the next vertical jump (Amanovic, Milosevic, Mudric, Dopsaj, & Peric, 2006; Milosevic, Blagojevic, Pilipovic, Tosic, 2000a; Milošević, Mudrić, Dopsaj, Blagojević, & Papadimitriou, 2004; Milošević, Mudrić, Mudrić, Milošević, 2012; Milosevic, & Milosevic, 2013; Milosevic, Nemec, Zivotic, Milosevic, Rajovic, 2014a; Milošević, Milosevic, Nemec, Zivotic, & Radjo, 2014b; Milošević, Džoljić, Milošević, & Yourkesh, Behm, 2014c; Milošević, Nemec, Yourkesh, Nemec, Milošević, & Behm, 2016). At the elite volleyball players' matches 71% of high jumps is realized during spike, 20% in service and 9% in the block (Wagner, Tilp, Von Duvillard, & Muller, 2009). Since a spike is the most frequently used technique during the game it is quite natural that the spike is analyzed for the production of muscle force and its development by training, which is the focus of this paper. The main problem to be solved in this paper, in relation to the training of muscle force is to discover the adaptation mechanisms which cause changes in neuromuscular apparatus and to determine its technology of development.

Biomechanical analysis of spike
Spike realization can be divided into 4 stages: initial, preparatory, primary and final stage in which following elements are alternating: initial diagonal position, run-up, takeoff, flight and landing (Djurović, Marelić, Hraski, & Šikanja, 2005; Tillman, Hass, Brum, & Bennett, 2004; Tomić & Nemec, 2012). In the initial phase a volleyball player can be in the front or back zone in a high diagonal position (Djurović, et al., 2005; Tomić & Nemec, 2012). Position height is slightly higher when a player is in the back zone (Djurović, et al., 2005; Tillman, et al., 2004; Tomić & Nemec, 2012; Wagner, et al., 2009). In the initial phase, immediately before the onset of the preparation phase, volleyball players shift the center of mass onto the front part of their feet by moving the shoulder forward (Djurović, et al., 2005; Tomić & Nemec, 2012). From this position on starts the preparation phase, the spike run-up. Right-handed persons use the usual 4 steps volleyball approach pattern R-L-(RL) or R-L- R-L (Djurović, et al., 2005; Tillman, et al., 2004; Tomić & Nemec, 2012; Wagner, et al., 2009). The main task of the run-up

is for the volleyball player to achieve the highest possible horizontal velocity and blend the approach with the takeoff (Djurović, et al., 2005; Ivancevic, & Ivancevic, 2006; Tillman, et al., 2004; Tomić & Nemec, 2012; Wagner, et al., 2009). Explanation for the set task can be found in the fact that the level of the horizontal velocity is conditioned by the fact that muscles protagonists of amortization and takeoff do not generate immediately the maximum level of muscle force, but by the exponential function in a time whose form it is:

$$F_m(t) = F_{\max} \cdot \left(1 - e^{-k \cdot \Delta t}\right)$$

where: F_m - is a level of 1%, 2%,....,99% of the maximum muscle force expressed in daN; F_{max} - maximum force generated by leg extensors expressed in dekanewtons (daN); k - is a constant that characterizes the speed of the motor units recruitment expressed in index units (IU); t - is the time in which the appropriate level is achieved from the maximum muscle force expressed in seconds (s) (Milosevic, et al., 2000, 2014a, b, c). This function shows that the run-up horizontal velocity is conditioned by the maximum velocity of the muscle force generation (in elite volleyball players 7666.42±1105.42 $daN{\cdot}s^{-1}$ - 14988.69±1795.46 $daN{\cdot}s^{-1}$ for a period ranging from 0.063±0.007 s up to 0.082±0.020 s) and the motor units recruitment velocity (in elite volleyball players 64.9±7.14 IU - 79.6±6.85 IU) of the leg extensors muscles to absorb (an eccentric phase of the reversible contraction) the run-up horizontal velocity and immediately perform the adequate high jump (concentric phase of the reversible contraction) (Milosevic, et al., 2000a, 2004, 2012, 2014a,b,c; Milosevic, & Milosevic, 2013, 2014; Zatsiorsky, & Kramer, 2006).

Maximum velocity of the muscle force generation that leg extensors achieve up to 0.100 s directly depends both on the motor units recruitment velocity and on the level of the motor units synchronization (Figure 2), as well as on the level of muscle force produced by certain groups of motor units (Figure 1) and the intramuscle coordination (Milosevic, et al., 2000a, 2004, 2012, 2014a,b,c; Milosevic, & Milosevic, 2013, 2014; Zatsiorsky, & Kramer, 2006). That is to say that the bigger the muscle force generation velocity of the leg extensors in elite volleyball players, the quicker they will perform amortization with higher run-up velocity in a shorter time and will attain faster transition into the concentric phase of the muscle force generation, which will in turn increase the height of the vertical spike jump and vice versa. The run-up protagonists are the plantar flexors in the upper ankle joint, then the muscle group of the knee extensors, extensors and flexors of the hip joint (m. triceps surae, m. quadriceps, m. iliopsoas and m. gluteus maximus) functioning in the reverse regime (Ivancevic, & Ivancevic, 2006; Milosevic, et al., 2000a, 2012, 2014c). Run-up velocity is increased in the first three steps and is the largest in the third step (Djurović, et al., 2005; Tillman, et al., 2004; Wagner, et al., 2009). In the elite volleyball players horizontal velocity of the take-off in the third step ranges from 3.8 to 4.2 $m{\cdot}s^{-1}$ (Djurović, et al., 2005; Tillman, et al., 2004; 2012; Wagner, et al., 2009). Preparation for the blending of the approach phase and take-off begins in step 4, whereupon the extension of the last step and planting on both feet occur, reducing the horizontal velocity from 1.8 up to 2.4 $m{\cdot}s^{-1}$ and lowering the center of mass at the expense of reducing the angle in the knee joint, which at the moment before the vertical jump varies, depending on the volleyball players constitution from 118^0 up to 143^0 (Djurović, et al., 2005; Tillman, et al., 2004; Tomić & Nemec, 2012; Wagner, et al., 2009). The protagonists of reducing the horizontal velocity are the knee and hip extensors (m. quadriceps, m. gluteus maximus) that function in an eccentric mode regime - the first phase of the reversible contraction (Ivancevic, & Ivancevic, 2006; Milosevic, et al., 2000a, 2012, 2014c; Zatsiorsky, & Kramer, 2006).

