STUDIA UBB EDUCATIO ARTIS GYMN., LXII, 4, 2017, pp. 87 - 102
(RECOMMENDED CITATION)
DOI:10.24193/subbeag.62(4).36

VERTICAL JUMP ENHANCEMENT WITH RESPECT TO VOLLEYBALL VERTICAL JUMP

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ABSTRACT. The purpose of next review is to present the knowledge gained about the mechanical and physiological aspects that responsible for vertical jump (VJ) height, as well as the general training methods for VJ enhancement, with specific reference to volleyball players. Several intertwined aspects determine VJ capacity: muscle power, neural properties and elastic properties of muscles and tendons. Three major methods for enhance VJ are discussed in this review: Plyometric training (PT), which involve jumping, hopping, and skipping and reinforces muscle's neural activity and the ability to restore elastic-energy; Electromyostimulation (EMS), which increases the ability to recruit muscles' motor units; And resistance training (RT), which is usually performed using weights and increases muscles' power generation. These methods complement one another and therefore present the best results when integrated. In addition, part of the reviewed studies claims for even better VJ enhancement when RT are performed in the VJ pattern. Therefore, ballistic RT and Olympic weight-lifting (snatch, clean and jerk) in relatively low resistance (30-50% of IRM) at high velocity are preferable as RT for VJ enhancement. The effect of PT and RT, when integrated into specific volleyball training, even increases VJ because this specific leg power training can be transferred more efficiently into a volleyball specific VJ.

Keywords: *Vertical Jump, Plyometric Training, Stretch-Shortening Cycle Electromyostimulation, Resistance Training, Ballistic Resistance Training.*

Introduction

Volleyball is considered one of the most explosive and fast-paced sports (Stanganelli et al., 2008). For example, according to data examined among elite male players, they have performed between 250 to 300 actions requiring

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explosive force production during a five-game match. The vertical jump (VJ) constitutes most of these actions (Hasegawa et al., 2002). Of these activities, the attack and block situations represent 45% of the total actions of the game and are also responsible for 80% of the points obtained within international matches (Voigt & Vetter, 2003). Setting for spike in high level volleyball, is also performed by VJ to shorten the flight time of the ball in the transition from passing to attack or from defense to offence (Borràs et al., 2011).

The range of VJ is wide and ranges from 65 to 136 average VJ per five-game match, according to the following roles: the setter jumps the highest number of jumps: 136 VJ, but the jumps for setting are not performed with maximum force. The centers (middle blockers) perform 97 VJ, the opposite perform 88 VJ and the left side hitters 65 VJ. A major part of the VJ of all players are block jumps (Fontani et al., 2000; Borràs et al., 2011). The performance of volleyball VJ skills, attack and block, as well as jump service, depends on the height at which these motor actions occur in relation to the height of the net and is determined by the capacity of the athlete to raise vertically his center of gravity. Thus, when planning volleyball training practices, one of the main objectives is the development of the VJ capacity (Stanganelli et al., 2008).

In aim to develop effective training programs to enhance jump capacity of adult volleyball players, volleyball coaches, strength and conditioning coaches, athletic trainers, and physiotherapists, who work regularly with the players throughout the training program, should obtain relevant information on physical and physiological aspects of VJ in volleyball (Ziv & Lidor, 2010). Therefore, the purpose of the next review is to present the knowledge gained about the mechanical and physiological aspects that responsible for VJ height and what are the general training techniques for high VJ development, with specific reference to volleyball players. The review will also address the methods of measuring VJ in general and specifically for volleyball players.

Factors affecting VJ performance

VJ performance is determined by a complex interaction among several factors including maximal force capacity, rate of force development and the mechanism of stretch-shortening cycle (SSC) (Baker, 1996). VJ performance is affected by both muscular and neural aspects. In order to jump higher, the greatest vertical acceleration should be achieved before leaving the ground. This acceleration will create the greatest initial vertical velocity. The greater this velocity is, the higher the center of mass that will be reached. In aim to achieve the greatest vertical acceleration, the player needs to create as much force as possible over the shortest period of time. By increasing muscle strength on one hand and by training neural mechanisms (e.g., muscle spindle and stretch reflex) on the other hand, the player can enhance her or his VJ (Ziv & Lidor, 2010).

