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Effect of Additional Load on Power Output during Drop Jump Training

by
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Plyometrics can be an effective way of improving power performance in many sports. The purpose of this study was to examine the effects of additional loading on power during drop jump training. Forty-two untrained physical education students with plyometric training background participated in a six-week training 3 times a week. Subjects were randomized to one of three training groups: without (FREE) and with a weight vest (VEST; 5% body weight), and a control group (CON). Pretraining and post-training measures of concentric peak power (PP), force (F_{PP}) and velocity (v_{PP}) at peak power and, in addition, time between eccentric and concentric peak power (t_{PPEC}) were analyzed in a countermovement jump (CMJ) and a drop jump (DJ) from a height of 0.3 m. The FREE and VEST groups considerably improved PP in CMJ ($p < 0.05$), but v_{PP} significantly increased ($p < 0.05$) and t_{PPEC} significantly decreased ($p < 0.05$) only in the FREE group. The enhancement of PP and v_{PP} was only demonstrated by the FREE group in DJ. The FREE group significantly decreased ($p < 0.05$) and the VEST group significantly increased ($p < 0.05$) t_{PPEC} in DJ. It can be concluded that using additional load during drop jump training does not produce superior gains in power output when compared to a traditional drop jump training program..

Key words: plyometrics, stretch-shortening cycle, peak power, dynamography, kinetics

Introduction

Plyometric exercises involve specific muscle action called a stretch-shortening cycle (SSC). This sequence of rapid eccentric (stretching) and concentric (shortening) action produces more powerful gains than concentric action alone (Finni et al., 2001). As power is the main determinant of sports performance (Kawamori & Haff, 2004), plyometric exercises are often used in many training programs (Luebbers et al., 2003; Myer et al., 2006; Makaruk & Sacewicz, 2010).

Because the specificity of each sport requires increased power in different conditions (e.g., shot put vs. sprint runs), power training programs should also take into consideration the components of power: force (*F*) and velocity (*v*). While many studies also point out that an additional load is the best training stimulus to maximize power output (Jones et al., 2001; Hoffman et al., 2005; Winchester et al., 2008), it is crucial, however, to find an optimal load to achieve the training goals.

The issue of using an additional load during plyometric training is complex. Bosco et al. (1986) reported that 3 weeks of strength training with plyometric exercises with a weight vest (7-8% of body weight; BW) significantly improved performance in sprint runners, whereas there were no changes in the control group. On the other hand, Larson's study (2003) did not show differences in jumping heights between groups with and without the additional load during pure plyometric training.

Drop jump training with a weight vest or belt/barbell is even more controversial. During a drop jump (DJ), an explosive vertical jump occurs immediately after preloading, by dropping down from a given height, usually between 0.2-06 m (Markovic, 2007). It has been demonstrated that DJs result in muscle damage because of eccentric contraction and

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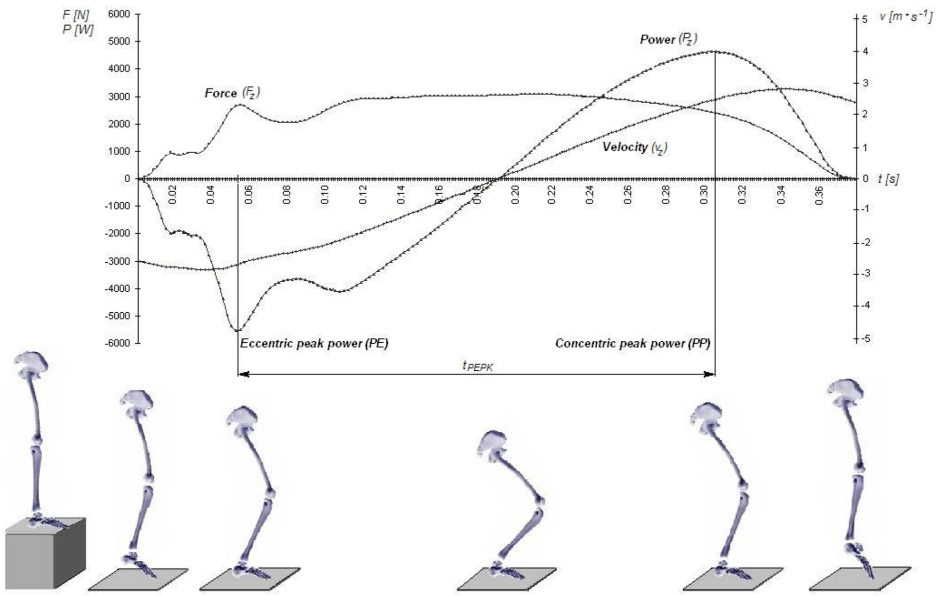

