The Effect of Training with Accentuated Eccentric Load Counter-Movement Jumps on Strength and Power Characteristics of High-Performance Volleyball Players

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ABSTRACT

The purpose of this study was to evaluate the training effects of using accentuated eccentric load counter-movement jumps on lower-body power characteristics in high-performance volleyball players. Sixteen volleyball players training full time with the state high-performance team participated in this 5 week training study. Prior to and at the completion of the study, jump squat testing with a lightweight (350 g) bar was conducted to determine kinetic and kinematic values for the lower body. Players were divided into either the accentuated eccentric load counter-movement jump group (AEJ) or normal (body-mass) counter-movement jump group (BMJ). The increases in displacement, velocity, and power values observed in the AEJ group were superior to those of the BMJ ($p = 0.001$-0.05, $d = 1.06$-1.97). The results of this study indicate that training with additional load during the eccentric phase of a counter-movement jump yields superior jump squat performance in comparison to typical counter-movement jump training in volleyball players who are already performing a high volume of jumping.

Key words: Eccentric Muscle Action, Kinematics, Kinetics, Stretch-Shortening Cycle, Verticle Jumps

INTRODUCTION

Sequencing of the eccentric-concentric action of a stretch-shortening-cycle (SSC) in jumping contributes to greater jump heights compared with jumps where no SSC occurs [1, 2]. This phenomenon is attributable to both neurogenic and myogenic factors that are enhanced by the eccentric loading that the SSC provides [3, 4]. As a result, training activities that include a SSC (such as counter-movement vertical jumps), but also those that accentuate the eccentric load of the SSC (such as drop-jumps) are often utilised in training volleyball players and other jumping athletes [5-9].

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Research has demonstrated that an accentuated eccentric load can increase the maximum load lifted in the concentric phase of the movement in comparison to a more typical training condition where the load lifted in the eccentric and concentric phases are equal [10]. We recently published research demonstrating that vertical jumps that involve an accentuated (additional) eccentric load produce higher jump heights, power output, velocity, and force generation than vertical jumps that do not use an extra load [11]. To simplify, utilizing an extra load during the lowering phase of a counter-movement vertical jump, and releasing this load just prior to initiating the upward phase of the jump, produced superior kinetic and kinematic values compared to a typical counter-movement jump movement where load is equal in the eccentric and concentric phase.

Whether long-term training with an accentuated eccentric load leads to a superior chronic training effect in the lower-body, and hence jumping ability, is unknown. Furthermore, whether training in this manner transfers to enhanced performance in conditions where the activity does not involve an accentuated eccentric load, is also unknown. Therefore, the purpose of this study was to evaluate the effects of 5 weeks of accentuated eccentric load vertical jump training on lower-body power in a group of high-performance volleyball players.

METHODS

SUBJECTS

Sixteen high-performance volleyball players whose age, height, and mass were 21.8 ± 4.9 yrs, 195.7 ± 8.7 cm, and 83.7 ± 4.2 kg, respectively, participated in this study. Players were randomly assigned to either an accentuated eccentric loaded jump (AEJ) group or a body-mass loaded jump (BMJ) group, which were performed in concurrence with their typical strength training regimen (Table 1). The AEJ group consisted of 6 males and 2 females, and the BMJ group consisted of 4 males and 4 females. The groups were not significantly different in height, weight, age, or jump squat performance (force, power, velocity, or displacement) variables. All participants were engaged in long term (>2yr) strength training. Those in the AEJ group were familiarized with the procedures involved in utilizing accentuated eccentric loading via a pre-familiarization session. All subjects received a clear explanation of the study, including the risks and benefits of participation. The study and test protocols were in accordance with and approved by institutional ethics, and written consent for testing was obtained in the athlete's scholarship holder's agreement.

TESTING PROCEDURES

Prior to and at the conclusion of the training study, subjects performed 4 trials of a maximal effort counter-movement vertical jump without additional load while kinetic and kinematic data were collected using a combined force plate and linear position transducer system. Counter-movement vertical jumps were conducted standing on a commercially available force plate (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia). A rotary encoder-type position transducer (PT5A, Fitness Technology, Adelaide, Australia) was connected to a lightweight wooden pole (350 g) held across the back of the shoulders (Figure 1), and as such, no arm swing contribution was involved in the testing of the jump. Both the force plate and position transducer were interfaced with computer software (Ballistic Measurement System, Fitness Technology, Adelaide, Australia) that allowed direct measurement of displacement, force, velocity, and power variables, with data sampled at 200 Hz. The subjects performed the 4 maximum effort counter-movement vertical jumps; and the best trial, as determined by maximum displacement, was kept for analysis. Subjects were instructed to jump as high as possible on each of the single repetitions. Sixty-second rest periods were given between each jump trial.

