EFFECT OF LOAD POSITIONING ON THE KINEMATICS AND KINETICS OF WEIGHTED JUMPS

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The present study sought to examine the effect of altering the position of external loads on the kinematics and kinetics of weighted vertical jumps in 29 resistance trained rugby union athletes. Vertical jumps were performed with loads of 20, 40 and 60% squat 1RM with the load positioned: 1) on the posterior aspect of the shoulder using a traditional barbell (TBJ); and 2) at arms' length using a hexagonal barbell (HBJ). Weighted jumps performed with the load held at arms' length resulted in significantly greater values for jump height, peak force, peak power, and peak rate of force development ($p<0.05$), indicating a greater training stimulus for the HBJ than TBJ. These results suggest that when using weighted vertical jumps to improve lower body muscular performance, the jumps should be performed with the external load at arms' length rather than on the shoulder.

KEYWORDS: Ballistic; power; weight-training.

INTRODUCTION: The vertical jump is an important feature of many sports and is often incorporated with other explosive body weight exercises in plyometric training programs aimed at developing muscular power and athletic performance. Resistance is frequently added to the vertical jump to increase the intensity of the training stimulus (Saez-Saez De Villarreal, 2009). The most common methods of applying resistance to the vertical jump include the use of dumbbells, barbells, weighted vests and elastic resistance bands secured to the floor. Research has shown that when resistance is applied to the vertical jump there is a significant change in the expression of force, velocity, power and rate of force production (Cormie, 2007; Moir 2005; Stone, 2003). Consistently, studies have demonstrated that the addition of resistance increases force production and decreases velocity and rate of force development (Cormie, 2007; Moir 2005; Stone, 2003). Varied results have been reported for the effect of added resistance on power production during vertical jumps. Some studies have reported that added resistance of approximately 40 to 60% 1RM may be required to maximise power (Stone, 2003; Sleivert, 2004). However, recent studies suggest that power is maximised when vertical jumps are performed unloaded (Cormie, 2007; Bevan 2010). If large external loads are included to alter the biomechanical stimulus of the vertical jump it is likely that positioning of the external load will be an important factor in determining the kinematic and kinetic changes. Difficulties exist in applying large resistances in the form of dumbbells, weighted vests or elastic bands. As a result, heavy loaded vertical jumps are customarily performed with the external load positioned on the posterior aspect of the shoulder using a straight barbell. An additional method which has not been considered in the literature is the use of the hexagonal barbell (Figure 1). The non-conventional barbell would enable the athlete to apply loads similar to that used during jumps with the weight placed on the shoulders. In addition, the design of the hexagonal barbell would enable the athlete to position the load closer to the body's centre of mass and reduce the resistance moment at the hip joint. As the weighted jump is considered one of the most effective methods to enhance lower body power (Baker 1996), the purpose of the study was to investigate whether changing position of the external resistance from the shoulders to arms' length would affect the kinematic and kinetics of the movement. Because this was an exploratory study, no formal hypotheses were specified.

METHODS: Twenty nine male rugby union athletes (age: 26.3 ± 4.6 yr; stature: 182.4 ± 6.8 cm; mass: 94.5 ± 13.1 kg; 1RM Squat: 153.7 ± 20.3 kg) gave informed consent to participate in this study, which was granted institutional ethical approval. All athletes had extensive resistance training experience and regularly performed weighted jumps in their strength & conditioning sessions. Data were collected for each subject over two sessions separated by one week. The first session involved 1RM testing in the squat and hexagonal barbell deadlift. The second session involved maximum effort jumps with loads of 0, 20, 40 and 60% of the recorded squat 1RM. Loaded jumps were performed across two conditions that altered the positioning of the external resistance. The first condition required the load to be placed across the posterior deltoids using a traditional barbell (TBJ). During the second condition subjects held the external resistance at arms' length using a hexagonal barbell (HBJ). All jumps were performed in a randomized order with two repetitions performed in each trial to assess reliability. Unloaded jumps (0% 1RM) were performed with the arms held stationary at the side of the body.

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 at the athletes' COM during unloaded trials, and at the system COM (athlete + external load) during loaded trials 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 and motionless. Once data acquisition was initiated, subjects were instructed to lower themselves to approximately 120° of hip flexion, where they then reversed the movement and attempted to jump as high as possible. 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 athlete + external resistance) 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. The vertical velocity of the system at take-off was used to calculate jump height using the constant acceleration equation (Jump height = $(TOV)^2$ / 2g, where TOV = vertical velocity of the system COM at take-off, g = $9.81ms^{-2}$). Instantaneous power was calculated by taking the product of the VGRF and the concurrent vertical velocity of the system. Analyses were performed for the ascent phase only.

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 $p<0.05$

Figure 1: Weighted jumps performed with the traditional straight barbell and the hexagonal barbell.

