ENERGY STORED AND OUTPUT DURING A VOLLEYBALL ATTACK JUMP FOR DIFFERENT SKILL LEVELS OF FEMALE PERFORMERS

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The purpose of the current study was to investigate the mechanical energy stored and output during a volleyball attack jump for different skill levels of female players. Five female skilled volleyball players and five recreational female volleyball players were recruited. Each participant performed five maximum regular 4-step attack jumps on two Kistler force platforms with conjunction of 3D motion analysis. Results indicated that there was no significant difference of energy stored between the two groups of performers. The mechanical energy output of the competitive group was significantly greater than the recreational group. Finally, the energy stored, output, and CoM downward displacement were statistically associated with jump height in skilled group and only energy returned was a significant variable that associated with jump height in non-skilled group (*P* <.01).

KEY WORDS: mechanical energy, skill level, volleyball attack jump.

INTRODUCTION: The ability to jump high is crucial for most sports performance. There is a vast body of research on the biomechanics of jumping (e.g., Bobbert & Richard Casius, 2005; Moran & Wallace, 2007; Wagner, Tilp, Duvillard, & Mueller, 2009). One prominent theory explaining the enhancement of muscle force and power output for the jump height is due to the stretch-shortening cycle (SSC) of the skeletal muscle tendon unit (Cavagna, Saibene, & Margaria, 1965; Cavagna, Dusman, & Margaria, 1968; Thys, Faraggiana, & Margaria, 1972; Sinkjaer, Toft, Andreassen, & Hornemann, 1988). Studies support this finding by identifying that with an increased eccentric loading, the mechanical output would be enhanced (Cavagna et al., 1965; Bober, Putnam, & Woodworth, 1987).
The SSC had been extensively investigated from many different perspectives. Studies (e.g., Komi & Bosco, 1978; Hudson & Owen, 1985) examined the efficiency of the reutilization of elastic energy between men and women. Furthermore, Moran and Wallance (2007) extended the examination to the joint kinetics in both eccentric loading and positive work done in the concentric phase for men. These studies have shown statistical differences between reutilizing elastic energy stored in addition to eccentric loading (i.e., drop jump) enhanced the energy stored when compared to the squat jump.
Studies about the volleyball attack jump performance have identified kinematic variables that are associated with the jump height and the approach run prior to takeoff can significantly enhance jump height (Kayambashi, 1977; Wagner et al., 2009; Hsieh & Christiansen, 2010). Moreover, the muscle pre-activation level was found to result in a greater muscle activity during the eccentric phase due the approach run and contribute to the following concentric phase muscle power output (Viitasalo, Salo, & Lahtinen, 1998; Ruan & Li, 2010). However, there are very few studies examining the kinetic factors that contribute to the jump height in different skill levels of female volleyball players during an attack jump.
Consequently, the purpose of this study were to: 1) investigate the differences of eccentric loading stored; 2) analyze the jump height variation; 3) determine the active work done; and 4) compare the vertical CoM displacement during downward and upward phases between different skill levels of female volleyball players in a regular attack jump. Finally, the association between these measured variables and jump heights in different skills levels were examined.
METHODS: All policies and procedures for the use of human subjects were followed and approved by the university Institutional Review Board. Five female volleyball players (1.76 ±0.09 m; 62.65 ±7.4 kg) were recruited from a highly competitive team and another five recreational volleyball players (1.73 ±0.03 m; 67.25 ±9.97 kg) were recruited from the local university recreation center. The players in the skilled group are all outside hitters. Each

subject was required to warm-up for at least 5 minutes by jogging and dynamic stretching for jumping performance and practicing several 4-step approach volleyball attack jumps (VJ) in front of the cameras. All subjects performed a maximum of five VJs on the two force platforms (Kistler 9286; 1080 Hz). Each subject took a half minute break between each trial.
Three-dimensional coordinate data were obtained with two 60-Hz digital video cameras (Cannon) in conjunction with a motion analysis system (Vicon Motus: 9.2) and synchronized by using Remote Video Synchronization Unit. A model using 17 points which composed 14 segments was used. Anthropometric parameters from Clauser, McConville, and Young (1969) were used. All video trials were cropped from the 10th field before the first contact with the force platform to the 10th field after the peak of the jump. The kinematic data were then low-pass filtered using a fourth-order zero-lag Butterworth filter and a cut-off frequency (4 Hz) determined with a previously established optimization approach (Jackson, 1979). Vertical force data was synchronized with kinematic data by using event synchronization unit.
Figure 1 represents the relationship between vertical GRF and the displacement of CoM and the timing of the countermovement jump. Energy stored in the muscles was determined by using equation: $\int_{T_0}^{T_1} (F_{GRFv}) \times \Delta d_{CoM}$, where T_0 was the instant of the first foot impact on the force platform, T_1 was the lowest vertical CoM location, and d_{CoM} was the vertical displacement of CoM. Returned energy was determined by using formula: $\int_{T_1}^{T_2} (F_{GRFv}) \times \Delta d_{CoM}$, where T_2 was the instant of takeoff. The difference between returned energy and energy stored was active work done.