Subjects were tested during the week prior to the initiation of the study and the week after its conclusion. In the 24-hour period prior to performing the tests, the subjects did not engage in activity that was considered unduly fatiguing with regard to the vertical jump testing. Because the subjects involved in this study were involved in frequent training, typically training >15 hours per week, this was accomplished by testing the athletes the day after a complete rest day.

As per the normal testing protocol for this group, the subjects completed their typical strength training warm-up prior to testing sessions, as outlined in Table 1. This was followed by 3-5 minutes of rest prior to commencing the testing session.

Prior to all data collection procedures, the force plate was calibrated using a spectrum of known loads, and then assessed against 3 criterion masses. The position transducer was calibrated using a known distance of 1.0 m. The ICC and % Technical Error of the displacement, force, velocity, and power measures used in the assessment methodology, with this population group, has been previously calculated at 0.77-0.95 (3.0-8.3%), 0.95-0.97 (3.1-4.0%), 0.71-0.83 (3.3-7.3%) and 0.80-0.98 (3.0-9.5%), respectively [12].

Figure 1. Starting Position of Unloaded Jump Squat Using Portable Force Plate and Linear Position Transducer

TRAINING

Both groups performed similar strength training programs 3 times per week for 5 weeks, as outlined in Table 1. When performing jumps, however, the BMJ group jumped without any additional weight. In contrast, the AEJ group augmented the load during the eccentric (downward) phase of the jump. This was accomplished by having the subjects hold either a 20 kg (males) or 10 kg (females) weight plate in each hand and dropping the weight plate prior to initiating the concentric action of the jump squat. These loads were selected based on pilot testing that indicated that males responded best at the heavier (40 kg) eccentric loads whilst the females responded better with a lighter load (20 kg) in our subject population. Once the weight was released, subjects were encouraged to use an active arm swing in the propulsive (upward) phase of the jump. The BMJ group technique for jumps was highly similar in that the subjects kept their arms low and in front of the body during the decent of the counter-movement, and then utilized an active arm swing in the propulsive phase of the jump (similar to a block jump in volleyball).

All subjects performed 15 strength and conditioning sessions, and 25 on-court volleyball training sessions. One-half of the subject pool included accentuated eccentric jumps (AEJ, n = 8) during each of the 15 strength and conditioning sessions. The other half of the subject pool (BMJ, n = 8) performed normal counter-movement vertical jumps to equate for total jumping load between the groups.

STATISTICAL ANALYSIS

Data were determined as normally distributed via the Kolmogorov-Smirnov test for normality. Dependent-samples t-tests were used to assess for changes within group before and after the training intervention. Independent-samples t-tests were performed to assess for differences of changes between groups. Alpha was set at $p < 0.05$. The meaningfulness of these differences was interpreted using Cohen's effect sizes (d), where > 0.7 = large, 0.3-0.6 = moderate, and < 0.3 = small magnitudes of effect [13]. Data are reported as means ± SD unless otherwise stated.

RESULTS

DISPLACEMENT

The BMJ group recorded a non-significant decrease in displacement of -0.010 ± 0.036m (-2%), whereas the AEJ group significantly (p = 0.001) increased their displacement by 0.053 ± 0.027m (11%), with large magnitude of effect (d = 1.00)(Figure 2). The change in displacement for the AEJ group was significantly (p = 0.001) greater than that of the BMJ group, and this difference was of a large magnitude (d = 1.97).

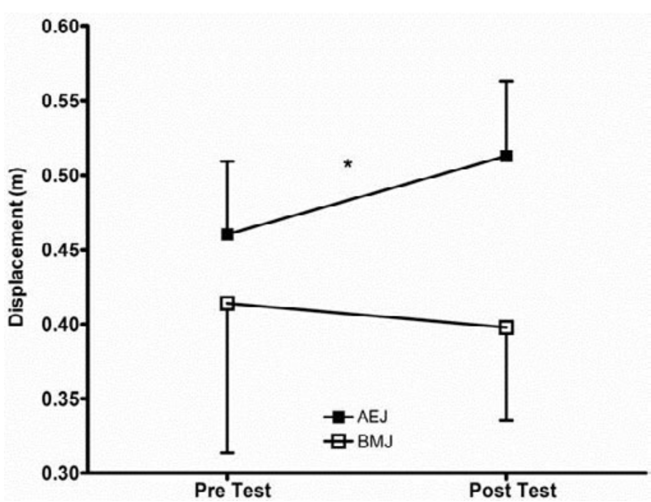

Figure 2. Change in Displacement Following a 5-Week Training Program of Either Bodyweight Jumps (BMJ) or Accentuated Eccentric Jumps (AEJ)

*Indicates significantly different from BMJ.