Figure 1

Illustration of the measured and computed data during drop jump from height of 0.3 m

high ground reaction forces (GRF) (Robinson et al., 2004; Miyama & Nosaka, 2007). Therefore, additional loading during drop jumps may induce excessive stress on muscles and joints (Fowler et al., 1994; Kulas et al., 2008), as well as increase contact time, and these two variables considerable deteriorate the SSC (Saez-Saez de Villarreal et. al, 2010). On the other hand, Jansen and Ebben (2007) did not oppose to using the additional load during drop jumps. They claim that loaded drop jumps are usually performed from low heights, which provide less gravitational acceleration and moderate intensity of the jumps.

The main purpose of this study was to determine the effects of additional loading on power output during drop jump training, which was preceded by establishing differences in kinetics between drop jumps without and with an additional load. It was hypothesized that drop jumps with an additional load would not produce greater gains in power than traditional drop jumps.

Material & Methods

Subjects

Forty-two untrained physical students (aged 21.2±1.3; body weight 76.1±7.7 kg; body height 1.82±0.06 m) volunteered for this study. The subjects were randomly assigned to one of three groups: drop jumps without an additional load (FREE; *n*=14), with 5% of BW (VEST, *n*=14), and a control group (CON, *n*=14), which underwent no plyometric intervention. All subjects were experienced in drop jumps because they had participated in plyometric training studies at least twice before the study. Participants were asked to abstain from any other strength and power activities during the period of study. All subjects attended the same classes (i.e., football, taekwon-do, and Nordic walking); each for two hours per week. The subjects were given an explanation on the nature of this study and all were provided written informed consent in accordance with the demands of the Research Ethics Committee of the University of Physical Education in Warsaw.

Measurements

Kinetic data were recorded using a piezoelectric force platform (Kistler 9281CA, Switzerland), with sampling frequency of 500 HZ. Signals from the platform were amplified and recorded on a PC computer using a 16-bit A/D board and Bio Ware 3.24 software.

The following parameters were analyzed in eccentric and concentric phases (Figure 1): peak power (P_z), instantaneous ground reaction force (F_z) and velocity (v_z) at peak power. In addition, the time between eccentric and concentric peak power (t_{PPEC}) was measured.

The vertical acceleration of the center of mass was calculated according to the following formula:

$$a_z(t) = \frac{F_z(t) - m \cdot g}{m} \quad (1)$$

The vertical velocity of the center of mass was obtained by numerical integration of the vertical acceleration $a_z(t)$

$$v_z(t) = \int_0^t a_z(t)dt \quad , \quad (2)$$

where t = foot contact time. Peak power (P_z) was calculated as the product of instantaneous vertical ground reaction force F_z and vertical velocity v_z

$$P_z(t) = F_z(t) \cdot v_z(t) \quad (3)$$

Testing

In the preliminary study, subjects performed three randomly ordered trials of DJ in each of the six conditions: from heights of 0.2, 0.3, and 0.4 with 0 and 5% of BW. The best trial (peak concentric power; *PP*) was used for data analysis. The interval between trials was about 30 seconds and for each condition there was a 3- or 4-minute pause. The instruction given to each subject was "drop off the box, and immediately jump as high as you can". The upper extremities first swung backwards and then high upwards. The knee flexion angle was not specified. In the primary study, a countermovement jump (CMJ) and a DJ from the height of 0.3 m were performed twice: 3 days before the training period and then after its completion during the second part of the study. Testing procedures were the same as above.

The reliability of measurements in CMJ and DJ was evaluated one week before the study. The interclass coefficients were 0.87-0.92 for peak power in different conditions, and 0.93-0.95 for force at peak power and 0.85-0.90 for velocity at peak power.