At the moment of amortization (first phase of the reversible contraction), knee and hip extensors accompanied by the plantar flexors in the upper ankle joint, move into the second concentric phase of the reversible contraction, generate the force by the maximum velocity that amounts up to 14988.69±1795.46 $daN{\cdot}s^{-1}$ (Milosevic, et al., 2000a, 2014c; Milosevic, & Milosevic, 2013, 2014; Zatsiorsky, & Kramer, 2006). Its vertical component conditions volleyball players body movement into the vertical jump with a starting velocity of 2.5 up to 2.9 $m{\cdot}s^{-1}$ (Djurović, et al., 2005; Milosevic, et al., 2000a, 2014c; Tillman, et al., 2004; Wagner, et al., 2009). During the vertical jump spinal column extensors maintain their stability working in the isometric regime whereby achieving a maximum velocity of the motor units recruitment of 27.0 IU at a time of 0.005 s with a force of 23.60 daN and the muscle force generation velocity of 4720.4 daN/s. Extensors of the knee joint as protagonists of the vertical jump are trying to shorten the time of transition from the eccentric into the concentric phase of the reversible contraction (Milosevic, et al., 2000a, 2012, 2014c; Milosevic, & Milosevic, 2013, 2014; Zatsiorsky, & Kramer, 2006).

The volleyball player would swing both arms back to the waist and then swing the arms forward and upward and with each run up step will use retroflexors in the shoulder joint in an effort to generate power for the spike (Djurović, et al., 2005; Tillman, et al., 2004; Wagner, et al., 2009). In a moment of take-off volleyball player's body pulls up and inclines slightly forward with both hands forward. While the volleyball player's body lifts up vertically after the takeoff he raises his right hand in a distinctive attacking spike position (elbow angle ranging from 44^0 to 47^0) thus activating first m. deltoideus, then m. supraspinatus and finally m. biceps brachii (Djurović, et al., 2005; Ivancevic, & Ivancevic, 2006; Tillman, et al., 2004; Wagner, et al., 2009). At the same time shoulders are rotated to the right. This movement includes first m. biceps brachii and then m. wrist extensor. In addition, at the same time trunk rotates to the right (m. obliquus internus abdominus and m. psoas major et minor). Thus, the first (eccentric) phase of the reversible contraction in spike is being implemented simultaneously in torso, shoulder, elbow and finally, ankle joints. Implementation of the second (concentric) phase of the reversible contractions in spike is carried out successively.

It is first realized in the trunk joint angle (trunk rotators to the left) whereby the motor units recruitment velocity is 22.00 IU in the interval of 0.005 s, at the force of 17.20 daN, and the maximum muscle force generation velocity of 3440.00 daN·s^{-1} of shoulders (anteflexsors in the shoulder joint - m. deltoideus and m. pectoralis major), then the elbow (elbow extensors - m. triceps brachii) whereby the maximum motor units recruitment velocity is 34.00 IU, in the interval of 0.005 s, at the force of 43.55 daN, and the motor units recruitment velocity of 8710.0 daN·s^{-1}, and finally in the hand wrist (right fist flexors) whereby the motor units recruitment velocity is 95.0 IU, in the interval of 0.003 s, at the force of 14.40 daN, and the maximum muscle force generation velocity of 4800.1 daN·s^{-1} (Djurović, et al., 2005; Ivancevic, & Ivancevic, 2006; Milosevic, et al., 2000a, 2014a; Milosevic, & Milosevic, 2010, 2014; Tillman, et al., 2004; Tomić & Nemec, 2012; Wagner, et al., 2009). In each joint it is strong, lightning rapid, timely (perfect intra and intermuscular coordination) (Milosevic, et al., 2000a, 2012, 2014a,b,c). Successive series of muscle contractions produce a force that allows the ball flight velocity of 21.5 m·s^{-1} and even higher (Djurović, et al., 2005; Tillman, et al., 2004; Wagner, et al., 2009).

The elbow angle at the moment of spiking the ball from the back zone is 146^0 and in spiking the ball from the front zone it is 159^0 (Djurović, et al., 2005). After a realized spike there follows a final phase, landing on the toes of both feet at the same time, in which plantar flexors in the upper ankle joint, knee and hip joint extensors work in the eccentric regime performing the amortization, whereas the spinal column extensor, by isometric contraction, maintain a stability of the trunk. The elite volleyball players achieve the maximum muscle force generation velocity of the leg extensors 7666.42±1105.42 daN·s^{-1} in the interval of amortization of 0.082±0.020 s, at the knee joint angle of 132.2^0 ±10.85^0, level of muscle force of 628.65±91.68 daN, and the motor units recruitment velocity of 64.9±7.14 IU (Milosevic, et al., 2000, 2012, 2014a,c). If, after landing immediately follows take-off the leg extensors of the elite volleyball players again work in the reverse regime (the eccentric and concentric phase are connected with the aim to shorten the interval between the phases as much as possible) whereby they achieve the maximum motor units recruitment velocity of 14988.69±1795.46 daN·s^{-1} in a time interval of transition from the eccentric to concentric contraction of 0.063±0.007 s, muscle force level of 944.26±113.11 daN, and the motor units recruitment velocity of 79.6±6.85 IU, in order to achieve the necessary vertical jump height from which to successfully perform a spike or block (Milosevic, et al., 2000a, 2004, 2012, 2014a,b,c; Milosevic, & Milosevic, 2013, 2014).