PEAK VELOCITY

The BMJ group experienced a non-significant decrease in peak velocity of -0.079 ± 0.435m.s^{-1} (-3%), while the AEJ group significantly (p = 0.031) increased their peak velocity

Table 1. Typical Exercises Performed by AEJ and BMJ Groups.

Order	Exercise	Tempo	Rest	Week One S & R	Week Two S & R	Week Three S & R	Week Four S & R	Week Five S & R
Warm Up	Hang Snatch to Overhead Squat	Tech	30 s	2 x 6	2 x 6	2 x 6	2 x 6	2 x 6
	Double MB Plyometric Push-Ups	Hold	30 s	2 x 10	2 x 10	2 x 10	2 x 10	2 x 10
	Hops for Height (Spot)	Height	30 s	2 x 10 e.l.	2 x 10 e.l.	2 x 10 e.l.	2 x 10 e.l.	2 x 10 e.l.
	Drop Jumps for Height	Stiffness	30 s	2 x 6	2 x 6	2 x 6	2 x 6	2 x 6
	Back Rack (2 Point)	Thoracic	60 s	2 x 30 s	2 x 30 s	2 x 30 s	2 x 30 s	2 x 30 s
1a	Hang Clean to Push Press	Dynamic	120 s	3 x 5	3 x 5	3 x 5	3 x 5	3 x 5
1b	Spike Approach Box Jumps	Height	180 s	3 x 3	3 x 3	3 x 3	3 x 3	3 x 3
2a	Jumps (accentuated eccentric [AEJ] or body mass only [BMJ])	Expl	60 s	2 x 5	2 x 5	2 x 5	2 x 5	2 x 5
				2 x 5	2 x 5	2 x 5	2 x 5	2 x 5
					2 x 5	2 x 5	2 x 5	2 x 5
						2 x 5	2 x 5	2 x 5
							2 x 5	2 x 5
2b	Bench Throws	Ht/MP	60 s	5-5-5-5	5-5-5-3	5-5-3-3	5-3-3-3	3-3-3-3
	Box Push-Ups (Loaded)	Low	120 s	12-10-8	12-10-8	12-10-8	12-10-8	12-10-8
4a	Lunges – 3 Point	Dynamic	60 s	2 x 12 e.l.	2 x 12 e.l.	2 x 12 e.l.	2 x 12 e.l.	2 x 12 e.l.
	Lateral Weight-Shift	CoM	60 s	2 x 10 e.s.	2 x 10 e.s.	2 x 10 e.s.	2 x 10 e.s.	2 x 10 e.s.
4b	Resisted Lateral Slide	Drive	120 s	4 x 5 e.s. + 2	4 x 5 e.s. + 2	4 x 5 e.s. + 2	4 x 5 e.s. + 2	4 x 5 e.s. + 2
5a	Bent Over BB Row	Range	60 s	12-10-8	12-10-8	12-10-8	12-10-8	12-10-8
5b	Stiff Legged Deadlift	Assis	120 s	2 x 10	2 x 10	2 x 10	2 x 5/5	2 x 5/5
Core	Double SB Bridge	Control	60 s	2 x 60 s	2 x 60 s	2 x 60 s	2 x 60 s	2 x 60 s
	Kneeling Cable Crunches	Control	60 s	2 x 20	2 x 20	2 x 20	2 x 20	2 x 20
	Side Bends	Control	60 s	2 x 20 e.s.	2 x 20 e.s.	2 x 20 e.s.	2 x 20 e.s.	2 x 20 e.s.

e.l. = each leg, e.s. = each side

by 0.506 ± 0.532m.s^{-1} (16%), with large magnitude of effect (d = 1.03)(Figure 3). The increase in velocity for the AEJ group was significantly (p = 0.03) greater than that of the BMJ group, and this difference was of a large magnitude (d = 1.20).