Training Procedure

Eight conditioning sessions and two plyometric-oriented sessions were conducted before the training period. Plyometric training programs were conducted 3 days a week for 6 weeks (Monday, Wednesday, and Friday), apart from the first and last week of intervention (only Monday and Friday).

All training sessions were performed indoors on a synthetic (tartan) surface. Each session lasted 40-45 minutes. The warm up consisted of 5-minute jog, 5-minute dynamic stretching (swings, rotations, and bends), abdominal and back exercises (each 2 x 10 repetitions) to protect the back, and rope jumps 6 x 10. Three types of drop jumps were implemented as core exercises to maximize power output (Figure 2): (a) drop jump, (b) drop jump with two boxes (DJ2), (c) drop jump with hurdle (DJH). Subjects were instructed to jump as quickly as possible to a maximum height in DJ, on box in DJ2, and over the hurdle in DJH. In addition, all tasks were performed with full extension in the hip and knee joint, and the feet were set slightly outwards. The rest interval between sets was about 2 minutes. No subject complained of muscle or joint pains. After each session, hanging on the bar (3 x 5 seconds) and abdominal and back exercises (2 x 10 repetitions) were performed again. The training programs were identical (Table 1) except for the additional load in the VEST group (5% of BW).

Statistical analysis

The Shapiro–Wilk test was used to check the normality of the data. The statistical significance of the differences between variable means (peak power, force, velocity, and time peak power in eccentric and concentric phases between unloading and loading

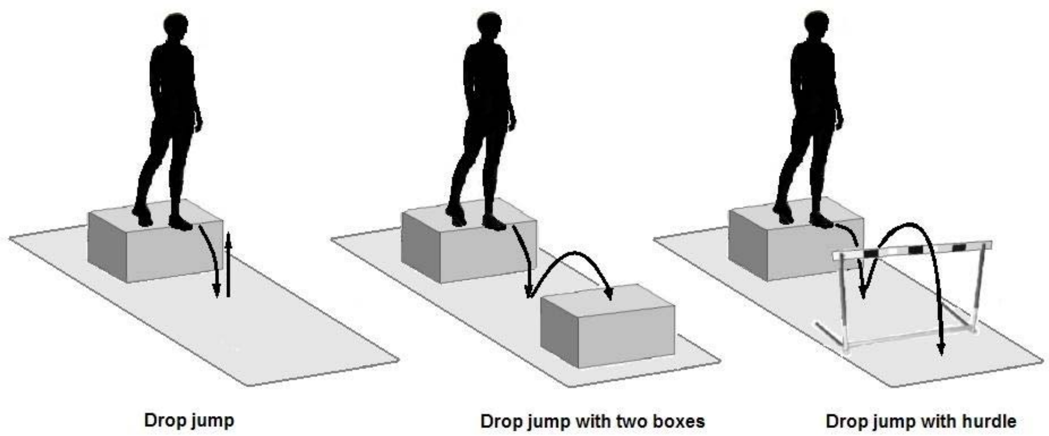

Figure 2
Illustration of drop jump (DJ), drop jump with two boxes (DJ2), and drop jump with hurdle (DJH)

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Table 1

Summary of drop jump training program

Week	Drop height 0.2 m	0.3 m	0.4 m
	Set x repetition	Set x repetition	Set x repetition
1	3 x 5 – DJ	4 x 5 – DJ2	-
2	2 x 5 – DJ	4 x 5 – DJH	2 x 5 – DJ2
3	2 x 5 – DJ2	3 x 5 – DJ	3 x 5 – DJH
4	2 x 5 – DJH	4 x 5 – DJ2	3 x 5 – DJ
5	2 x 5 – DJ	4 x 5 – DJH	3 x 5 – DJ2
6	2 x 5 – DJ2	3 x 5 – DJ	3 x 5 – DJH

Drop jump (DJ), drop jump with two boxes (DJ2), drop jump with hurdle (DJH)

conditions) was assessed by means of a Student's *t*-test. A two-way (group x time) repeated-measures ANOVA with Tukey post hoc adjustments were used to compare the changes in the dependent variables among the groups over the intervention period. Statistical significance was set at $p<0.05$. Statistica v. 5.1 program was used for the calculations.

Results

Preliminary study

The velocities at eccentric peak power (v_{PE}) for DJ from height of 0.2 and 0.4 m were significantly higher in loading versus unloading conditions (Table 2), but the force at eccentric peak power (F_{PE}) was significantly lower in DJ from the height of 0.4 m.