Physiological analysis of muscle force production in spike

In all movements in the realization of spike, except in landing, muscle force production is enabled by the reversible muscle contractions. Reversible contractions consist of the eccentric and concentric phases in which the shortening of muscles is preceded by their sudden elongation (Milosevic et al., 2000a, 2004, 2012, 2014, b, c, 2016; Zatsiorsky, & Kramer, 2006). A combination of the eccentric concentric contraction (a cycle) in the described spike movements is called a reversible contraction (Milosevic et al., 2000a, 2004, 2012, 2014B, c; Zatsiorsky, & Kramer, 2006). In the eccentric concentric cycle, during shortening phase (concentric contraction) a greater force is produced than individually in the eccentric or concentric muscle contraction for several reasons. First, at the highest point of the cycle, at the moment when the elongation stops and shortening of a muscle begins, force is developed in isometric conditions (Milosevic, et al., 2000a, 2004, 2012, 2014a,b,c, 2016; Zatsiorsky, & Kramer, 2006). Second, considering the fact that the force begins to increase in the eccentric phase, the time at which it is possible to generate a force in a reversible contraction is extended (Milosevic, et al., 2000, 2004, 2012, 2014a,b,c, 2016; Zatsiorsky, & Kramer, 2006). Third, the level of muscle force is affected by the muscle tendon elasticity (accumulation of elastic energy in the phase of muscles and tendons elongation), and fourth, reflex muscle contraction (Milosevic, et al., 2000, 2014a,b,c; Zatsiorsky, & Kramer, 2006).

It has already been said that the length of all the muscles involved in spike changes causing the same abrupt changes of their level of muscle force. This is particularly pronounced in the knee extensors after contact with the ground in landings or jump landings. Thus, the muscles are forcingly elongated and at the same time their tension is greatly increased (Milosevic, et al., 2000a, 2004, 2012, 2014a,b,c, 2016; Zatsiorsky, & Kramer, 2006). Those changes are simultaneously controlled and partly held in balance by the common function of the two motor reflexes: elongation reflex, maintaining optimal muscle length, and Golgi tendon organ reflex, preventing the extreme and damaging muscle strain. Eccentric discharge to the muscle in the elongation phase is modified by the joint action of the two reflexes, elongation reflex and Golgi tendon organ reflex. Stretch reflex has a positive effect (increasing discharge) while Golgi reflex has a negative (inhibitory) efferent effect, and their effect is manifested by the muscle force measure. What is important to learn about reversible contractions during the large muscle strains in volleyball is that the activation of the Golgi tendon organ inhibits further muscle activity, i.e. concentric contraction because it prevents efferent inflow into the muscle. However, in landing with amortization or block, jump landing with rapid elongation due to the possibility of the body integrity violation CNS reacts by the amplification and disinhibition effects at different levels. In this case, the reticular system begins to operate by amplification increasing the efferent inflow. Then, there occurs central inhibition of the Renshaw's inhibitory interneurons resulting in the free passage of the increased efferent consecutive inflow of impulses. Also, Golgi tendon organ is inhibited peripherally thus removing the last obstacle to an increased influx of the efferent impulses to the muscle.

The neural disinhibition, from the above mentioned conditions, causes the increase in stretch reflex (shortens the reflex latency time and increases the velocity and level of muscle force produced in a reflex). Furthermore, neural disinhibition causes an increase in the motor units recruitment velocity by controlling the release and diffuse rate of Ca^{++} ions and inhibition of the troponin - tropomyosin complex in muscle fibers, which essentially represents a muscle fiber disinhibition; then, there is increase in the level of the synchronization of the muscle motor units functioning, change in the motor units recruitment pattern, whereby the first involved are the highest firing rate motor units and muscle force, (intramuscular coordination).

Also, there are increases in the intramuscular coordination and reprogramming (by increasing) the limits of muscle force of all motor units above the maximum measured on standard tests. By increasing the motor units recruitment velocity, their synchronization, intra and intermuscular coordination and muscle force level of the individual groups of motor units, muscle force generation velocity and level are increased, as well as the velocity of its generation changes.

Thus, the greatest impact on the enormous increase in muscle force along with the shortening time of its generation in a reversible contraction in all phases of service and spike, is attributed to the neural component of muscle contraction, primarily to the disinhibition process at all levels (Milosevic, et al., 2000a, 2004, 2012, 2014a,b,c, 2016; Zatsiorsky, & Kramer, 2006). The biggest challenge to the mind of the elite volleyball players in learning and mastering a reversible contraction is learning how to master disinhibition.

Those volleyball players who are bad at mastering disinhibition process in a reversible contraction, in spite of achieving much higher levels of maximal muscle force in tests, as compared to those who have mastered reversible contraction, as a rule, have a weaker serve, spike, jumps and landings, due to the lack of training and mastering the knowledge of the effects of the Golgi tendon reflex in the concentric contraction phase.

Muscle force measuring methodology

The force generated by all muscle groups participating in the realization of spike, or the realization of exercises designed for its development, is measured in isometric and dynamic mode of muscle functioning.
The force in the isometric mode is measured by specially designed and certified hardware and software system (Programme Engineering, Belgrade). Peripheral equipment for isometric muscle force measuring are tensiometric probes with measurement range from 0 do 15000 daN and measurement accuracy of 0.0002 daN. For muscle force measuring, for all muscle groups Belt method is used (Milošević & Milošević, 2010, 2014; Milosevic, et al., 2004, 2014a,c).

The force $F_m(t)$ to a level of 1%, 2%,...., 99% of maximum muscle force expressed in daN and the time intervals of their generation (s) are measured. Then the maximum muscle force F_{max} also expressed in daN[1] and the time intervals of their generation are measured (Milošević & Milošević, 2010, 2014, Milosevic, et al., 2004, 2014a). Thus designed system allows (during isometric measurement) the control and varying of the muscle length (the angle at which the muscle works), time and manner of its work (smooth and twitch) and the number of muscles and joints involved in measurement (one joint, two or more joints). Each test is repeated three times and the best result is selected. Muscle force measurement in dynamic mode is performed by the optoelectronic system, force plate and a certified hardware and software (Bioengineering VAC) system, which consists of free weights with equipment allowing time measurement (s), vertical and horizontal weights bar change positions every 1 mm in the whole lifting range (Bobbert, Gerritsen, Litjens, Van Soest, 1996; Gavrilovic, 1992; Milošević & Milošević, 2010, 2014, Milosevic, et al., 2000a, 2014B, c, 2016). Force plate and optoelectronic systems measure muscle force production during different types of jump landing, landings, vertical jumps and run-up vertical jumps. Piezoelectric sensors built into the platform register at high speed (1000 Hz) compression muscle forces during the execution of jump landing, landings, individual or serial jumps and provide for a detailed dynamic analysis of all the phases of the jump and the high validity of every single performed movement.