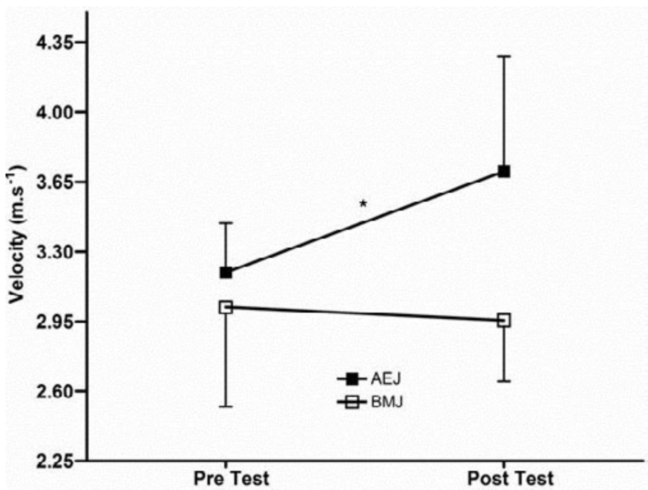

Figure 3. Change in Peak Velocity Following a 5-Week Training Program of Either Bodyweight Jumps (BMJ) or Accentuated Eccentric Jumps (AEJ).

*Indicates significantly different from BMJ.

PEAK FORCE

The BMJ group experienced a non-significant peak force increase of 52.52 ± 107.2 N (3%). The AEJ group experienced a non-significant (p > 0.05) increase in peak force output of 69.96 ± 119.4 N (4%)(Figure 4). These differences in change of peak force were not significant.

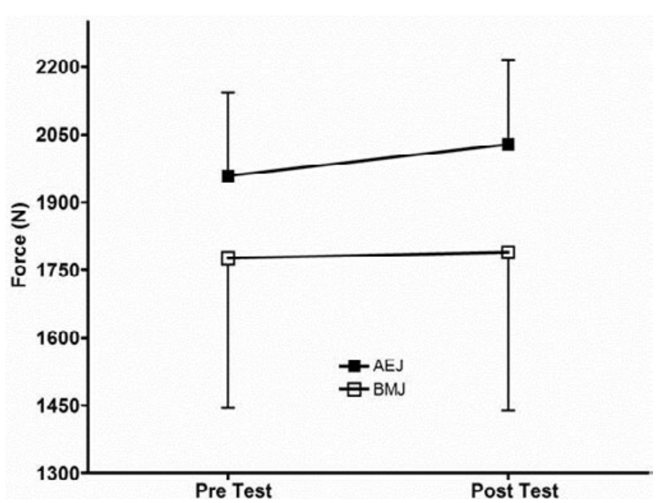

Figure 4. Change in Peak Force Following a 5-Week Training Program of Either Bodyweight Jumps (BMJ) or Accentuated Eccentric Jumps (AEJ)

PEAK POWER

The BMJ group experienced a non-significant peak power decrease of 58.03 ± 675.2 W (1%). The AEJ group significantly ($p = 0.036$) increased their peak power by 1083 ± 1183 W (20%), with a large magnitude of effect ($d = 0.830$)(Figure 5). The increase in peak power of the AEJ group was significantly ($p = 0.05$) greater than that of the BMJ group, and this difference was of a large magnitude ($d = 1.06$).

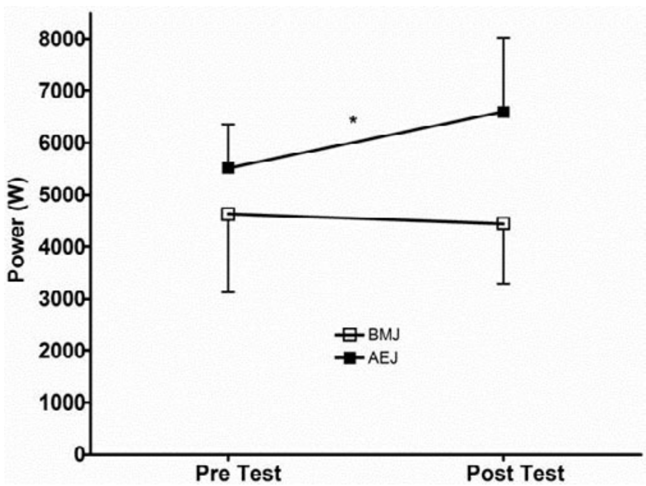

Figure 5. Change in Peak Power Following a 5-Week Training Program of Either Bodyweight Jumps (BMJ) or Accentuated Eccentric Loaded Jumps (AEJ).

*Indicates significantly different from BMJ.

