QUANTIFICATION OF DROP JUMPS FOR TRAINING IMPLICATION

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Peak vertical ground reaction force (F_{zpeak}), duration on force plate, flight time, and the eccentric loading rate (ELR) were examined during seven drop jumps (DJ) from 22.9 to 68.6 cm and a counter movement jump (CMJ). Thirty-four volunteers performed 16 jumps (14 DJs and 2 CMJs). Subjects were instructed to drop without changing the vertical component of the center of mass. They jumped maximally each jump using any technique and a rest period of 3+min between each jump was implemented. The data were gathered via force plate. Results indicated a significant F_{zpeak} difference between trials. There was a significant flight time difference between CMJ and DJs in a given trial, but no differences between DJs in a given trial. No significant differences were present for time spent on the plate between jumps, however; the ELR was different for DJs at the extremes.

KEY WORDS: plyometrics, vertical jump, stretch shortening cycle, countermovement jump

INTRODUCTION: Coaches and athletes use plyometric exercises to increase power production in skeletal muscle and increase performance. A plyometric exercise is a quick, powerful movement in which the muscle goes through two phases: a rapid eccentric contraction phase, which stretches the muscle, immediately followed by the concentric phase, which shortens the muscle. This process of eccentric contraction followed by a concentric contraction is identified as the stretch-shortening cycle (SSC) and involves the stretch reflex and elastic recoil of muscle (Ebben, Blackard, & Jensen 1999).

During a drop jump (DJ), an athlete drops from a raised platform and then maximally jumps (vertically) immediately after touching the ground. During the eccentric phase, elastic energy is stored in the stretching muscle(s) and is added to the energy produced in the concentric phase (Kollias et al., 2004). As soon as the knee flexion ceases the immediate concentric phase (muscle shortening) takes place, causing knee extension.

The maximal jump height, which an athlete can attain from a specific drop height, has become the standard dependent variable when analyzing a DJ. Lees and Fahmi (1994) found that the optimal drop height for a maximal jump height was 12 cm. They stated their findings contradicted the 40 cm drop height recorded by Asmussen and Bonde-Petersen (1974) and the findings of Komi and Bosco (1978), who found no significant differences in jump height between CMJ and DJ.

A way to monitor load or stress produced by DJ is needed to design training programs. By standardizing workloads, the principles of progressive overload and periodization can be more closely manipulated to obtain greater benefits for athletes. Ebben, Blackard, & Jensen (1999) and Wilson, Murphy, & Giorgi (1996) have been the only researchers, thus far, to quantify plyometric loads for exercise prescription.

This study sought to quantify work loads of DJs from various heights for practical implementation of training. In addition, vertical jump (VJ) height, contact time on ground (plate), and/or optimal platform height for VJ were used as variables to indicate a recommended drop height.

METHODS: Approval for the use of Human Subjects was obtained from the institution prior to commencing the study. Thirty-four NCAA Division II football players (mean ± SD: height = 184.3 ± 6.0 cm, weight = 91.5 ± 11.4 kg, age = 19.4 ± 1.6 yrs) volunteered to partake in all aspects of the study. A warm-up session was implemented with four-six minutes of jogging and five minutes allotted for static stretching, targeting the lower limbs and hip muscles. Subjects were verbally instructed on proper drop technique and performed two practice jumps from a platform height of 42 cm. Two trials of eight total jumps including a CMJ and

DJs from 22.9, 30.5, 38.1, 45.7, 53.3, 61.0, 68.6 cm were performed for maximal height.
Data were collected at 2000 Hz using an AMTI OR6-7-2000 force plate via BioSoft 1.0 software (AMTI, Watertown, MA). Placement of the boxes' closest edge was 12.7 cm from the closest edge of the force plate. The F_{zpeak}, flight time, duration on the plate and the ELR (moment from toe touch to F_{zpeak}) were recorded.
Statistical treatment of the data was performed using One-Way and Two-Way Repeated Measures Analysis of Variance (ANOVA) and Intraclass Correlation Coefficients (ICC) to evaluate F_{zpeak} values between trials (SPSS, v12.0, 2002). Flight times, duration on the plate and the ELR were measured and a Repeated Measures ANOVA was performed for jump height across each box height and the CMJ.

RESULTS: Although reliability estimates for the F_{zpeak} indicated an Intraclass Correlation Coefficient of r = 0.89; there was a significant difference ($p < 0.0015$) between the two trials (mean ± SD 3768.0 ± 1383.4 N and 3957.4 ± 1599.0 N). Figure 1 illustrates the F_{zpeak} response which increased with an increase in platform drop height. The relationship between the two trials for the CMJ and seven drop jumps was almost identical and showed a linear response. Across heights, the F_{zpeak} was different at a $p < 0.05$ level.

