The Effect of Accentuated Eccentric Load on Jump Kinetics in High-Performance Volleyball Players

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ABSTRACT

The purpose of this study was to evaluate the effects of an accentuated eccentric load on subsequent concentric kinetic factors and block jumping performance in elite male volleyball players. Eleven male volleyball high-performance players (18.9 ± 2.6 years, 203.6 ± 5.6 cm, 91.4 ± 8.2 kg), who were training full time with the national team development squad, participated in this within-subject, counter-balanced study. One half of the subjects performed the block jumps (BJ), followed by a 20 kg accentuated eccentric load block jump (AEBJ) condition, whilst the other half of the subject pool performed the testing in the reverse sequence. Superior jump heights (4.3%) and kinetic and kinematic enhancements (9.4, 3.9, 3.1% for peak power, peak force, and peak velocity, respectively) were observed in the AEBJ condition compared to the BJ condition, with no order effect observed. The differences between conditions were statistically significant ($p < 0.05$), with moderate magnitudes (ES = 0.1-0.4). The results of this study demonstrate that an accentuated eccentric load evokes acute increases in vertical jump height, as well as in the kinetic and kinematic variables that are considered important to vertical jumping ability (force, velocity, and power).

Key words: Eccentric Muscle Action, Force-Velocity Relationship, Stretch-Shortening Cycle

INTRODUCTION

Elite volleyball players produce greater vertical jump scores than non-elite and developing players. [1, 2] Most volleyball coaches would consider vertical jumping ability as the most important physical attribute for volleyball players. As such, a great deal of emphasis has been focused on methods of increasing vertical jump [3, 4], as well as physical factors that

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contribute to vertical jumping specific to volleyball athletes [5, 6, 7]. In particular, loaded and unloaded jump squats and vertical jumps have been found to be effective methods in the training of vertical jump of volleyball players. [3, 4]

The eccentric-concentric action of a stretch-shortening-cycle (SSC) in jumping contributes to greater jump heights when compared to jumps where no SSC occurs. [8] This phenomenon is attributable to both neurogenic and myogenic factors that are enhanced by the eccentric loading that the SSC provides [8]. 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 utilized in training volleyball players and other jumping athletes. [9, 10]

Research has demonstrated that an accentuated eccentric load can increase the maximum load lifted in the concentric phase of the movement in comparison to the more typical training condition where the load lifted in the eccentric and concentric phase are equal. [11] However, the effect of force-velocity characteristics of an accentuated eccentric load during a ballistic movement such as the vertical jump, has not been investigated previously. Although the work of Doan et al. [11] suggests that the accentuated eccentric load assists in increasing force producing capabilities, it is unknown if this phenomenon occurs in a 'power' movement such as the vertical jump. The purpose of this study was therefore to evaluate the kinetic characteristics of an accentuated eccentric load jump in a block-jump condition in high-performance volleyball players, in order to evaluate whether superior kinetic values could be achieved by the accentuated eccentric load condition.

METHODS

SUBJECTS

Eleven male high-performance volleyball players whose age, height, and mass were 18.9 ± 2.6 years, 203.6 ± 5.6 cm, 91.4 ± 8.2 kg, training as part of the development squad of the national team program, participated in this study. The subjects were familiarized with the procedures involved in utilizing accentuated eccentric loading through multiple prior training experiences. All subjects received a clear explanation of the study, including the risks and benefits of participation. Testing was 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

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 maximal strength, vertical jump, or power testing. Because the subjects involved in this study were 'full-time' athletes, typically training for more than 25 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 practice warm-up prior to testing sessions. In brief, this warm-up included 10 minutes of general activity (cycling, light stretching), followed by 10 minutes of dynamic activity that increased in speed and intensity (skips, leg swings, arm swings), followed by 3-5 minutes of rest prior to commencing the testing session. Subjects were re-familiarized with the testing protocol via two sub-maximal practice attempts.

The subjects performed two trials of each of the experimental jump conditions, whilst kinetic and kinematic data were collected using a combined force plate and linear position transducer system (Fitness Technology, Adelaide, Australia). The best trial from the two attempts for each condition, as determined by maximum displacement, was kept for analysis.

The linear position transducer was mounted above the athlete, using a 4-metre high overhead boom, with the cable attached to the athlete via a cinched belt around their trunk at the level of the umbilicus (Figure 1). Both the force plate and position transducer were interfaced with computer software (Ballistic Measurement System, Fitness Technology, Adelaide, Australia) that allowed direct measurement of force-time characteristics (force plate) and displacement-time and velocity-time (position transducer) variables as outlined by Dugan et al. [12].

