THE EFFECTS OF ECCENTRIC PHASE DURATION ON CONCENTRIC PHASE FORCE PRODUCTION DURING DEPTH JUMPS

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The purpose of the study was to test the yet unproven theory, which states that the faster a muscle is stretched the greater force it produces in the subsequent concentric phase during plyometric exercises. Thirty-three trained male athletes performed plyometric depth jumps from two heights (trial A=33.02cm, trial B=47.94cm) landing on a force platform, followed by an immediate counter jump. Researchers determined the duration of eccentric phase and the relative peak concentric force of each jump using the data from the force platform. Results indicated a significant inverse relationship between eccentric duration and relative peak concentric force in both trials ($p=0.019$ and $p<0.001$). This relationship was stronger as the height of the depth jump increased ($r=-0.40$ in trial A and $r=-0.62$ in trial B).

KEY WORDS: plyometrics, force production, eccentric phase.

INTRODUCTION: Plyometrics are commonly used exercises in various sports and have been shown to increase explosive power output (Gehri, Ricard, Kleiner, & Kirkendall, 1998; Luebbers, et al., 2003). Plyometric exercises are based on the notion of stretch-shortening cycle (SSC) (Gehri et al. 1998; Potteiger, et al. 1999; Read & Cisar, 2001), where a rapid eccentric muscle action (stretch) is followed by a concentric action (shortening) (Bosco, Viitasalo, Komi, & Luhtanen, 1982; Luebbers, et al., 2003; LaChance, 1995; Wagner & Kocak, 1997). It has been concluded that the rapid prestretching of the muscle fibers provides a more powerful concentric action in the movement than could be generated during a concentric action from a static position (Asmussen & Bonde-Peterson, 1974; Cavagna, 1977; Potteiger, et al. 1999; Read & Cisar, 2001). The physiological explanation to this phenomenon is generally explained by the myotatic reflex (commonly referred to as the stretch reflex) (Holocomb, Lander, Rutland, & Wilson, 1996; Lundin & Berg, 1991; Luebbers, et al. 2003; LaChance, 1995; Wagner & Kocak, 1997). Specifically, the muscle spindles that are sensitive to the amount and rate of stretching in the muscle initiate the stretch reflex due to the sudden forced lengthening (Huber, 1987; Lord & Campagna, 1997). This results in a protective mechanism, in which the frequency of motor unit discharge and the number of activated motor units increases (Clutch & Wilton, 1983; Thomas, 1988). Furthermore, during the rapid stretch of the muscle fibers, elastic energy may be stored in the muscles (Asmussen & Bonde-Peterson, 1974; Cavagna, 1977; Gollhofer, & Kyrolainen, 1991; Lundin & Berg, 1991; Thys, Faraggiana, & Margaria, 1972). This stored elastic energy then complements the normal voluntary concentric contraction, providing an extra force production during the concentric phase (Bosco et al. 1982; Komi & Bosco, 1978; Holocomb et al. 1996; Read & Cisar, 2001). The accumulated and stored elastic energy is only available in the subsequent concentric phase if the time between the eccentric and concentric phase (commonly called the amortization phase) is short (Cavagna, 1977; Gollhofer, & Kyrolainen, 1991; Lord & Campagna, 1997). On the other hand, if the amortization phase lasts too long, partial relaxation of the muscle fibers may take place, through which the stored energy may dissipate into heat and the advantage of pre-stretch may disappear (Cavagna, 1977; Thys et al. 1972). Some researchers further suggested that certain factors may affect the ability of the muscle fibers to store elastic energy and later utilize it for extra concentric force production. LaChance (1995) theorized that age, gender, fiber type, and surface contact stiffness could affect the elastic energy. Gehri et al. (1998) indicated that the speed of the stretch, length of the stretch, force at the end of the stretch, and length of time that stretch is held all influence one's ability to store and utilize elastic energy.

Several authors have argued that the speed of the stretch (the duration of the eccentric phase) greatly affects the amount of force produced in the subsequent concentric phase. Chu (1983), Huber (1987), and Thomas (1988) stated that the faster a muscle is stretched, the greater the concentric force developed. All these authors based their argument on Grieve's (1970) statement, who did not perform a scientific investigation to prove this hypothesis. Other authors (Luebbers et al. 2003; Wagner & Kocak, 1997) claim this theory based on Clutch and Wilton (1983) and Lundin and Berg (1991), while these investigators did not directly suggest it in their publications. After a thorough review of the literature, a misunderstanding has been revealed that may account for the use of an unproven theory as scientific fact. The phrase "amortization phase" specifically refers to "an electromechanical delay" between the eccentric and concentric phases of the movement (Holocomb et al. 1996). That is the amount of time that it takes to change directions in the movement. Multiple investigations on SSC have demonstrated that the amortization phase must be short in order to avoid muscle relaxation and the potential loss of elastic energy (Cavagna, 1977; Gollhofer, & Kyrolainen, 1991; Thys et al. 1972). In fact, one of the main characteristics of plyometric exercises is to train the neuromuscular system to switch rapidly from eccentric to concentric movements (Holocomb et al. 1996; Read & Cisar, 2001), thereby reducing the duration of amortization phase. On the other hand, some authors (Chu, 1983; McFarlane,1984) interpreted the amortization phase as the total time from the beginning of the eccentric phase to the beginning of the concentric phase, thus combining the eccentric and amortization phases and labeling them as "amortization phase". This incorrect use of the terminology may have led other authors to accept the theory of a shorter eccentric phase producing a more powerful concentric action. Although Asmussen and Bonde-Peterson (1974) suggested a negative correlation between the mathematically calculated average eccentric phase durations of various depth jumps and the energy expenditure during the subsequent concentric phases, no studies have directly investigated this theory. Therefore, the purpose of this study was to examine the relationship between the duration of the eccentric phase and the peak force production in the concentric phase of plyometric jumps.