Some of the physiological aspects, affecting VJ height, can be studied from the effect of Post-activation Potentiation (PAP) which, under certain conditions, affect immediately and positively VJ height. PAP refers to the acute enhancement of muscular function as a direct result of its contractile short history (couple of minutes prior to an explosive movement) (Dello Iacono et al., 2015). It is also defined as an increase in muscle performance after a conditioning contraction. The conditioning contraction could be a maximal voluntary contraction, (Hamada et al., 2000), or a series of evoked twitches (Sale, 2002). It has been shown consistently that such conditioning stimuli can increase twitch contractions, rate of force development and explosive movements. With relation to VJ an example of PAP is an acute enhancement in the VJ height, occurs immediately (2-5 minutes) after high load resistance action, which is usually carried out using weights (3RM) (Xenofondos et al., 2010; Robbins, 2005; de Villarreal, 2007; Güllich & Schmidtbleicher, 1996).

The VJ factors that are enhanced under the effect of PAP, are teaching about the characteristics that generate higher VJ capacity (1) People with leg muscles of higher percentage in type II motor units (fast twitch muscle fibers), exhibit greater PAP (Hamada et al., 2000) and therefore, higher VJ (Xenofondos et al, 2010). This is because type II motor units undergo greater phosphorylation of myosin regulatory light chains then slow twitch muscle fibers and as a result, develop greater force production per single fiber (Moore and Stull, 1984; Sweeney, 1993; Zhi et al., 2005). In addition (2) the neural effect: PAP increases the recruitment of higher percentage of fast twitch muscle fibers. Athletes with higher recruitment capacity of type II motor units exhibit faster explosive movement, greater potentiation and therefore higher VJ, this is due to greater twitch force and H-reflex (Hodgson et al, 2005). H-reflex is analogous to the stretch-reflex which stimulates muscle-spindles as a respond for muscle fibers stretching throughout the eccentric phase of VJ (Ziv & Lidor, 2010). From the above, it implies that chronic enhancement in both muscle fiber's force production and increasing in type II (especially type IIb) motor units' recruitment, have major role in generating higher VJ.

Third important contribution for VJ height is the SSC mechanism which describes an eccentric phase or stretch followed by an isometric transitional period (amortization phase), leading into an explosive concentric action. The SSC explains why VJ that preceded by a countermovement or a pre-stretch, increases vertical displacement above a squat jump (one with no pre-stretch). During hopping, jumping, and running. In this manner, for example, our legs exhibit similar characteristics to a spring, whereby the leg spring compresses on ground contact and stores energy, before rebounding at push-off and releasing energy. It is currently recognized that the tendon is the primary site for the storage of elastic energy (Turner & Jeffreys, 2010). These authors indicate that there is connection between the stretch reflex (muscle spindles), neural property, and SSC in the eccentric phase. However, in an untrained athlete, the stretch reflex is in fact acting but as a counter-reaction and as a defense mechanism, in which Golgi tendon organs moderate the stretching reflex. Gradual plyometric training, which will discuss later, moderates this Golgi tendon organs reaction and enables stretch reflex to be significant in creating a higher VJ.

To conclude, three physiological and mechanical aspects should be taken into consideration when physiological manipulation is required to enhance VJ capacity: Muscle power, neural properties and elastic properties of muscles and tendons. These characteristics work together in every VJ, in every sport that VJ are part of it.

Vertical jump tests

Many tests that measure leg force production use VJ as a manifestation of this capacity, because of the simplicity of its performance. At most of the studies, three types of VJ are examined: Squat Jump (SJ), carried out without any pre-movement, from approximately °90 in the knee angle, neutralizes the eccentric contraction phase in the leg's extensor muscles; Counter-Movement Jump (CMJ), carried out as a regular standing VJ, with or mostly without the swing of the hands (hands kept on waist), with the pre-eccentric contraction phase in the leg's extensor muscles; Drop Jump (DJ), mostly carried out while dropping from 40cm height, with or mostly without the swing of the hands. This VJ is carried out while overcoming the braking force with the immediate transition to jump. CMJ integrates, in addition to muscle force production, the stretching reflex and SSC as mentioned before and DJ is an extension of the CMJ which is reflected in plyometrics and in the use of muscles and tendons stored elastic energy. Plyometrics will discuss later as an important training technique for VJ enhancement. On the other hand, SJ neutralizes stretching reflex and SSC and enables to measure only the leg extensors power (Komi & Bosco, 1978; Bosco et al. 1982, 1986; Baker 1996).