For the block-jump condition trials, subjects were instructed to confine their active arm-swing to only the concentric phase of the jump, therefore the arms were not able to swing back behind the body, but remained below the waist and in front of the body (i.e., hands move from low position in counter-movement to upward propulsion) as this movement is typical of blocking in volleyball. This block-jump movement was also performed with the addition of an accentuated eccentric load. This was accomplished by having the subjects hold a 10 kg weight plate in each hand and dropping the weight plate prior to initiating the concentric action of the block jump. This allowed for a replication of the amount of active upward arm-swing, as the subjects were able to release the load and then actively jump up with concentric action arm swing similar to the typical block-jump condition. The experiment utilized a within-subjects, repeated measures design, with counter-balancing for order effect. One half of the subjects performed the block jumps (BJ), followed by the accentuated eccentric load block jump (AEBJ), whilst the other half of the subject pool performed the testing in the reverse sequence. Jump trials were separated by 1-2 minutes of passive rest.

The 20 kg load was selected based on pilot testing (n = 5) during some of the familiarization sessions, where it was observed that within this subject pool, the 20 kg load tended to evoke the greatest improvement in jump kinetics. (10, 20, 30, and 40 kg accentuated eccentric loads were trialled). In the pilot study, it was hypothesized that lower loads (i.e., 10 kg) were insufficient in evoking the greatest response because they did not provide enough neural stimulation or myogenic alterations, whilst the larger loads may have attenuated favourable response due to neural inhibition caused by the larger magnitude of force in the eccentric phase.

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 m. The intra-class correlation (ICC) and relative technical error of measures (%TE) of maximum displacement (DISP), peak force (PF), peak concentric velocity (PV), and peak power (PP) measures used in the assessment methodology, with this population group, were 0.95 (3.0%), 0.96 (3.5%), 0.83 (3.3%) and 0.89 (7.1%) respectively.

STATISTICAL ANALYSIS

All data were deemed to be normally distributed, with skewness values within ± 2.00. Dependent samples T-tests were performed to assess the significance of jump kinetic and kinematic differences between the block jump conditions of BJ and AEBJ. An alpha level of $p < 0.05$ was applied as the criterion for statistical significance. In addition, Cohen's effect size statistics (ES) were calculated for the magnitude of difference between groups, using the following descriptors: > .5, large; .1 to .4 moderate; < .1 small. [13]

RESULTS

All 11 subjects responded favourably to the AEBJ condition in comparison to the BJ condition, with increases in all subjects observed for DISP, PF, PV, and PP. These jump performance enhancements observed in the AEBJ condition were statistically significant ($p < 0.05$). No significant differences between conditions were observed for counter-movement depth, or counter-movement speed. The mean ± SD, relative difference between groups, and ES are presented in Table 1.

Table 1. Mean ± SD, Difference (% Change), P-Value, and Effect Size (ES) Between Block Jump (BJ) Condition and Accentuated Eccentric Load Block Jump (AEBJ) Condition

Kinetic Variable	BJ Condition	AEBJ Condition	Change %	P-Value	ES
Jump Height (cm)	48.4 ± 0.1	50.5 ± 0.1	4.3	0.01	0.20
Peak Power (W)	4655.9 ± 1034.0	5095.5 ± 1225.4	9.4	0.00	0.39
Peak Force (N)	2181.4 ± 419.5	2265.9 ± 455.8	3.9	0.04	0.19
Peak Velocity (m/s)	2.8 ± 0.4	2.9 ± 0.4	3.1	0.01	0.25

DISCUSSION

This study evaluated the effects of an accentuated eccentric load on vertical jump performance in high-performance volleyball players. The study was believed to be worthwhile, as previous research has established superior strength performance with an accentuated eccentric load condition [11], but evaluations of accentuated eccentric loads in power movements such as the vertical jump have not been conducted.

The results of this study clearly demonstrate that an accentuated eccentric load evokes acute increases in vertical jump height, as well as in the mechanical variables that are considered important to vertical jumping ability (force, velocity, and power). Similar results have been observed in vertical jump performance when comparing drop jumps with counter-movement jumps [8] and in comparing one-repetition maximum accentuated eccentric load bench press with equated eccentric-concentric bench press. [11] Therefore, use of an accentuated eccentric load may offer coaches an additional means (to compliment depth jumping) to increasing jump height in comparison to typical counter-movement jump conditions.

The mechanisms behind the acute evocation of higher kinetic values in these movements have been proposed to be a combination of neurogenic and myogenic factors. [11, 14] A possible contributing neurogenic mechanism for the acute enhancement in kinetic values observed in this study is the increase in neural stimulation that may have been provided by the accentuated eccentric load [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. This explanation is supported by the slight increase (3.9%) observed in force of the AEBJ condition in comparison to the BJ conditions in this study.

Another logical mechanism that could have contributed to the enhancements observed in this study is the elasticity of the muscle-tendon unit. The stretch of the parallel elastic components (passive structures of the muscle and connective tissue) 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. [16]

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 force. However, there was no difference in gross eccentric movement velocity between the conditions, suggesting that in this study, rate of pre-stretch may not have 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), this 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 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.

Another contributing myogenic mechanism, and likely the mechanism most responsible for influencing the observations in this study relates to the structural state within a muscle that occurs during a counter-movement jump. As a muscle performs the eccentric action in any stretch-shortening cycle (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. [14, 17] In this study, the eccentric force was greater than normal due to the accentuated eccentric load. In order to accommodate the larger forces in the eccentric action, a greater number of cross-bridges would conceivably occur in the AEBJ condition in comparison to the BJ condition. This would result in greater joint moments at the initiation of the concentric action, likely contributing greatly to the superior jump heights and superior mechanical parameters observed in this study.