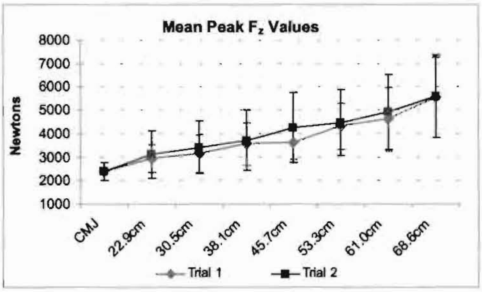

Figure 1 Means & deviations for peak vertical forces (F_z) for both trials and shows a linear response with drop height and Newton load. Trial two was significantly higher ($p < 0.0015$).

Flight time for the eight jumps showed that the CMJ had the highest VJ and the jump height decreased as the platform height increased. However, the 68.6 cm drop height produced jumps higher than the 45.7 cm, 53.3 cm, and the 61.0 cm DJs respectively. The pattern between trial one and trial two had a similar response (see Figure 2) although trial one jumps had higher heights attained. No significant differences in jump height were found across DJs from the eight platform heights within the same trial. In addition, the CMJ was significantly higher ($p < 0.05$) than many DJs in trial one and all DJs in trial two.
The duration on the plate between each DJ height showed no significant differences ($p>0.05$) for either trial. Although no significant differences were shown, the speed of the jump (time on plate) displayed a tendency to get faster from the 22.9 cm drop to the 38.1 cm drop (the fastest jump) in a linear fashion. After which, higher drops caused the speed of the jump to slow down, up to the 68.6 cm drop (the slowest jump), see Figure 3. Mean time (seconds) on the plate for trial 1 = .46 ± .12 and trial 2 = .47 ± .15.

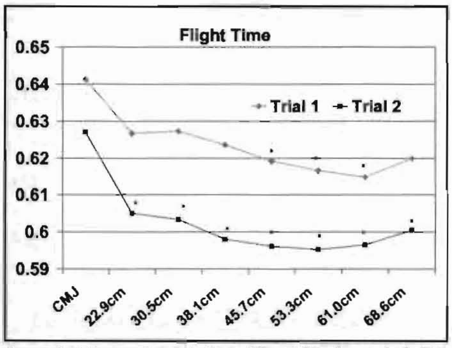

Figure 2 Shows the relationship of the jump heights for the countermovement jumps (CMJ) and drop jumps (DJ) for eight heights. The CMJ jump was significantly higher (*) than most of the DJs in trial 1 ($p < 0.05$) and significantly higher than all DJs in trial 2. The trend does show higher jumps in the shorter drops.

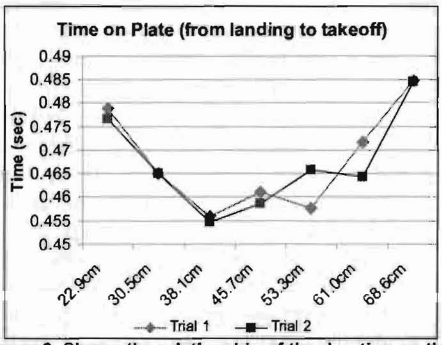

Figure 3 Shows the relationship of the duration on the force plate from toes touch to take off. No significant differences were found ($p > 0.05$). However, the trend is very similar to one another. The jump speed became faster in a linear fashion as the platform height increases to 38.1 cm (quickest jump) and then slowly, a slight linear fashion, became slower to the 68.6 cm drop jump (slowest jump).

The ELR of the jump did show significant differences, see Tables 1 and 2, between the extremes of DJ heights. Secondly, an increase in the eccentric loading rate as the platforms height was increased was witnessed. There was a consistent decrease in the rate of eccentric loading from about 73 thousandths of a second for trial one and 67 thousandths of a second for trial two (drop height of 22.9 cm) to about 49 thousandths of a second for both trials, in jumps from the 68.6 cm drop height.

Table 1 Means and standard deviations of eccentric loading rates (milliseconds) for DJs in trial 1, N = 32.

Drop Jump	Mean	Std. Deviation
22.9 cm (a)	$72.75^{c,d,e,f,g}$	31.59
30.5 cm (b)	$67.38^{a,e,f,g}$	24.76
38.1 cm (c)	$62.91^{a,e,f,g}$	21.12
45.7 cm (d)	$58.72^{a,f,g}$	14.36
53.3 cm (e)	$54.13^{a,b,c,g}$	12.87
61.0 cm (f)	$48.56^{a,b,c,d}$	13.45
68.6 cm (g)	$48.66^{a,b,c,d,e}$	12.19

$^{a,\,b,\,c,\,d,\,e,\,f,\,g}$ significant difference between jumps ($p < 0.05$).

Table 2 Means and standard deviations of eccentric loading rates (milliseconds) for DJs in trial 2, N = 31.