However, in researches that conducted on volleyball players, the specific volleyball VJ volleyball attack jump (VAJ) and volleyball block jump (VBJ), were tested in addition or separately from the traditional VJ tests (Newton et al., 1999; Newton et al., 2006; Ziv & Lidor, 2010). Stanganelli et al (2008) took it even farther and suggested that using VAJ and VBJ tests seem to be more sensitive to the training-induced adaptations and better reflect the specificity of volleyball game then the traditional VJ tests. In fact, VBJ is performed similarly to CMJ without arm swing and VAJ is a combination of DJ and CMJ. These VJ can be a valid measurement instrument, instead of the traditional VJ among volleyball players (Sattler et al., 2012).

Methods for the improvement of VJ

Various training methods have been applied to enhance VJ. The methods that will be reviewed relate to plyometric training (PT), electromyostimulation (EMS) and resistance training (RT), which is usually performed using weights.

Plyometric training

Since the improvement of the elastic properties of the tendon-muscle has an important role in the whole enhancement of VJ capacity, PT tends to be the most influential factor in enhancing the VJ height. PT constitute a natural part of most sport movements because they involve jumping, hopping, and skipping (i.e., such as high jumping, throwing, or kicking) (Bauer et al, 1990).

PT come in various forms depending on the purposes of a training program. Typical plyometric exercises include the CMJ, the drop jump (DJ). These exercises can be either combined within a training program or can be applied independently. Furthermore, plyometrics can be performed at various intensity levels, ranging from low-intensity double-leg hops to high unilateral-intensity drills. As far as the lower body is concerned, plyometrics includes the performance of various types of body-weight jumping exercises, such as DJ, CMJ, alternate-leg bounding, hopping, and other SSC jumping exercises. These exercises are characterized by SSC actions; that is, they start with a rapid stretch of a muscle (eccentric phase) and are followed by a rapid shortening of the same muscle (concentric phase) and ends by maximal force at the detachment of the ground (de Villarreal et al, 2009; Bobbert, 1990; Markovic, 2007).

More about the effect of PT we can learn from the meta-analytical review by Markovic (2007) of total 26 studies, yielding 13 data points for SJ, 19 data points for CMJ, 14 data points for CMJ with arm swing and 7 data points for DJ. The analysis of the gathered data demonstrates that PT provides both statistically and practically, relevant significant enhancement in VJ height with the mean effect ranging from 4.7% for SJ and DJ, over 7.5% for CMJ with the arm swing and 8.7% for CMJ hands kept on waist. The author suggests that the effects of PT are likely to be higher in slow SSC vertical jumps like CMJ and CMJ with the arm swing, rather than in either concentric jump only like SJ, or fast SSC jump like DJ.

De Villarreal et al (2009) concluding that athletes with more experience in a specific sport, are better responding to combinations forms of PT and obtained greater enhancements in VJ height. This does not mean that subjects in both good or bad physical condition cannot benefit also from PT. These authors add that men obtain better power results than women using PT. In addition, they indicate that the training volume of more than 10 weeks (with more than 20 sessions), using high intensities (with more than 50 jumps per session), is the optimal strategy that maximize one's probability of obtaining significant VJ enhancement.

Electromyostimulation training

Short term of neuromuscular electrical stimulation (EMS) protocols, known as electromyostimulation, such as those commonly used in rehabilitation medicine, can increase strength in healthy muscles. Although the magnitude of the increase is no greater than the enhancement that can be achieved with voluntary training, the increases can be achieved in considerably less time (Enoka, 1988). In the recent years, it has also been used by athletes in the context of training programs to develop strength and physical performance (Malatesta et al., 2003).

EMS training, is an involuntary resistance training, that induce both neural and muscular adaptations in healthy humans (Gondin et al., 2005). EMS, is generally delivered to the muscle in static conditions (without functional movement occurring) and at sufficiently high current intensities to evoke visible muscle contractions (beyond motor threshold). EMS is an effective strength training tool for healthy subjects and athletes, since its chronic use may induce neuromuscular adaptations similar and complementary to voluntary strength training (Maffiuletti et al., 2011). EMS found as an effective training in sports where high VJ is important in the general functioning of the athletes (Malatesta et al., 2003; Babault et al., 2007; Maffiuletti et al., 2000).