In addition to standard parameters, force plate allows for the monitoring of dynamics and transitivity development of muscle force, the jump execution velocity, the degree of the take-off and landing depth, the stretching effects, the abilities of rapid alternation of the eccentric and concentric contraction and elastic energy transfer (Bobbert, et al., 1996) and numerous other parameters. Hardware Software (Bioengineering VAC) system is used to measure muscle force in weightlifting.

[1] 1 daN = 10^1N

It allows for measurements to be controlled and varied: muscle length (angle), the time, the weight of the length and speed of work, shortening velocity (concentric contraction) and elongation of muscles (eccentric contraction), the time of transition from eccentric to concentric contraction (reversible contraction). When lifting all weights, vertical and horizontal bar position changes time is measured, vertical on each 5.8 mm and horizontal on each 1 mm, spanning the whole range of muscle work. Each test was repeated three times and the best result was selected.

The attempts whose horizontal barbell displacement is not permitted in the allowed zone (4-5 cm) were disregarded. On average, 100 points are observed per measurement. Based on the data length vs time one calculates vertical velocity and acceleration for each monitored sample as the first and the second performance per time. Results of velocity and acceleration to are fitted before the muscle force is calculated. Then, based on the fitted results, one calculates force in each measurement in the entire range of lifting according to the following formula (Milošević & Milošević, 2010, 2014, Milosevic, et al., 2014B, c, 2016):

$$F = m (a + 9.81) / 10$$

where F - is the force expressed in [1]daN, m - is the mass of the barbell expressed in kg, and a is the acceleration ($m \cdot s^{-2}$) observed in a certain measurement. In both working regimes, there were measured ratio of force time on each 1% of the maximum muscle force, and maximum force and the time during which it is generated. From the obtained data for muscle force and time, one calculates the muscle force production velocity as their sums per time for all the muscle groups involved in the testing.

From the data obtained for muscle force and time one calculates muscle force production velocity as their performance per time for all the muscle groups involved in the testing. Force in vertical jumps in spike, which are performed during the match can be calculated through the vertical jump height, body height and body weight of each volleyball player. Once the results are known for the vertical jump in spike, body weight and body height of the volleyball player the force is calculated using this function (Milošević & Milošević, 2010, 2014):

$$F = [(G \cdot VJ_h) \cdot BH^{-1}] \cdot 10^{-1}$$

where F - is the level of muscle force expressed in decanewtons (daN) G - is the body weight expressed in newtons (N), VJ_h – is a vertical jump height expressed in centimeters (cm), BH - is the body height in meters (m).

The force of torso, shoulder girdle and hand rotators in spike is calculated using partialization method. (Milošević & Milošević, 2010, 2014). In isometric and dynamic measurement regime, in the entire range of muscle force generation, for every 1%, one calculates muscle force generation velocity according to the formula:

$$RFD=F/t$$

where RFD - is muscle force development rate expressed in decanewtons in seconds ($daN \cdot s^{-1}$), F - is an adequate level of muscle force expressed in decanewtons (daN) and t - is the time of muscle force observation expressed in seconds (s).

From the data force time for both measurement regimes changes of muscle force generatiion velocity are calculated according to the formula:

$$CRFD = (F_2-F_1) / (t_2-t_1)$$

where CRFD - is change in muscle force generation velocity expressed in decanewtons in second ($daN \cdot s^{-1}$), for each % of the measured muscle force, force (F) from 1% to 100% and time (t) expressed in seconds (s) when it happens, F_1 and F_2 - are adequate levels of k force expressed in decanewtons (daN), and t_1 and t_2 -are the time of muscle force observation expressed in seconds (s). From the data force time, obtained by means of the Belt method and weight lifting motor units recruitment velocity was calculated for each F_t according to the formula (Amanović, et al., 2006; Milošević & Milošević, 2010, 2014; Milosevic, et al., 2004, 2014a,c):

$$k = - (1/t) * \ln ((1 - F_t/Fmax))$$

where: Ft - is a level of 1%, 2% .... 99% of the maximum muscle force expressed in decanewtons (daN); F_{max} - is a maximum force generated by the actual muscles expressed in decanewtons (daN); k - is a constant which characterizes the motor units recruitment velocity expressed in index units (IU); t - is the time in which to achieve the appropriate level of the maximum muscle force expressed in seconds (s). When using force plate for measuring muscle force in landings, landing blocks, landing jumps, run-up take-off, motor units recruitment velocity is calculated by the following formula (Gavrilovic, 1992; Milošević & Milošević, 2010, 2014, Milosevic, et al., 2004 , 2014c):

$$k = \mathrm{Ln}\ (1 - F_{exp} / A / e^{B \times \beta\ exp}) \Delta t_{exp}$$

where k - is a constant which characterizes the motor units recruitment velocity expressed in index units (IU); F_{exp} – is the level of muscle force registered in the dynamic conditions of muscle functioning during the period when a muscle strains under isometric conditions expressed in decanewtons (daN), βexp - is the angle of the knee joint in which the angular velocity is zero, expressed in degrees (^{0}); Δt_{exp} – is the time interval elapsed since contact with force plate until the moment in which the angular velocity of the knee joint is equal to zero, expressed in seconds (s). From the data force time and motor units recruitment velocity cluster analysis was applied to determine the classes of motor units (Milošević & Milošević, 2010, 2013, 2014, Milosevic, et al., 2004, 2014) according to the level of the muscle force generation (daN) for each observed moment or measurement (*Graph* 1).

