EFFECT OF INCREASING VERTICAL CENTRE OF MASS DISPLACEMENT ON THE BIOMECHANICAL STIMULUS OF TRADITIONAL RESISTANCE TRAINING EXERCISES

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This study investigated the effect of systematically increasing vertical COM displacement on the biomechanical stimulus of a traditional resistance training exercise. Fourteen male rugby union athletes performed maximum velocity repetitions of the deadlift to four different final vertical positions with external loads of 20, 40 and 60% 1RM. Significant increases in force, velocity and power were obtained with lifting techniques that resulted in greater vertical COM displacement, although significant interaction effects revealed that improvements were attenuated with heavier loads. These results have applications to strength and conditioning practice, whereby the traditional resistance training exercise stimulus can be augmented without imposing the overly large eccentric musculoskeletal loads characteristic of landing from maximal weighted vertical jumps.

KEYWORDS: Ballistic, power, weight-training.

INTRODUCTION: Performing resistance training with the intention to lift the load as fast as possible is a common training method used among athletic populations. The practice is commonly referred to as ‘explosive’ resistance training (ERT) and is currently recommended to improve muscular power and athletic performance (ACSM, 2009; Stone 1993). Theoretically, ERT provides an effective training method as both the intent to lift a load as fast as possible and rapid movement velocity have been shown to be important stimuli that elicit high-velocity-specific neuromuscular adaptations (Kawamori 2006). Exercise selection is considered to be an important acute program variable for ERT and the development of muscular power (ACSM, 2009). Customarily, two broad categories of resistance exercises (referred to as traditional and ballistic) are used. However, performing ERT with traditional resistance exercises may not be optimal due to the suggestion that the stimulus is limited by periods of deceleration and reduced force production during the latter stages of the movement (Newton 1996). Instead, researchers generally recommend ERT be performed with ballistic exercises so that force and acceleration can be maintained throughout the movement (Newton 1996; ACSM, 2009). Various ballistic movements (e.g., jump squat and bench throw) are performed by modifying traditional resistance exercises by throwing or jumping with the load at the end of the concentric lifting phase (Newton 1996; Cormie 2007). When these traditional resistance exercises are performed ballistically, there is a significant increase in force, velocity and power production (Newton 1996; Cormie, 2007). However, decelerating these projected loads during ballistic resistance exercises may lead to overuse injuries (Hoffman, 2005). The objective of this study was to quantify the change in biomechanical stimulus as a traditional resistance exercise was gradually modified to a ballistic movement. It was hypothesized that the magnitude of the kinematic and kinetic variables measured would increase with vertical displacement and that significant increases in the mechanical variables could be achieved during augmented vertical displacements that were less than maximum.

METHODS: Fourteen male rugby union athletes (age: 24.1 ± 3.5 yr; stature: 181.1 ± 6.6 cm; mass: 94.1 ± 10.3 kg; 1RM: 171.7 ± 18.2 kg) gave informed consent to participate in this study, which was granted institutional ethical approval. All athletes had extensive resistance training experience and had recently completed an eight week mesocycle where they regularly performed the deadlift movement to the different postures investigated in this study. Data were collected for each subject over two sessions separated by one week. The first session involved 1RM deadlift testing. During the second session subjects performed maximum effort trials with 20, 40 and 60% of their predetermined 1RM. Each load was lifted under four conditions that progressively increased the vertical COM displacement. Condition 1) subjects completed the concentric phase of the movement in an erect standing position with heels in contact with the ground. Condition 2) subjects completed the concentric phase of the movement in an erect standing position with ankles at maximum plantar flexion. Condition 3) subjects completed the concentric phase of the movement by performing a submaximum vertical jump with the external load held at arms‘ length. Condition 4) subjects completed the concentric phase of the movement by performing a maximum vertical jump with the external load held at arms‘ length. Two repetitions were performed in each trial to assess reliability.