Drop Jump	Mean	Std. Deviation
22.9 cm (a)	$67.32^{d,e,f,g}$	30.120
30.5 cm (b)	$62.03^{d,e,f,g}$	22.388
38.1 cm (c)	$57.58^{f,g}$	17.027
45.7 cm (d)	$54.87^{a,b,f,g}$	14.322
53.3 cm (e)	$53.00^{a,b}$	15.194
61.0 cm (f)	$49.19^{a,b,c,d}$	10.904
68.6 cm (g)	$48.65^{a,b,c,d}$	8.983

$^{a,\,b,\,c,\,d,\,e,\,f,\,g}$ significant difference between jumps ($p < 0.05$).

DISCUSSION: The present study found no difference in jump height over the seven drop heights, which was similar to the findings of Bobbert et al. (1987). The current study would indicate that peak power output is the same for any drop height. Keir, Jamnik & Gledhill (2003) derived a nomogram for peak leg power output in the VJ using body weight and jump height to determine peak power in Watts. Wattage provides a potential avenue to implement periodization into jump training. However, usage of this nomogram would not be practical for DJ training. Changes in height of the platform would score the same power scores because the jump height attained with DJs in the current study showed no significant differences. Therefore, this information is ineffective when trying to incorporate the component of periodization or progressive overload to DJ training not only because of similar DJ height attainment for different platform heights, but because the current study shows that the ELR and F_{zpeak} does change with different platform heights. When used in a different sense, the nomogram could provide feedback and be used to monitor power changes due to training.

The CMJ was higher that the DJ heights ($p < .05$) which was in contrast to the findings of Lees & Fahmi (1994) and Komi & Bosco (1978) who found CMJ and DJ heights to be equal. This would indicate that the peak power output would best be indicated by a CMJ for performance measurement purposes. The height attainments for CMJs greater than DJ heights were also witnessed in a variety of athletes by Kollias et al. (2004).

The F_{zpeak} response had a similar pattern, but the jumps showed an increase in force during the second trial for all conditions. Although the data revealed a fairly high ICC, the increase in the mean F_{zpeak} from trial one to two indicates a possible learning effect. Additional trials may be needed to stabilize the F_{zpeak} value.

Although the previous research has shown the F_{zpeak} value to increase with the speed of the jump, meaning less contact time on the plate (Walsh, 2004), F_{zpeak} seems to be the best indicator of load to manage and manipulate for purposes of training. It would be virtually impossible to control the speed of every jump for an entire team of athletes (such as in American football with 100+ athletes). Although training sessions may have numerous trainers and coaches, the equipment and time it takes to analyze one jump reduces the efficiency of the time spent in a training session. However, because the F_{zpeak} values occurred in the eccentric portion of the DJ, F_{zpeak} may not be relevant to the concentric phase. The time spent on the plate for all drop jumps and the height attainment for each DJ was the same, therefore further analysis of why the F_{zpeak} values were different across jumps is warranted. The ELR for DJs were different (Figure 4) and the rate increased linearly with increases in the height of the jump.

Because of this, the power formula (Power = Force × Speed) indicates that the higher drops do indeed give a much larger power production in the eccentric phase. The higher drops gave larger F_{zpeak} with less time spent in the eccentric loading of the force. Therefore, the opposite may be true for the concentric phase. Because higher drops had a faster eccentric rate, the concentric phase could possibly be slower (indicated by the duration on the plate for each DJ equaling each other). This would indicate more force production in the concentric phase, if a jump height attainment (power) was the same and the concentric loading rate was slower. Using a higher drop height might be more efficient for concentric training since forces could be greater when jump height attainment stays the same as lower drops.

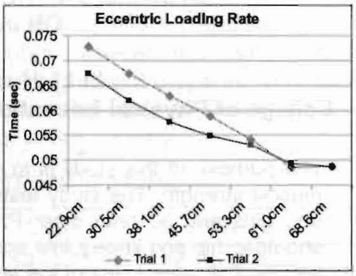

Figure 4 ELR for seven DJ platform heights.

The jumps heights decreased in trial two even though the F_{zpeak} value increased in the same trial. Thus, the F_{zpeak} value may only be relevant in eccentric loading and may only produce effects in the eccentric loading rate and eccentric power. This suggests that the elastic energy could be lost during a slight pause before the concentric phase, thus losing the effect of the SSC. This is supported by the second trial which had an increase in F_{zpeak}, similar time on the plate, and less VJ attainment. This is in contrast to the previous paragraph and suggests that dropping from higher platforms has no impact on the concentric performance.

CONCLUSION: A visual interpretation of the second trial shows jump heights leveled off at a drop height of 38.1 cm, though they decreased in both trials. Although the 38.1 cm drop height was the fastest jump in total, the fastest ELR and greatest F_{zpeak} were seen in the 61.0 and 68.6 cm platform heights. If the concentric phase slows down and displays greater forces at higher drop heights to attain the same VJ height, the higher drops may be better for concentric training. However, the second trial with less VJ attainment and greater F_{zpeak} indicates that greater F_{zpeak} may not directly impact concentric performance. The current study suggests that a DJ from 38.1 cm would be the optimal height as it is most likely to train all of the dependent variables at the same time. This is in agreement with previous research.

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