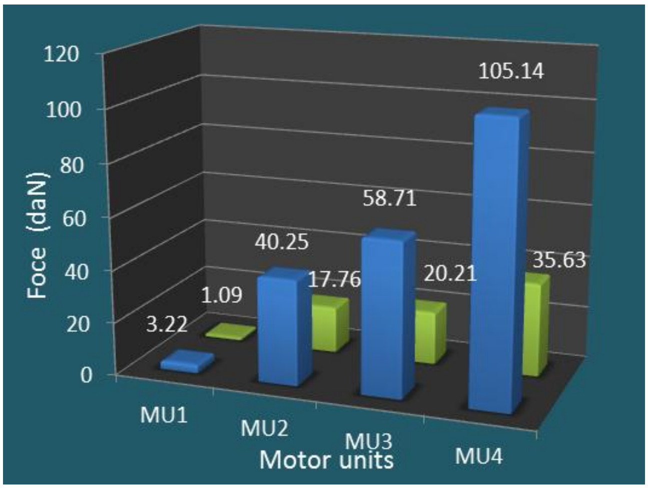

Figure 1. Muscle force of some motor unit groups of the knee extensors in two elite volleyball players during vertical jump expressed in decanewtons daN

Based on the relationships between the force time, recruitment velocity and the level of muscle force of the individual motor units in the whole range of muscle force generation, by fitting , one calculates the level of motor units work and synchronization is expressed as a percentage (%) (Milošević & Milošević, 2010, 2013, 2014, Milosevic, et al ., 2004, 2014a).

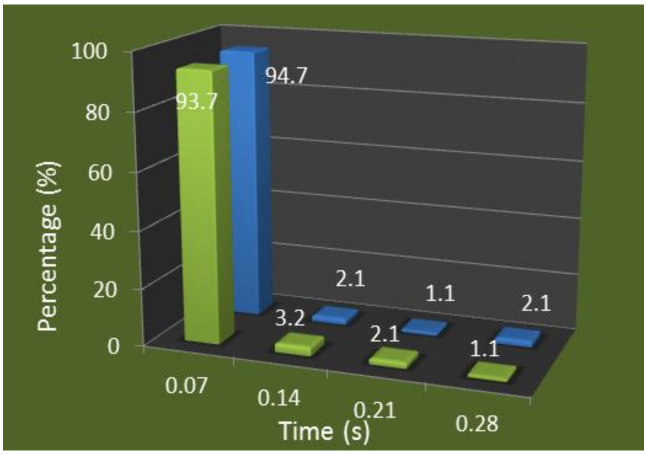

Figure 2. Leg extensors motor units work synchronisation in two elite volleyball players during vertical jump expressed in percentages (%)

Fitting the data on the level of muscle force of the individual motor units and the time of its achievement in the entire range of muscle force generation for one or more muscles, the optimization of their work is calculated (Milošević & Milošević, 2010, 2013, 2014, Milosevic, et al., 2004, 2014a) on the intra or intermuscular level.

All the measurements for biomechanical analyzes were performed on 21 elite volleyball players.

Methodology of muscle force development in spike in elite volleyball players

The main problem in relation to the muscle force training is still nowadays present (Milošević & Milošević, 2010, 2013, 2014; Milosevic, et al., 2000a, 2004, 2012, 2014a,b,c, 2016; Zatsiorsky, & Kramer, 2006) as it was many years ago (Friedebolt, Nussgen, & Stoboy, 1957; Stoboy, Nussgen, & Friedebolt, 1959; Duntsh & Stoboy 1996) and it is a discovery of the mechanism of adaptation that causes changes in neuromuscular apparatus in accordance with the expressed needs of sports, and consequently, determining technology for its development. Friedebolit, Stoboy, Duntsh & Stoboy (Friedebolit et. al., 1957; Stoboy et. al., 1959; Duntsh and Stoboy 1996) locates adaptation mechanism at the level and method of motor units activation. Friedebolit et. al., 1957, assumes that the increased level of the motor units work synchronization explains the muscle force generation velocity, while Duntsh and Stoboy 1966 (Duntsh & Stoboy 1996) explain this phenomenon by the increased number of active motor units and (or) increased frequency of the impulses reaching the muscle. Neural disinhibition causes an increase in the motor units recruitment velocity by controlling the release and diffuse rate of the Ca^{++} ions and controlling inhibition of the troponin - tropomyosin complex in muscle fibers, which essentially represents a muscle fiber disinhibition; then, there is an increase in the level of synchronization of the muscle motor units functioning, change in the motor units recruitment pattern, whereby the first involved are the highest firing rate motor units, and muscle force, (intramuscular coordination).

Also, increased is the intramuscular coordination and reprogramming (by increasing) the limits of muscle force of all the motor units above the maximum measured on standard tests. (Milošević & Milošević, 2010, 2013, 2014; Milosevic, et al., 2000a, 2004, 2012, 2014a,b,c, 2016; Rodacki, Fowler, & Bennett, 2002; Sheppard, Nolen, & Newtton, 2012: Zatsiorsky, & Kramer, 2006). By increasing the motor units recruitment velocity, their synchronization, intra and intermuscular coordination and muscle force level of the individual groups of motor units, muscle force generation velocity and level are increased, as well as the velocity of its generation changes. The above mentioned increases cause an increase in the maximum muscle force production velocity and its production change velocity.