Maffiuletti et al (2000) found in basketball players 14% increase in SJ after four weeks and 12 EMS trainings and 17% enhancement in CMJ after four more weeks of regular trainings, by comparison to baseline. Malatesta et al. (2003) found in volleyball players that ten days after the end of 4-weeks EMS training program, the jumping height significantly increased compared to baseline: SJ 6.5% and CMJ 5.4%. The authors claim that sport-specific workouts following EMS would enable the central nervous system to optimize the control to neuromuscular properties. It implies that EMS training has a long-term effect on VJ enhancement.

Resistance training

In aim to maximize athletic explosive performance like VJ, athletes should increase strength in the hip, knee, and ankle joints and improve the rate of force development training with relatively low resistance (30-50% of IRM) at high velocity. This effect the increase in the rate of force development and the gains in strength, in specific sports (Newton et al., 1999; Thompson et al., 2007). Although traditional RT has been shown to improve VJ performance as much as 2-8 cm or 5-15%, it seems that lighter and more explosive lifts, may be more effective than heavier lifts that are performed at lower velocities (Fatouros et al., 2000).

Channell and Barfield (2008), have compared between the contribution of the olympic weight-lifting (snatch, clean and jerk) (OL) and the traditional RT to VJ enhancement. They concluded that traditional exercises, such as squats and squat variants, have been determined to be excellent exercises for improving lower-body strength. However, they have a low correlation to VJ performance. In addition to other several studies (Garhammer & Gregor; 1992, Garhammer; 1993, Kraemer & Newton. 1994) they indicate that the pattern of OL movements is similar to the pattern of VJ. This explain why weight-lifters have been shown to have a higher VJ and power output compared to other athletes (Kraemer & Newton. 1994). Therefore, OL movements have been considered as more specific to VJ than the traditional RT and more effective for improving VJ capacity (Garhammer & Gregor. 1992, Garhammer. 1993). Coaches of OL are in general agreement that the most rational technique for executing competitive lifts, is including phases that can be characterized as jumping vertically but with a barbell (Garhammer and Gregor, 1992).

The specificity of training model suggests that RT exercises to enhance VJ, should be performed by similar movement patterns and joint angels as the VJ. This will elicit the greatest improvement in VJ performance (Baker. 1996; Semenick & Adams. 1987). In contrast to traditional low speed power lifts, ballistic resistance exercises like OL, moving with lower resistance at higher velocities and results in acceleration through the entire movement. This may launch an object or the body, fast into free space (Newton and Kraemer. 1994). Ballistic resistance training is the dynamic weight training, performed at the load that maximizes mechanical power output. This training strategy involves lifting relatively light loads (approximately 30% of maximum) at high speed (Wilson et al., 1993). Low-resistance ballistic exercises may produce smaller gains in strength, compared with heavy resistance training, but they also may produce significantly higher gains in speed strength or power as measured by the force-time curve (Young, 1993).

Strength and force production in sport are influenced by a range of neuromuscular factors. It means that muscle performance is determined by a combination of muscle cross-sectional area and the extent to which the muscle mass is activated, that is the neural factors. General strength training might be beneficial for athletes because of the potential to enhance force-generating capability of the muscle, which leads to increasing in muscle's mass, which reduces the risk of sports injuries and enhance core stability. However, direct conversion to enhance specific sport performance might be limited by such training in experienced athletes. Although nonspecific resistance training can induce neural adaptations and increase the force production of individual muscles, it appears that in aim to maximize transfer to specific sports skills, training should be as specific as possible, especially regarding to movement pattern and contraction velocity. The specific training may enhance intermuscular coordination and may ensure that muscles are "tuned" to any newly acquired force-generating capacity (Young 2006).

Whilst the role of special strength training is often seen to be that of "converting" strength into power, the role of specific strength exercises is thought to be to further convert power into the actual specific jumping requirements of the sport. For example, an increase in maximal squat jumping power will transfer only slightly across a sport specific VJ. However, when it integrated with some specific jump training, the increase in jumping power may transfer across to a sport specific VJ by as much as 78% (Baker, 1996).