Trials were performed with a separate piezoelectric force platform (Kistler, Type 9281B Kistler Instruments, Winterthur, Switzerland) under each foot. Displacement, velocity and power data were calculated for the lifter and external load as a single system. This was achieved by incorporating the vertical ground reaction force (VGRF) data and using the principle that the impulse applied to the system equals its change in momentum (Kawamori 2005). Briefly, trials were initiated with subjects standing erect with the load held at arms' length. Changes in vertical velocity of the system COM were calculated by multiplying the net VGRF (VGRF recorded at the force plate minus the weight of the system) by the intersample time period divided by the mass of the system. Instantaneous velocity at the end of each sampling interval was determined by summing the previous changes in vertical velocity to the pre-interval absolute velocity, which was equal to zero at the start of the movement. The position change over each interval was calculated by taking the product of absolute velocity and the intersample time period. Vertical position of the system COM was then obtained by summing the position changes. Instantaneous power was calculated by taking the product of the VGRF and the concurrent vertical velocity of the system.

A general linear model with repeated measures and Bonferroni *post hoc* tests were used to determine significant differences. All statistical analyses were conducted using SPSS Version 15.0, with statistical significance accepted at a level of $p<0.05$

RESULTS: Test-retest reliability for average velocity, peak velocity, average power, peak power, average force, peak force and COM displacement were all high (ICC = 0.92, 0.89, 0.97, 0.94, 0.98, 0.97, and 0.90), respectively. Vertical displacements of the system COM during the ascent phase of the four lifting conditions are presented in Table 1.

Table 1. Vertical displacements of the system COM during the four lifting conditions with 20, 40 and 60% 1RM barbell loads.

Condition	COM Displacement 20% 1RM (cm) Mean ± SD	COM Displacement 40% 1RM (cm) Mean ± SD	COM Displacement 60% 1RM (cm) Mean ± SD
1	49.9 ± 6.4	48.1 ± 6.0	46.5 ± 5.0
2	61.5 ± 9.9	59.8 ± 6.2	51.6 ± 4.7
3	70.3 ± 8.5	66.0 ± 6.6	54.9 ± 4.6
4	89.1 ± 12.0	77.1 ± 9.1	61.1 ± 4.8

Displacement had a significant effect on the biomechanical stimulus of the exercise, as shown by main effects obtained for lifting condition and all variables measured ($p<0.05$). The results demonstrated a positive relationship between vertical displacement and the magnitude of the mechanical variables analyzed (Figure 1). Significant interaction effects of lifting condition and load were obtained for peak velocity, average power, peak power, average force and peak force. The interaction effects reveal that as the external load increased the augmentation of the mechanical stimulus as a result of increased vertical displacement became attenuated, with the greatest attenuations occurring in the maximal jump condition.