In addition to initiating disinhibition mechanism in the course of training, listed parameters on which the force depends can be developed by initiating the specific mechanisms of their adaptation thus achieving their high intensity and arrangement in a time interval ranging from 0.005 s to 0.082 s, which is determined by the spike characteristics (Friedebolit et. al., 1957; Duntsh and Stoboy 1996; Milošević & Milošević, 2010, 2013, 2014; Milosevic, et al., 2000a, 2004, 2012, 2014a,b,c, 2016;

Rodacki, et al., 2002; Stoboy et. al., 1959; Zatsiorsky, & Kramer, 2006). The best results in the development of muscle force generation velocity, the maximum muscle force of certain groups of motor units, motor units recruitment velocity, muscle force generation velocity change, motor units work synchronization are achieved through training using maximum work speed, lifting free weights (load), through jumps, leaps, landings, landing jumps, and sprints with direction changes (Milošević & Milošević, 2010, 2013, 2014; Milosevic, et al., 2000a, 2004, 2012, 2014a,b,c, 2016), in the reversible contraction in landing jumps from 60 cm, then in landing block (brutal plyometrics) from the height of 120 to 200 cm, and weight training 80% and 100% of 1RM most intensively develops maximum muscle force generation velocity. Development of the maximum muscle force of the muscle groups as well as the maximum muscle force of the certain groups of motor units is achieved in a reversible contraction using weights and applying different training methods (Milošević & Milošević, 2010, 2013, 2014; Milosevic, et al., 2000a, 2004, 2012, 2014a,b,c, 2016). The most commonly used weights are those of 30%, 40%, 50%, 70%, 75%, 80%, 85%, 90%, 95%, 97%, 100%, 130% and 150% of the 1RM which are lifted at the maximum velocity in different combinations (Milošević & Milošević, 2010, 2014; Milosevic, et al., 2014a,b,c, 2016). To develop the maximum muscle force of all groups of motor units following weights are used of 90%, 95%, 97% to 100%, 130% and 150% (Milošević & Milošević, 2010, 2014; Milosevic, et al., 2014a,b,c, 2016).

To develop the maximum muscle force of a group of motor units of the high and the highest level of muscle force generation weights of 80%, 85%, 90 and 95% or 100%, 95% and 85% are used (Milošević & Milošević, 2010, 2014; Milosevic, et al., 2014a,b,c, 2016). To develop the maximum muscle force of the motor units of the medium, large and maximum levels of muscle force generation weights of 75%, 80%, 85%, 95% are used (Milošević & Milošević, 2010, 2014; Milosevic, et al., 2014a,b,c, 2016). Only for the motor units of the maximum level of muscle force generation the weights of 80%, 85%, 90%, 95% are used, and for the lowest level of motor unit muscle force generation the weights of 30% to 50% of 1RM are used (Milošević & Milošević, 2010, 2014; Milosevic, et al., 2014a,b,c, 2016).

In the reversible contraction landing jump from the height of 76 cm and weight lifting 70% of 1RM most intensively develop the motor units recruitment velocity (Milošević & Milošević, 2010, 2014, Milosevic, et al., 2012, 2014c). With 85% of the maximum weight lifted in one elevation (1RM), at a maximum speed of lifting and in landing jumps from the height of 80 cm most intensive changes in the muscle force generation occur, together with the most intense process of creating proteins actin and myosin, but there is also an increases in both inter and intramuscular muscle coordination and the level of changes in the muscle force generation (Milosevic & Milošević, 2010, 2014, Milosevic, et al., 2012, 2014c). The highest level of motor units work synchronization is achieved in landing drop jump-block (brutal plyometrics) from the heights of 120 to 200 cm, lifting the maximum weights (100% 1RM), at the maximum speed, and movement direction changes from sprints (Milošević & Milošević, 2010, 2014, Milosevic , et al., 2012, 2014c). Training optimization of motor units functioning in intermuscular and intramuscular level is achived using weights and varying the speed of lifting and weight of barbells in a series (Milošević & Milošević, 2010, 2014; Milosevic, et al., 2014b,c, 2016). The most commonly used weights are those of 30%, 40%, 50%, 70%, 75%, 80%, 85%, 90%, 95% and 100%. The excellent results of the optimization of motor units work in the intermuscular and intramuscular level and development of the maximum muscle force for certain groups of motor units are achieved by various combinations of the leaps, jumpings, landings, landing drop jumps (Milošević & Milošević, 2010, 2014, Milosevic, et al., 2014c).The most common combinations in jumps or leaps are the heights of 60% to 100% and lengths from 40% to 100% of the maximum. In landing release heights of 30 to 80 cm are combined, in landng spring upward height of 100 to 170 cm are combined. In optimization conditions, with the aim of achieving disinhibition effect landings from the height of 100 to 200 cm and landing jumps -block from a height of 120-200 cm are used (Milošević & Milošević, 2010, 2014, Milosevic, et al., 2014c). The best training results are achieved if presented laws are used and if the training is programmed specifically for each individual athlete (Milošević & Milošević, 2010, 2013, 2014; Milosevic, et al., 2000a, 2004, 2012, 2014a,b,c, 2016). Training sessions are programmed to last for four weeks on the basis of the current state of each volleyball player (Milošević & Milošević, 2010, 2013, 2014; Milosevic, et al., 2000a, 2004, 2012, 2014a,b,c, 2016). After each month of the training application regardless of how it is directed, diagnostics should be repeated and the existing training reprogrammed, that is the new one should be designed, suitable to the current status with the potential to result in the planned changes.

During each training session all the relevant muscle groups are treated. Monthly training sessions are designed in such a way to develop motor units recruitment velocity in the first week, the muscle force generation velocity and optimization of motor units at the intramuscular level and increase in the level of diffusion speed of Ca ++ ions and their removal (Milošević & Milošević, 2010, 2014; Milosevic, et al., 2014b,c, 2016).

In the second week the maximum force of certain groups of motor units, that is muscle groups, is developed, as well as the muscle force generation velocity and optimization of the motor units at the intramuscular level (Milošević & Milošević, 2010, 2014; Milosevic, et al., 2014b,c, 2016).

In the third week disinhibition mechanisms are developed, then the optimization of motor units in the intramuscular level, muscle density and the speed of Ca ++ ions diffusion are also increased (Milošević & Milošević, 2010, 2014; Milosevic, et al., 2014b,c, 2016). In the fourth week the work on the development of motor units synchronization is emphasized, also the optimization of the motor units at the inter and intramuscular level as well as the disinhibition mechanisms are focused on (Milošević & Milošević, 2010, 2014; Milosevic, et al., 2014b,c, 2016). The amount of work for any athlete per training session is designed in relation to his or her current status (Milošević & Milošević, 2010, 2013, 2014), capacity (Milosevic et al., 2016), functions by which to develop or maintain force (Milošević & Milošević, 2010, 2013, 2014; Milosevic, et al., 2014a,b,c) the effects and the changes that are meant to occur, that is, the definition of the objectives of training one wants to achieve (Milošević & Milošević, 2010, 2013, 2014).
Muscle force development lasts each year for eleven months of the annual cycle (Milošević & Milošević, 2010, 2013, 2014).