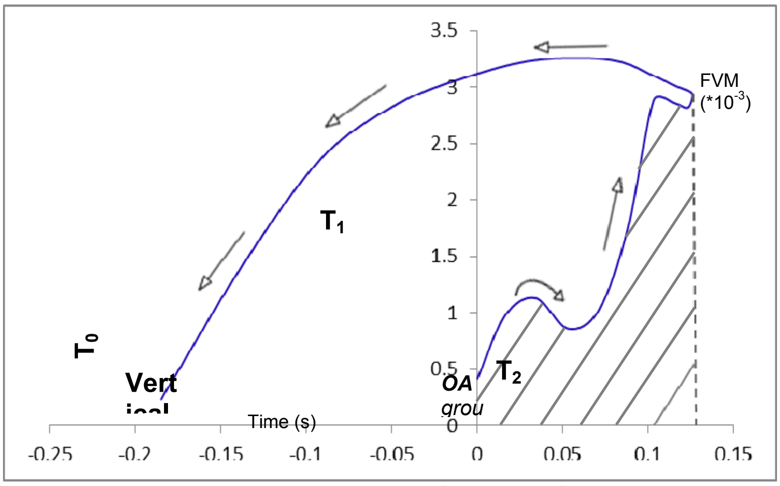

Figure 1: The relationship between vertical GRF and CoM vertical displacement.

Standard T-tests were applied to compare jump height, energy stored, active work done, and vertical CoM displacement during downward and upward phases between skilled volleyball players and healthy active females. To control for type I errors, Holm's correction formula was utilized to calculate new adjusted critical *P*-values $= \alpha/(n-i+1)$, where *n* is the total number of comparisons and *i* is the order of comparison (Lundbrook, 1998). Each observed *P*-value was compared to the new adjusted critical *P*-value. Zero-order correlation was performed to analyze the associations between jump height and the variables measured above. The statistical significance level was set at $p < 0.05$.

RESULTS: Table 1 showed statistically significant differences in jump height, active work done, and both CoM down and up phases between female competitive and recreational volleyball players. There was no significant difference of energy stored between different skilled volleyball players (P = 0.142). Correlations were statistically confirmed between jump height and three of the four original variables: energy stored, active work done, and CoM down for competitive players. For recreational players, only active work done was correlated with jump height (Table 2).

Table 1: Differences of main variables between different skill levels of female volleyball players.

Skill Level	Jump Height (m)	Energy Stored (BWm)	Active Work Done (BWm)	CoM Down (m)	CoM Up (m)
Competitive	.42 ±.06*	-.21 ±.07	.55 ±.11*	.14 ±.03*	.33 ±.04*
Recreational	.25 ±.04	-.18 ±.08	.39 ±.07	.10 ±.03	.28 ±.02

Note: * indicates significant difference with *P*-value less than new adjusted critical *P*-value.

Table 2: Correlation between variables and jump height for different skill levels of volleyball players.

Skill Level	Energy Stored (BWm)	Active Work Done (BWm)	CoM Down (m)	CoM Up (m)
Competitive	-.67*	.67*	.78*	.19
Recreational	.28	.67*	-.31	-.07

Note: * indicates significant difference with *P*-value <.01.

DISCUSSION: The most interesting finding was that there was no statistical difference of energy stored between competitive and recreational female volleyball players. The jump height was significantly associated with energy stored only in the competitive group. Moreover, the correlation matrix also indicated that there was a significant association between energy stored and active work done in the competitive group (r = -.66, P <.01) but not in the recreational group (r = .27, P = .2). This indicates that the recreational players could generate similar amounts of passive energy as competitive players, but may not utilize the energy stored as efficiently as skilled players to enhance the mechanical energy output.

A volleyball attack jump consists of an approach run, arm swing, and countermovement jump and the function of these three factors have been identified as crucial factors for the attack jump height (e.g., Hsieh & Christiansen, 2010; Kayambashi, 1977; Wagner et al., 2009). For a countermovement jump, the downward movement stretches the muscle tendon unit that stores elastic energy, triggers the neuromuscular reflex, and lengthens the skeletal muscle to optimal distance which enhances the muscle force and power output in the following concentric muscle action phase (Cavagna et al., 1965; Cavagna et al., 1968; Thys et al., 1972; Sinkjaer et al., 1988). Since there is no significant difference of mechanical energy stored between competitive and recreational players in the current study, the increase of the mechanical energy output may due to different neuromuscular control of jumping performance. Enoka (1996) concluded that unique activation strategies are required by the nervous system during eccentric muscle action.

The neuromuscular control due to eccentric loading can change the recruitment order, discharge rate, threshold of motor units within the muscle, and influence the motor units' activity among synergist muscles (Schieppati, Valenza, & Rezzonico, 1991; Enoka, 1996; Bobbert & Richard Casius, 2005). Pre-activation of muscle activity during eccentric phase could also be increased with approach run (Ruan & Li, 2010). Moreover, studies (Kyröläinen & Komi, 1995; Viitasalo et al., 1998) have found that pre-activation of major muscle groups during the drop jump test to be higher and started earlier in skilled than non-skilled athletes. This high muscle activity favors the storage and output of mechanical energy. Since there was no significant different eccentric loading between skilled and non-skilled players in the present study, the transition from approach run to takeoff and SSC training may be important neuromuscular interventions for the non-skilled group to improve their mechanical energy output (Kyröläinen, Komi, & Kim, 1991).

CONCLUSIONS: The current study found that non-skilled female volleyball players could produce similar amounts of passive energy as skilled female volleyball players. Since the association between jump height and mechanical energy stored was only statistically significant in skilled players, the transition from approach run to takeoff and SSC training may be useful neuromuscular interventions to enhance the mechanical efficiency for non-skilled female volleyball players to improve jump height.

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