Integrated methods to enhance VJ

Although each one of the three methods for VJ enhancement has validated to enhance VJ without integrating another method, combination of methods creates even higher enhancement. Adams et al (1992) compared the effectiveness of three training programs: squat (RT), PT and squat plus PT, in increasing hip and thigh force production as measured by VJ. After 14 trainings, the mean results showed: Squat group increased VJ in 3.30 centimeters, PT group increased VJ in 3.81 centimeters and the squat and PT group increased in 10.67 centimeters. The authors indicate that both squat and PT training are necessary for improving hip and thigh force production as measured by VJ ability.

Toumi et al. (2004a,b) suggest that a change in maximal strength and/or explosive strength training does not necessarily creates changes in combined movement such as the SSC, which is an important factor in CMJ or any jump that involves eccentric phase, transition isometric phase and concentric phase. Thus, among the variety of the RT methods, specificity of training is considered as an important criterion to determine optimal training strategies for the enhancement of VJ. The authors suggest that the combination of resistance training and VJ training will provide a significant improvement in VJ height, which has a combination of SSC mechanism. This mechanism is involved in all jump styles in all ball games.

Wilson et al. (1996) found that Plyometric training enhance the rate of eccentric lower body force production, while weight-training primarily enhance concentric function. De Villarreal et al (2009) add that PT significantly improves VJ height when it integrates several forms of plyometrics and the most beneficial PT should also integrate versions of SJ, CMJ and DJ. An original way to overload leg muscles and integrate it into VJ training is to practice on sand. Mirzaei et al (2014) found that performing DJ, as manifestation of PT, with CMJ training on sand, two days a week for six weeks improved significantly DJ and CMJ, 16.2% and 13.5% respectively.

Arabatzi et al (2010) studied the combination of RT and PT regarding to the periods of the whole season. They suggest that PT, OL and a combination of PT and OL are affecting positively VJ enhancement. They claim that OL exercises are more appropriate in pre-competition period, PT are more appropriate in the competitive period and the combination of OL and PT are practically useful to allow an easy transition from OL to the sport-specific exercises at the transition from preparatory period to competitive period.

Integrated methods to enhance VJ in volleyball players

Because volleyball is a game of jumping in its nature, each one or combination of the three methods (PT, EMS and RT) for VJ enhancement are in fact, integrated into jumping exercises that are part of the volleyball trainings and the nature of the game. Borràs et al. (2011) conducted a longitudinal descriptive study in a purpose to assess the physical state of male volleyball players. They compared their VJ heights along three consecutive seasons. The results of the study showed an increasing through the years for the two volleyball jumps, VAJ and VBJ.

The results found a progress in explosive strength, elastic-explosive strength, reflex-elastic-explosive strength, and arm use. This knowledge supports the fact that volleyball players should train all these properties that affect VJ height. This knowledge is also reinforcing the approach of integrating the methods for VJ enhancement. Stanganelli et al. (2008) indicate the necessity of PT in most of the integrated methods. They support the contention that the elastic properties of the muscle, which are trained mostly by PT, are important factors to enhance VJ height for volleyball players. Thus, training these properties should receive top training priority among volleyball players.

Marques et al (2008) tested a 12-week RT program for elite female volleyball players. Over 12-week in-season, the athletes performed 3–4 sets of 3–8 repetitions of ballistic type RT exercises and PT exercises during each training session. By the end of the period the researchers found an improvement of 3.8% in CMJ. Nonetheless, they suggest that caution is warranted even with elite players, to avoid overtraining, especially during the in-season. Moderate-intensity RT in combination with low-volume power drills maybe useful methods for enhancing VJ.

Several studies were dealing with the integration of EMS with PT. SSC, which is an important mechanism in the PT activity and the ability to tolerate high stretch loads, as in the DJ, is critical for VJ associated with volleyball performance (Sheppard et al., 2008) EMS training combined with PT training, found very efficient in VJ enhancement among volleyball players (de Villarreal et al., 2009; Maffiuletti et al., 2002). Maffiuletti et al (2002) studied the effect of the combination of EMS of the knee extensor muscles (48 contractions), EMS of the plantar flexor muscles (30 contractions), and 50 PT jumps in volleyball players, three times per week. At the end of the four weeks training program, VJ was increased in 8.3% for the CMJ with arm swing and in 21.4% for the SJ, with respect to baseline. These results were maintained with even a little insignificant improvement, within the next two weeks of volleyball training.