The drop jump without the additional load (FREE) from the height of 0.3 m resulted in higher *PP* values, whereas higher v_{PP} values were associated with drop jumps from the heights 0.2 and 0.3 m, relative to loaded conditions (VEST). The differences in t_{PPEC} between both conditions were significant at all starting heights and t_{PPEC} was shorter for the DJ without an additional load.

Primary study

The effects of drop jump training on kinetics are presented in Table 3-4. Both FREE and VEST groups increased *PP* in CMJ (there was a significant group x time interaction: $F_{2,39}=4.26$; $p < 0.05$). A significant increase in v_{PP} and decrease in t_{PPEC} (group x time interaction: $F_{2,39}=3.95$; $p < 0.05$ and $F_{2,39}=10.12$; $p < 0.01$, respectively) were observed only in the FREE group.

A significant improvement in *PP* and v_{PP} was observed for DJ in the FREE group (there was a significant group x time interaction: $F_{2,39}=3.31$; $p < 0.05$ and $F_{2,39}=3.49$; $p < 0.05$, respectively). A significant group by time interaction was found for t_{PPEC}, $F_{2,39}=11.38$; $p < 0.001$, whereby the decrease in the FREE group and the increase in the VEST group were noted.

Discussion

The main findings of the study indicate that drop jumps with an additional load do not demonstrate superior performance in power output when compared to traditional drop jumps (without the additional load). Moreover, greater gains in peak power or velocity at peak power were observed in the FREE group, which did not use any additional load during drop jumps.

The identification and comparison of kinetics in loading and unloading conditions were obtained at the starting point of the study. The additional load did not affect the peak power in the eccentric phase at all heights. This indicates that increasing body weight during drop jumps does not appear to be a superior stimulus for effective eccentric stretch to produce positive effects in concentric action (Moran & Wallce, 2007). The significant increase of the vertical velocity accompanied by substantial decrease of the vertical

Table 2

Mean ± SD of eccentric (PE) and concentric (PP) peak power, force (F_{PE}) and (F_{PP}), velocity (v_{PE}) and (v_{PP}) at peak power and time between eccentric and concentric peaks power (t_{PEPK}) for drop jumps (DJ) without and with additional load

Drop height (m)	Load (% BM)	Eccentric phase *PE* (W)	F_{PE} (N)	v_{PE} ($m \cdot s^{-1}$)	Concentric phase *PP* (W)	F_{PP} (N)	v_{PP} ($m \cdot s^{-1}$)	Time t_{PPEC} (s)
0.2	0	4806±325	2183±172	2.21±0.15	4744±529	2071±198	2.29±0.13	0.278±0.016
	5	4843±411	2127±181	2.28±0.12[b]	4643±347	2092±158	2.22±0.15[a]	0.294±0.018[c]
0.3	0	5573±501	2429±185	2.30±0.14	5258±427	2203±225	2.39±0.14	0.276±0.013
	5	5459±348	2348±209	2.33±0.16	4921±479[a]	2115±193	2.33±0.12[a]	0.288±0.017[c]
0.4	0	6881±703	2946±268	2.34±0.15	4981±387	2061±186	2.42±0.16	0.266±0.012
	5	6756±812	2777±293[a]	2.43±0.13[b]	5059±436	2153±208	2.35±0.13	0.278±0.015[b]

Significantly different from DJ without additional load from the same height: [a]-p<0.05; [b]-p<0.01; [c]-p<0.001

Table 3

Mean ± SD of changes for peak power (PP) and force (F_{PP}) and velocity (v_{PP}) at peak power in concentric CMJ and DJ during the training intervention

Type of jump	*Group*	*Concentric phase*					
		PP (W)		F_{PP} (N)		v_{PP} (m · s^{-1})	
		Pre	Post	Pre	Post	Pre	Post
CMJ	FREE	3447±383	3859±473[a]	1467±157	1556±171	2.35±0.013	2.48±0.16[a]
	VEST	3422±456	3877±408[a]	1432±149	1589±185	2.39±0.016	2.44±0.18
	CON	3339±491	3395±512	1409±165	1451±172	2.37±0.014	2.34±0.16
DJ (0.3 m)	FREE	5358±379	5729±476[a]	2329±171	2381±189	2.30±0.010	2.41±0.011[a]
	VEST	5119±497	5479±417	2248±208	2431±215	2.28±0.011	2.26±0.013
	CON	5352±522	5305±519	2359±211	2345±223	2.27±0.012	2.26±0.011