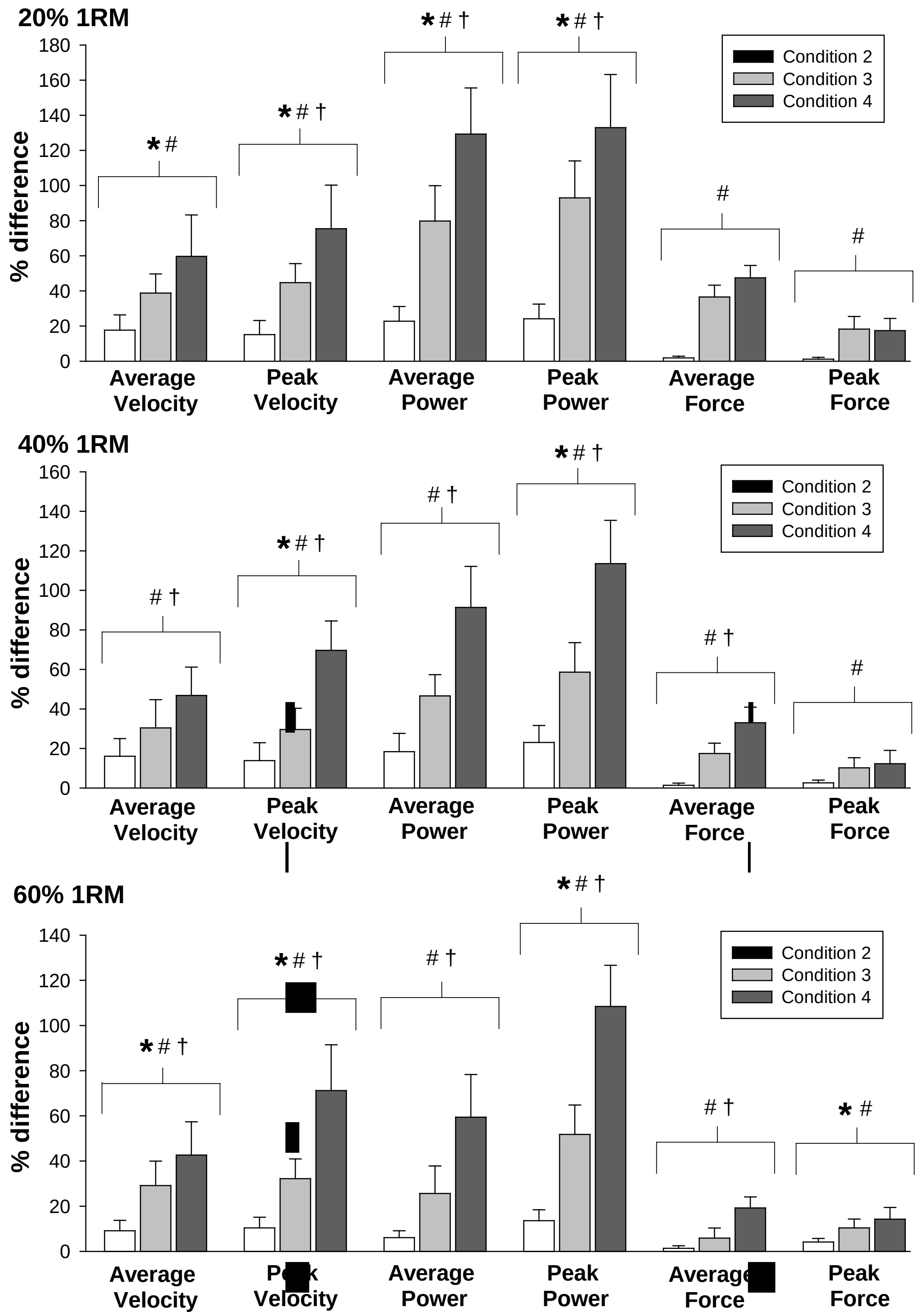

Figure 1. Kinematic and kinetic data for lifting conditions 2, 3 and 4 expressed as a percentage difference relative to lif[redacted]ng condition 1. *Conditions 2, 3 and [redacted] are significantly ($p < 0.05$) different from condition[redacted]1. #Conditions 3 and 4 are significa[redacted]y ($p < 0.05$) different from condition 2. †Condition 4 is significantly ($p < 0.05$) different from condition 3. Error bars represent ± SD.

DISCUSSION: The results of the current investigation show that a positive relationship exists between the vertical displacement of the COM during a resistance training exercise and the magnitude of the force, velocity and power produced. Similar findings have been reported in studies that have compared the mechanical stimulus of the traditional squat and the jump squat (Cormie 2007). By increasing the vertical displacement of the COM the athlete has more time to apply force and change the momentum of the overall system (Frost 2008). In resistance exercises where the body is free to move as a single unit, vertical displacement of the COM will be maximised by jumping with the external load at the end of the movement. Whilst this technique provides the impetus to produce greater amounts of force and power, jumping with an external load may require the athlete to absorb a substantial amount of kinetic energy during the landing phase. Research has shown that large eccentric muscular forces produced to decelerate the system during the landing phase may stimulate physiological adaptations that improve maximum strength (Hoffman, 2005). However, it is also acknowledged that during the landing phase the potential for injury is at its greatest (Hoffman, 2005). When implementing a structured periodization model it may be advantageous to include exercise variations which augment the biomechanical stimulus of traditional resistance training exercises, but do not expose the athlete to the large eccentric loads imposed by maximum weighted jumps. For an exercise such as the deadlift, this study shows that such variations can be obtained by simply plantar flexing the ankles or performing a short jump with the external load held at arms-length at the end of the concentric movement. Future research is warranted to investigate the longitudinal effect of incorporating lifting techniques which alter the vertical COM displacement within a structured periodized model.

CONCLUSIONS:
It is widely accepted that the mechanical stimulus of traditional resistance training exercises are enhanced when an athlete attempts to jump with the load as high as possible. However, the results of the current study reveal that significant increases in force, velocity and power can be obtained by increasing vertical COM displacement by simply plantar flexing the ankles or performing a submaximal vertical jump. This information may prove valuable for strength & conditioning coaches who wish to augment the stimulus of traditional resistance training exercise without imposing the large eccentric musculoskeletal loads that are imposed during the landing phase of weighted maximum jumps.

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