CONCLUSION

A greater than normal eccentric load in vertical jumping tasks can promote an acute increase in jump height and other kinetic and kinematic values such as force, velocity and power. The ability to evoke higher jump heights, force power and velocity in jump training follows the principles of high-quality training, where training variables are manipulated to promote optimal, chronic improvements in performance. Therefore, it is possible that training with accentuated eccentric loads could contribute to greater jumping performance. However, this cannot be asserted from the results of this study. Future research should aim to evaluate the chronic training affect of utilizing accentuated eccentric load jump training on vertical jump performance under conditions where an accentuated eccentric load is not utilized.

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REFERENCES

1. Fry, A. C., Kraemer, W. J., Weseman, C. A., Contory, B. P., Gordon, S. E., Hoffman, J. R. and Maresh, C. M., The Effects of an Off-season Strength and Conditioning Program on Starters and Non-Starters in Women's Intercollegiate Volleyball, *Journal of Applied Sport Science Research*, 1991, 5, 174-181.
2. Smith, D. J., Roberts, D. and Watson, B., Physical, Physiological and Performance Differences Between Canadian National Team and Universiade Volleyball Players, *Journal of Sports Sciences*, 1992, 10, 131-138.
3. Newton, R. U., Kraemer, W. J. and Hakkinen, K., Effects of Ballistic Training on Pre-Season Preparation of Elite Volleyball Players, *Medicine and Science in Sports and Exercise*, 1999, 31, 323-330.
4. Newton, R. U., Rogers, R. A., Volek, J. S., Hakkinen, K. and Kraemer, W. J., Four Weeks of Optimal Load Ballistic Resistance Training at the End of Season Attenuates Declining Jump Performance of Women Volleyball Players, *Journal of Strength and Conditioning Research*, 2006, 20, 955-961.
5. Peterson, M. D., Alvar, B. A., and Rhea, M. R., The Contribution of Maximal Force Production to Explosive Movement Among Young Collegiate Athletes, *Journal of Strength and Conditioning Research*, 2006, 20, 867-873.
6. Weiss, L.W., Relyea, G. E., Ashley, C. D. and Propst, R.C., Using Velocity-Spectrum Squats and Body-Composition to Predict Standing Vertical Jump Ability, *Journal of Strength and Conditioning Research*, 1997, 11, 14-20.
7. Young, W., Wilson, G. and Byrne, C., Relationship Between Strength Qualities and Performance in Standing and Run-Up Vertical Jumps, *Journal of Sports Medicine and Physical Fitness*, 1991, 39, 285-293.
8. Komi, P.V. and Bosco, C., Utilization of Stored Elastic Energy in Leg Extensor Muscles By Men and Women, *Medicine and Science in Sports and Exercise*, 1978, 10, 261-265.
9. Cresswell, A. G., Engel, T. J. and Nicol, S. M., Increase in Jump Height Associated With Maximal Effort Vertical Depth Jumps, *Research Quarterly for Exercise and Sport*, 1987, 58(1), 11-15.
10. Powers, M. E., Vertical Jump Training for Volleyball, *Strength and Conditioning Journal*, 1996, February, 18-23.
11. Doan, B. K., Newton, R. U., Marsit, J. L., Triplett-McBride, T. N., Koziris, P. L., Fry, A. C. and Kraemer, W. J., Effects of Increased Eccentric Loading on Bench Press 1-RM, *Journal of Strength and Conditioning Research*, 2002, 16(1), 9-13.

12. Dugan, E. L., Doyle, T. L. A., Humphries, B., Hasson, C. J. and Newton, R. U., Determining the Optimal Load for Jump Squats: A Review of Methods and Calculations, *Journal of Strength and Conditioning Research*, 2004, 18, 668 – 674.
13. Cohen, J., *Statistical Power Analysis for the Behavioural Sciences*, Lawrence Erlbaum, Hillsdale, NJ, 1988.
14. Walshe, A. D., Wilson, G. J. and Ettema, G. J., Stretch-Shorten Cycle Compared with Isometric Preload: Contributions to Enhanced Muscular Performance, *Journal of Applied Physiology*, 1998, 84, 97-106.
15. Enoka, R., *Neuromechanics of Human Movement*, 3rd ed., Human Kinetics, Champaign, IL, 2000.
16. Giovanni, A., Cavagna, A., Dusman, B. and Margaria, R., Positive Work Done By a Previously Stretched Muscle, *Journal of Applied Physiology*, 1968, 24, 21-32.
17. Bobbert, M. F., Gerritsen, K. G., Litjens, M. C. and Van Soest, A. J., Why is Counter-Movement Jump Height Greater than Squat Jump Height? *Medicine and Science in Sports and Exercise*, 1996, 28(11), 1402-1412.