RESULTS: Test-retest reliability for vertical jump height, average force, peak force, average velocity, peak velocity, average power, peak power and PRFD were all high (ICC = 0.98, 0.98, 0.97, 0.94, 0.90, 0.97, 0.94 and 0.80), respectively. Subjects were able to lift a significantly heavier 1RM load in the hexagonal barbell deadlift compared to the traditional barbell squat (195.4 ± 18.3 kg vs. 153.7 ± 20.3 kg, $p<0.05$). The mean jump height, peak force, peak velocity and peak power values for the group during the unloaded condition equalled 39.3 ± 5.5 cm, 1967 ± 202 N, 2.79 ± 0.18 ms^{-1}, 4324 ± 301 W, respectively. The addition of resistance to the vertical jump significantly increased peak force ($p<0.05$) and decreased peak velocity ($p<0.05$). Significantly greater peak power values were obtained for jumps performed with the hexagonal barbell and a load of 20% 1RM than all other conditions ($p<0.05$). Significantly higher weighted jumps were obtained when the external resistance was positioned at arms' length ($p<0.05$, Table 1).

Table 1. Loaded vertical jump heights obtained with 20, 40 and 60% 1RM barbell loads. *Significant difference of load position for corresponding load ($p<0.05$).

Condition	Vertical Jump Height 20% 1RM Mean ± SD	Vertical Jump Height 40% 1RM Mean ± SD	Vertical Jump Height 60% 1RM Mean ± SD
TBJ (cm)	20.2 ± 4.0*	14.0 ± 2.7	8.5 ± 2.1
HBJ (cm)	27.1 ± 3.9*	15.2 ± 2.6	8.9 ± 1.9

Significant main effects of load position were obtained for peak force, peak power, and peak rate of force development ($p<0.05$). For all variables measured there was a trend towards higher values when the external load was positioned at arms' length using the hexagonal barbell (Table 2).

Table 2. Kinematic and kinetic data for loaded jumps performed with 20, 40 and 60% 1RM barbell loads. *Significant difference of load position for corresponding load ($p<0.05$).

	20% 1RM Mean ± SD	40% 1RM Mean ± SD	60% 1RM Mean ± SD
TBJ Average Force (N)	1853 ± 214	2064 ± 204	2291 ± 201
HBJ Average Force (N)	1866 ± 164	2069 ± 171	2326 ± 163
TBJ Peak Force (N)	2243 ± 252*	2509 ± 233*	2726 ± 208*
HBJ Peak Force (N)	2353 ± 213*	2689 ± 252*	2945 ± 232*
TBJ Average Velocity (ms^{-1})	1.23 ± 0.12	0.98 ± 0.13	0.87 ± 0.15
HBJ Average Velocity (ms^{-1})	1.33 ± 0.11	1.03 ± 0.12	0.87 ± 0.07
TBJ Peak Velocity (ms^{-1})	2.28 ± 0.17*	1.94 ± 0.20	1.73 ± 0.21*
HBJ Peak Velocity (ms^{-1})	2.39 ± 0.18*	1.99 ± 0.16	1.76 ± 0.10*
TBJ Average Power (W)	1994 ± 224*	1857 ± 286	1590 ± 356
HBJ Average Power (W)	2158 ± 307*	2041 ± 279	1623 ± 202
TBJ Peak Power (W)	4091 ± 438*	4065 ± 508	3789 ± 542
HBJ Peak Power (W)	4606 ± 510*	4386 ± 544	3831 ± 345
TBJ PRFD (Ns^{-1})	4848 ± 1538*	4938 ± 924*	5085 ± 917*
HBJ PRFD (Ns^{-1})	27805 ± 2379*	9062 ± 2505*	8349 ± 2014*

DISCUSSION: Results demonstrated that positioning of the external resistance had a significant effect on the kinematics and kinetics of weighted jumps. Customarily, when athletes perform weighted jumps with substantial resistances the external load is positioned on the posterior aspect of the shoulder using a straight barbell. The current study shows that changing the position of the load from the shoulders to arms' length using a hexagonal barbell results in significant increases in peak force, peak power, and peak rate of force development, with a trend towards higher velocity, average force and average power values The results also demonstrate that the hexagonal barbell can be used to apply resistances equal to or greater than that obtainable with a straight barbell. As the analyses in this study were limited to the propulsive phase of the jump, future research should investigate whether positioning of the load effects landing kinematics and kinetics which are important factors for preventing injury.

Force and velocity data obtained in this study are similar to values reported previously for weighted jumps (Moir, 2005; Sleivert, 2004; Cormie 2007). Higher peak power values than those obtained here have been reported by Cormie et al (2007) and Sleivert et al (2003). Methodological differences in the calculation of power are likely to account for the variance in results. An extensive amount of research has been devoted to identifying loads that produce maximum power during vertical jumps due to the suggestion that these loads will be the most effective for developing power. When comparing unloaded and weighted jumps performed with the straight barbell in this study the results coincided with recent research (Cormie, 2007; Bevan 2010) showing that maximum power is produced during unloaded jumps. In contrast, when comparing jumps performed with the hexagonal barbell the results showed that maximum power was produced with a load of 20% 1RM, with no significant difference between the unloaded and 40% 1RM conditions. The results of this study should be used to inform the exercise and load selection for training sessions aimed at developing lower body power.

CONCLUSIONS: The weighted jump is considered to be one of the most effective exercises for developing lower body power. Traditionally, weighted jumps are performed with the external load positioned on the posterior aspect of the shoulder using a straight barbell. The results of this study show that a greater mechanical stimulus can be achieved by changing the position of the external load from the shoulders to arms' length through the use of a hexagonal barbell.

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