Similar conclusions obtained by Herrero et al (2006). They compared the effects of four-week training periods of EMS only, PT training only, or combination of EMS and PT. In each week, there were 2 days of EMS training and 2 days of PT training, with one rest day in between. Significant increase in combined EMS and PT was observed in SJ (7.5%) and CMJ (7.3%) after four weeks training. However, no significant VJ enhancement was observed in EMS training only.

Newton (1999), compared treatment and control groups of both elite volleyball players, for eight weeks of preseason volleyball training. The control group completed three sets each of squat and leg press exercises using load of 6RM while the treatment group completed ballistic resistance training consisting of six sets of jump squats with a counter movement. The treatment group produced a significant increase in VJ over the control group. One of the key questions about enhancing VJ for volleyball players is whether it is possible to maintain or even enhance VJ even during game season? Newton et al (2006) found that comparing to traditional leg resistance training, ballistic resistance training can better maintain VJ height during and until the end of volleyball game season.

Sheppard et al (2011), turned the conventional approach of weight loading in aim to chronically enhance VJ in volleyball players. Instead, they reduced body weight while exercising. The reduction in approximately 10 kg of body weight was executed by a bungee strip. They hypothesized that this VJ assistantship may encourage the leg extensor musculature to undergo a more rapid rate of shortening, while chronic exposure to this accelerated rate of shortening may promote an enhancement in VJ ability. Five weeks intervention plan, twice a week, had led to enhancement of 2.7 cm in CMJ and 4.6 cm in Volleyball Attack Jump (VAJ).

Discussion

Despite the contribution of the three methods to enhance VJ capacity: PT, EMS and RT, EMS is less useful to most of the volleyball teams and players, because of low availability and high cost. This leaves the methods of RT and PT that are simple to perform in different variations and are simple to adjust into volleyball training and site.

Some of the studies on the contribution of RT to the VJ enhancement, support that these methods should be carried out in an explosive movement, that is similar to VJ, with relatively low resistance (30-50% of IRM) at high velocity (Newton et al 1999; Thompson et al. 2007). This training approach has led to prevalent use of OL training as a ballistic RT which is similar and specific to the VJ pattern (Channell and Barfield, 2008; Garhammer & Gregor; 1992, Garhammer; 1993, Kraemer & Newton. 1994;) On the other hand, other studies support the performance of PT to enhance VJ capacity, because of their reinforcing effect on SSC and because PT constitute a natural part of most sport movements like volleyball (Bauer et al, 1990; de Villarreal et al, 2009; Bobbert, 1990; Markovic, 2007).

In aim to enhance VJ, volleyball players need to enhance explosive strength, elastic-explosive strength (SSC), reflex-elastic-explosive strength, and arm use. All these properties are synchronized into the VJ action (Borràs et al., 2011). It implies that great attention should be given for planning VJ integrated trainings, which strengthening at one practice unite muscle power, neural properties and elastic properties of muscles and tendons. Integrating PT and ballistic RT in one training unit, leads to an enhancement in VJ, which is more significant than the separate execution of each method (Adams et al., 1992; Toumi et al., 2004a,b; Wilson et al., 1996; De Villarreal et al., 2009; Marques et al., 2008). Another factor that supports the integration of these methods inside a specific volleyball training, is of the better conditions for immediate conversion of muscle's power into the actual specific jumping requirements of volleyball (Baker, 1996).

An important issue is regarding to the combinations of the methods to enhance VJ according to the annual periods of the activity. According to Arabatzi et al (2010), during the preparation period it is recommended to perform ballistic RT to increase power and during the competition period it is recommended to perform PT to increase neural functions and SSC. However, this review supports the importance of performing PT along all annual periods as well as ballistic RT. Therefore, it implies that the best is integrating low intensity PT with high intensity RT and ballistic RT during preparation period, and integrating low intensity ballistic RT with higher intensity PT during competition period.

In conclusion, many studies stress the importance of integrated training of PT, RT and EMS, to enhance volleyball VJ capacity. However, to the best of our knowledge, no studies have been found to determine the effect of volleyball VJ (VAJ and VBJ) to the maximum height a volleyball player can perform, as a method of enhancing VJ. Not as an independent training unit, not as a training unit that integrated with the other methods and not as a training that integrated into a specific volleyball training. Therefore, it is recommended to investigate the effect of performing maximal volleyball jumps (VAJ and VBJ) as another method to enhance VJ capacity among volleyball players.

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