DISCUSSION

This study evaluated the effects of 5 weeks of training with an accentuated eccentric load on lower-body power performance in high-performance volleyball players. The study was believed to be worthwhile, as previous research has established superior acute performance with an accentuated eccentric load condition in comparison to normal conditions [11]. However, no chronic training studies had been conducted to determine whether training with accentuated eccentric loads is superior to normal vertical jump training.

The results of this study demonstrate that an accentuated eccentric load promotes gains in power, velocity, and jump height characteristics of the lower body. Furthermore, it appears that during a 5-week period, training in this manner is superior to normal jump training.

The use of an accentuated eccentric load in vertical jump training offers coaches an additional means to increase jump height in athletes. In the present study, the accentuated eccentric load condition promoted significant and large gains in lower-body power, peak velocity, and jump height, while the normal vertical jump group experienced no improvement in 5 weeks of training. It could be reasoned that with athletes who are already performing large volumes of jump training like those involved in this study, the AEJ condition offers a unique and novel training stimulus that promotes superior results. The additional vertical jumps used in the BMJ condition are typical of block jumping in volleyball (a task that is performed numerous times in a training session) and as such, may offer limited additional overload to promote muscular adaptation.

The mechanisms behind the promotion of superior power, velocity and jump height values in the AEJ group are likely a combination of neurogenic and myogenic factors. [11, 14, 15] A possible contributing neurogenic mechanism for the enhancement promoted by the AEJ training in this study is the increase in neural stimulation that may have been provided by the accentuated eccentric load. [14, 15] The extra load could produce a greater stretch of the intrafusal muscle fibres, which would promote greater stimulation of the associated motor neurons, resulting in greater than normal afferent nerve impulses to the central nervous system. In turn, this greater than normal afferent signalling would result in a larger efferent impulse to the extrafusal fibres, thus increasing the force of the contraction in the muscle.

Another mechanism that could have contributed to the enhancements observed in the AEJ group in this study is the influence of the elasticity of the muscle-tendon unit. The stretch of the parallel elastic components (passive structures consisting of the muscle fasciae, other connective tissue, and sarcolemma) and series elastic components (active neural elements within the muscle-tendon unit and passive tendon collagen) of the muscle store elastic energy, and thereby contribute to force production in the opposing direction of the stretch. [14] Similar to an elastic band, the magnitude, rate, and time difference between direction changes of a pre-stretch likely influence the storage of elastic energy in the muscle-tendon unit which contribute to a greater concentric contraction force.

However, there was no difference in gross eccentric movement velocity between the two vertical jump conditions in a previous comparison [11], suggesting that rate of pre-stretch may have not contributed to greater storage of elastic energy. One might also consider that because there was also no difference in counter-movement depth (gross magnitude of stretch) between the AEJ and BMJ condition [11], that this also did not contribute to greater storage of elastic energy. However, due to the muscle-tendon unit elasticity, the greater eccentric load present prior to the start of the concentric phase in the AEJ training condition would result in greater tendon length changes. This phenomenon would be concomitant with myogenic differences between conditions; namely, less myofibrillar displacement, which could contribute to the greater force production through greater initial acceleration of the mass in the concentric phase of the movement, thus contributing to superior jump performances in training.

Another contributing myogenic mechanism, and likely the mechanism most responsible for influencing the observations in this study, is the structural state within a muscle that occurs during a counter-movement jump. As a muscle performs the eccentric action in any SSC, the agonist muscles achieve a preparatory active state with a portion of actin-myosin cross-bridges to be attached prior to the concentric phase of the movement [2, 4]. In an accentuated eccentric movement such as that used in this study, the eccentric force is greater than normal due to the accentuated eccentric load [11]. In order to accommodate the larger forces in the eccentric action, a greater number of cross-bridges would conceivably occur in comparison to a normal counter-movement vertical jump condition. This would result in greater joint moments at the initiation of the concentric action, contributing greatly to superior jump heights and superior mechanical parameters [14]. In this population of athletes, this training method promoted superior gains in jump height, power, and velocity in comparison to training with normal counter-movement jumps.

CONCLUSIONS

A greater than normal eccentric load in vertical jumping tasks can promote a chronic increase in jumping and power characteristics of the lower body that may be superior to jump training without these accentuated eccentric loads. The ability to evoke higher jump heights, power, and velocity in jump training follows the principles of high-quality training, where training variables are manipulated to promote the greatest performance in a training session allowing for greater chronic improvements. The results of this study support the contention that training with accentuated eccentric loads contributes to improved jumping performance. Future research in this area should aim to evaluate loading strategies (i.e., frequency, volume, load) and the length of time needed to observe training effects in utilizing accentuated eccentric load jump training.

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