In principle, the development of muscle force takes years and years of work (Milošević & Milošević, 2010, 2013, 2014), that is until the achievement and realization of the volleyball players genetic capacity is accomplished (Milosevic et al., 2016) according to the dynamics specific to each individual. Once this capacity is reached one starts programming of the training with the aim to maintain the achieved level of muscle force. In elite volleyball players, along with other training sessions, to develop muscle force two sessions a week are needed, between which there is a break of 72 hours (Milošević & Milošević, 2010, 2013, 2014; Milosevic, et al., 2014a,b,c, 2016). Each training session lasts for a maximum of an hour with a great amount of work (Milošević & Milošević, 2010, 2013, 2014; Milosevic, et al., 2014a,b,c, 2016). This approach is used when volleyball players do not have scheduled competitions or have just one competition (a match) a week. When they have two or three competitions (matches) a week the muscle force trainings are not recommended.

Conclusion

Based on the performed biomechanical and functional analyses it can be concluded that for the muscle force production in spike and landing one uses eccentric contraction but in all other cases a reversible contraction is used. Also, it was found that in order to achieve good results in spike, elite volleyball players need to have a developed muscle force production of all muscle groups involved in the realization of spike, further on they have to develop the recruitment velocity and synchronization of the motor units work, the maximum force of certain groups of motor units, the muscle force production velocity change, inter and intramuscular coordination. The maximum values of the cited values in spike in elite volleyball players are achieved in a time interval of 0.005 s to 0.082 s. The maximal muscle force production velocities in spike in elite volleyball players range from 3440.00 daN·s^{-1} to 14988.69daN·s^{-1} at motor units recruitment velocities from 22.00 IU to 95.0 IU. The force of certain groups of the knee extensors motor units in elite volleyball players ranges from 1.09 daN to 105.14 daN. In landing vertical jumps elite volleyball players synchronize up to 94.7% of the leg extensors motor units. The greatest impact on the enormously large muscle force production along with the shortening of the time of its generation in a reversible contraction, in all stages of the service and the spike, is attributed to a neural component of the muscle contraction, primarily to the disinhibition process at all levels. Finally, in accordance with the results of the analyses, a methodology of the muscle force development is suggested whereby besides learning how to master disinhibition process one composes a set of all required parameters on which the level and velocity of muscle force generation depends, concerning a daily, weekly, monthly and annual basis, by utilising special means and methods.

References

Amanovic, D., Milošević, B.M., Mudrić, R., Dopsaj, M., & Peric, D. (2006). Modeling Variability of the Assigned Level of Force During Isometric Contractions of the Arms Extensor Muscles in Untrained Males. *Facta universitatis – Series: Psysical education and sport*, *4*(1): 35-48.

Amasay, T. (2008). Static block jump techniques in volleyball: upright versus squat starting positions. *Journal of Strength and Conditioning Research*, *22,* 1242-1248.

Bobbert, M.F., Gerritsen, K.G, Litjens, M.C., & Van Soest, A.J. (1996). Why is countermovement jump height greater than squat jump height? *Medicine and Science in Sports and Exercise, 28*, 1402-1412.

Djurović, T., Marelić, N., Hraski, Ž., & Šikanja, Lj. (2005). Kinematical analysis of the front and back zone spike in volleyball. *Športskomed Vjesn*, *20*, 20-25.

Duntsch, G., & Stoboy, H. (1966). Das Verhalten von Kraft und Ausdauer wahrend eines isometrischen Trainigs in Abhangigheit von der Muskelmasse. [The behavior of strength and endurance during isometric training in Abhangigheit of muscle mass.. In German.]. *Sportarzt Sportmedizin*, *10*, 499-504.

Friedebolt, G., Nussgen,W., & Stoboy, H. (1957). Die veranderung der elektrischen aktivitat der Skelettmuskulatur under den Bedingungen eines isometrischen Trainings. [The changes in the electrical activity of skeletal muscle under conditions of isometric training.. In German.]. *Z. ges. Exp. Med.*, *129*, 401-411.

Gavrilović, P. (1992). *Komparativna analiza karakteristika prelaznog režima generisanja mišićne sile kod sportista različite sportske orijentacije pri voljnim kontrakcijama u dinamičkim uslovima naprezanja mišića.* [Comparative analysis of transitional regime of force development in athletes competing in different sports with willing contractions and dynamic muscle work. In Serbian.]. PhD Thesis, Belgrade: Faculty of Sport and Physical Education.

Ivančević, V., & Ivančević, T. (2006). *Natural biodynamics*. Singapore: World Scientific.

Milošević, B.M., Blagojević, M., Pilipović, S., & Tošić, B. (2000). The muscle contraction and the force production. *Proceedings of the XVIII International symposium of biomechanics in sport*, (pp. 183-186.), Hong Kong: Youlian Hong & David P. Johns.

Milošević, B.M., Blagojević, M., Tošić, B., & Pilipović, S. (2000). The Behavior of Muscles in External Instantaneous Force Fields. *Proceedings of the XVIII International symposium of biomechanics in sport*, (pp. 179-183.), Hong Kong: Youlian Hong & David P. Johns., pp. 179-183.

Milošević, M., Mudrić, R., Dopsaj, M., Blagojević, M., & Papadimitriou, E. (2004). The control of force creating in function of the muscle contraction intensity, *4th International Conference on Strength Training: Book of Abstracts*, (pp. 320–321.), Edited by: Kellis, E., Amiridis, I and Vrabas., I, Aristotle University of Thessaloniki, Department of Physical Education and Sport Science at Serres, Serres, Greece.