Significantly different from pretraining values [a]-$p<0.05$

ground reaction at eccentric peak power in drop jumps with the weight vest from the height of 0.4 m seem to point to a comparatively soft landing. This observation confirms the presence of protective inhibition against the impact stress during the eccentric phase, as reported by Gollhofer & Kyrolainen (1991) and Leukel et al. (2008).

The additional load considerably decreased peak power in drop jumps from height of 0.3 m in the concentric phase. This was probably associated with decreased velocity at peak power, which was noticed for DJ with the weight vest from the heights of 0.2 m and 0.3 m. These findings are supported by research conducted by Driss et al. (2001), who also showed decreased peak power and velocity at peak power by adding the additional load for CMJ in untrained males, and by Cormie et al. (2008), who reported that acceleration of the system mass decreases as the additional load is increased during squat jump.

The DJ with a weight vest elicited longer time between eccentric and concentric peak power. This suggests that it may decrease efficacy of SSC by a greater loss of stored elastic energy by minimizing the contribution of elastic elements of the muscle-tendon unit (Wilson et al., 1991).

Table 4

Mean ± SD of changes for time between eccentric and concentric peak power (t_{PPEC}) in CMJ and DJ during the training intervention

Type of jump	Group	Time; tPPEC (s)	
		Pre	Post
CMJ	FREE	0.342±0.041	0.322±0.039[a]
	VEST	0.350±0.036	0.364±0.034
	CON	0.358±0.040	0.350±0.038
DJ (0.3 m)	FREE	0.272±0.021	0.258±0.018[a]
	VEST	0.274±0.019	0.290±0.018[a]
	CON	0.280±0.018	0.286±0.022

Significantly different from pretraining values [a]-$p<0.05$

The primary study involved a comparison of drop jump training with and without the additional load. Both FREE and VEST groups significantly improved concentric peak power in CMJ. Such findings are consistent with those of Larson (2003), who reported that there was no need for adding a weight vest to increase effectiveness of plyometric training. In addition, the results of the present study also demonstrated that the unloading drop jump training provided a greater contribution of velocity to peak power production or decreasing time between eccentric and concentric peak power. This may indicate that plyometric training gains in power output are associated with the enhancement of speed of movement at a given force, rather than the improvement of muscle strength. Such a conclusion is in accordance with previous research in untrained individuals (Sorensen et al., 2006). These findings are valuable to ball games coaches, since it has been reported that during the competitive season in volleyball players, peak velocity for CMJ and DJ decreases (Newton, 2006). It is also worth mentioning that although changes in force at peak power were not significant ($p = 0.07$) for CMJ in the VEST group, trends may indicate that using the additional load affected muscle strength. Therefore, drop jump training with a weighted vest for athletes who require power production against large resistance (e.g., shot put or wrestling) may be considered. However, it should be examined in trained subjects in future studies.

The FREE group significantly increased peak power in DJ test, while the VEST group did not. As seen earlier in CMJ, gains in peak power resulted from increased velocity at peak power. However, the non-significant decrease of peak power in the VEST group was probably associated with time increase between eccentric and concentric peak power. This factor can deteriorate stretch-shortening cycle mechanism, as previously stated.

It is notable that both CMJ and DJ show different results, most probably due to the nature of both tests. The DJ is classified as fast SSC, characterized by a shorter contraction time and a smaller range of motion when compared with the CMJ, which is rated as slow SSC. It has been hypothesized that each of these can represent different muscle action patterns (Flanagan & Comyns, 2008). Thus, our research confirms that the DJ was more sensitive for detecting neuromuscular changes due to plyometric training in individuals than the CMJ. Also, Gheri et al. (1998) pointed out that drop jumps are more advantageous to sport-specific jumping and are applied in training more frequently than countermovement jumps.

From a practical perspective, the present findings suggest that traditional plyometric training is sufficient to enhance power output in beginners. However, inclusion of an additional load should be considered with caution for strength-power athletes.

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