METHODS: Trained male athletes (N = 33, mean age = 20.36 ± 1.11 years) participated in the study. All athletes were recruited from the varsity intercollegiate football team and had at least nine months of plyometric training and depth jumps experience. Subjects completed one depth jump from each of two heights, 33.02 cm (trial A) and 47.94 cm (trial B). The selection of these heights was based on the previous recommendations of 30 to 70 cm (Komi & Bosco, 1978) and 30 to 80 cm (Read & Cisar, 2001). One minute rest time was provided in between the jumps, thus preventing potential decrease in jump performance due to fatigue. After stepping off the box, subjects landed on both feet in the center of the AMTI force platform with their body already in a countermovement position and then immediately executed a maximal vertical jump. Minimum knee angle was calculated by placing reflective markers on the left malleolus, lateral epicondyle, and major trochanter. PEAK Performance (Peak Motus) software and a 60 Hz camera placed perpendicular to the sagittal plane of motion were used to identify initial contact, minimum knee angle, and takeoff. Concentric/eccentric vertical ground reaction forces and ground contact time were determined from the force plate data. Video and force platform data were synchronized to identify the duration of the eccentric phase of each jump by 1.66ms accuracy. Relative peak ground reaction forces were calculated for each jump by dividing the peak vertical force by the subjects' body weight. For validity purposes, the height of each jump was measured and compared to the maximal vertical jump measured during the seasonal performance testing.

RESULTS: The analysis of the subjects' performed vertical jump and their previously measured maximum vertical jump resulted in a significant and positive relationship ($r=0.85$, $p<0.0001$), indicating that subjects gave consistent effort on their jumps. The relationship between the duration of eccentric phase and relative peak concentric force was examined separately for trial A (Figure 1a) and trial B (Figure 1b), and was found similar for the two trials. In both cases there was a significant inverse relationship ($r=-0.40$, $p=0.0194$ in trial A, r=-0.62, p<0.0001 in trial B), indicating higher relative peak concentric force for shorter eccentric duration. A significant difference (p<0.001) was found between the trials when comparing the strength of the relationships of eccentric duration and peak concentric force.

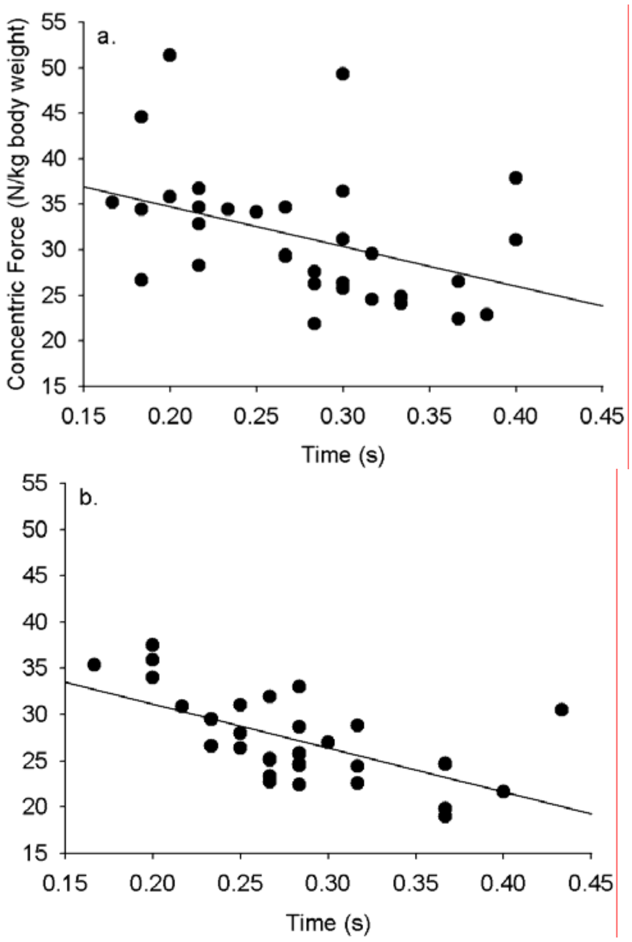

Figure 1 – The relationship between the duration of eccentric phase and relative peak concentric force for trial A (panel a) and trial B (panel b).

DISCUSSION: Significant inverse relationships were found in both trials between eccentric duration and relative peak concentric force, which provides evidence for the original hypothesis of "shorter eccentric phase producing a more powerful concentric action". The relationship was significantly stronger in trial B, the depth jump from the higher box. Regressions for the two relationships reveal that a faster pre-stretch yielding to a more powerful concentric contraction is more evident in higher intensity plyometric jumps. This finding is in accordance to the conclusions of Asmussen and Bonde-Peterson (1974), who examined the energy expenditure of a counter-movement jump and depth jumps from various heights, including 0.23, 0.40, and 0.69 m. These authors concluded that as the intensity of the jumps increased (i.e. the drop height), more energy was available for the elastic components (up to a certain height), which ultimately provided more energy for the concentric phase of the jumps. Similarly, the present study concluded that not only an inverse relationship exists between the duration of eccentric phase and relative peak concentric force production, but that the relationship may depend on the intensity of the plyometric exercise. Further investigation is desirable to examine the strength of the relationship at different plyometric exercise intensities.

CONCLUSION: The purpose of the present study was to examine the original hypothesis that shorter eccentric phase produces higher concentric force (Grieve, 1970). These findings indicated that a shorter eccentric phase produces greater peak concentric force. This relationship is more evident with higher intensity plyometric exercises. Overall, a key component to maximizing force production during plyometric exercises is to minimize the duration of the eccentric phase of the movement.

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