Milošević, B.M., & Milošević, M.M. (2010). *Physical Preparation of Elite Athletes: Standardization of Management Processes*. Belgrade: APP.

Milošević, M.M., Mudrić, M., Mudrić, R., & Milošević, B.M. (2012). Using the mind in reprogramming the limits of muscle force in the process of creating champions. *Sport science & practice, 2*(5), 39-58.

Milošević, B.M., & Milošević, M.M. (2013). Model for assessing the physical status, as well as prediction and programming of training and sports performance of a soccer player. *Journal of Physical Education and Sport, 13*(4), 479–488.

Milošević, B.M., Nemec, M.P., Životić, R.D., Milošević, M.M., & Rajović, D.R. (2014). Force distribution model of motor units of leg extensor muscles. Journal of Sports Sciences, 2(3), 195-199.

Milošević, B.M., Milošević, M.M., Nemec, M.P., Životić R.D. & Rađo, I. (2014). A new approach to development of human maximal muscle force. *Journal of Exercise Physiology online*, *17*(5), 70-80.

Milošević, B.M., Džoljić, E., Milošević, M.M., Yourkesh, M., & Behm, G.D. (2014). The Analysis of Muscle Force Development with Trained and Elite Athletes. *Physiology*, *24*(1-81), 5-12.

Milošević, B.M., & Milošević, M.M. (2014). *Special physical education: Textbook on the management of the construction of the physical integrity and capacity of police officers*. Saarbrücken, Germany: LAP Lambert Academic Publishing.

Milošević, B.M., Nemec, V., Yourkesh, M., Nemec, P., Milošević, M.M., & Behm, G.D. (2016). Determination of capacity and rules of the variability of maximum force using nonlinear mathematical models: a case study. *International Journal of Sport Studies, 36,* (S1)

Rodacki, A.L., Fowler, N.E., & Bennett, S.J. (2002). Vertical jump coordination: fatigue effects. *Medicine & Science in Sports & Exercise*, *34*(1), 105-116.

Sheppard, J., Nolen, E., & Newtton, R. (2012). Changes in Strength and Power Qualities over Two Years in Volleyball Players Transitioning from Junior to Senior National Team. *J of Strength and Conditioning Research*, *26*(1), 152-157.

Stoboy,H., Nussgen, W., & Friedebolt, G. (1959). Das Verhalten der motorrischen Einheiten unter den Bedingungen eines isometrichen Trainings. [The behavior of the motor units under conditions of isometric training. In German.]. *Int. Z. agnew Physiol. Arbeitsphysiol*, *17*, 391-399.

Tillman, M. D., Hass, C. J., Brum, D., & Bennett, G. R. (2004). Jumping and landing techniques in elite women's volleyball. *Journal of Sports Science and Medicine, 3*, 30-36.

Tomić, D., & Nemec, P. (2012). *Volleyball in theory and practice.* Beograd: SIA.

Wagner, H., Tilp, M., Von Duvillard, S., & Muller, E. (2009). Kinematic Analysis of Volleyball Spike Jump. *International Journal of Sports Medicine*, *30*(10), 760-765.

Zatsiorsky, V.M., & Kramer, W.J. (2006). *Science and Practice of Strength Training*. Champaign, IL.: Human Kinetics.

PROIZVODNJA I RAZVOJ MIŠIĆNE SILE U SMEČU KOD ELITNIH ODBOJKAŠA

Sažetak

Cilj ovog istraživanja je otkrivanje mehanizama generacije mišićne sile u smeču i određivanje metodologije njenog razvoja u tečaju elitnih odbojkaša. U ovu svrhu izvedene su biomehaničke i funkcionalne analize generacije mišićne sile i preložena je metodologija njenog razvoja. Ekscentrična kontrakcija korištena je za generaciju mišićne sile u smeču u slijetanju, međutim, u svim ostalim slučajevima koristi se reverzibilna kontrakcija. Za postizanje dobrih rezultata u smeču, pojedinac mora imati razvijenu generaciju mišićne sile svih mišićnih skupina uključenih u realizaciju smeča, zatim dobro razvijenu brzinu zapošljavanja motornih jedinica i dobru sinkronizaciju svog rada, maksimalnu silu određenih grupa motornih jedinica, promjenu brzine generacije mišićne sile te inter i intramuskularnu koordinaciju. Maksimalne vrijednosti specifiranih parametara kod elitnih odbojkaša postignute su u vremenskom intervalu opsega od 0,005 s do 0.082 s. Maksimalne proizvodne brzine mišićne sile kod elitnih odbojkaša su u opsegu od 3440.00 daN$\cdot$s^{-1} do 14988.69daN$\cdot$s^{-1} brzine zapošljavanja motornih jedinica u opsegu od 22.00 IU do 95.0 IU. Snaga određenih skupina motornih jedinica ekstenzora koljena kod elitnih odbojkaša je u opsegu od 1.09 daN do 105.14 daN. Tijekom skoka s okomitim slijetanjem elitni odbojkaši sinkroniziraju i do 94.7% motornih jedinica ekstenzora nogu. Najveći utjecaj na ogromno povećanje u mišićnoj sili, zajedno s vremenom skraćivanja u svojoj generaciji u reverzibilnim kontrakcijama u servisu pripisuje se procesu disinhibicije na svim razinama. U skladu s rezultatima analize, predlaže se metodologija razvoja mišićne sile, u kojoj je, u dodatku sa savladavanjem procesa disinhibicije, smišljen cijeli set traženih parametara, o kojem razina i brzina generacije mišićne sile ovise na dnevnoj, tjednoj, mjesečnoj i godišnjoj bazi, primijenjujući prikladna sredstva i metode za svaki osobiti parametar.

Ključne riječi: *odbojka, sila, brzina, motoričke jedinice, sinkronizacija,*

Received: February 17, 2016
Accepted: August 10, 2016
Correspondence to:
Milenko B. Milošević
Faculty of Management in Sport,
Alpha BK University,
3 Palmira Toljatija Street, 11000 Belgrade, Serbia
e-mail:mlsvc2010@gmail.com
Phone:+381 11 2606380