ACCURACY OF PREDICTED PEAK FORCES DURING THE POWER DROP EXERCISE

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The utility of a new method for estimating upper body plyometric forces was demonstrated and results compared with recent training load equations. Videography and force platform data were collected for subjects performing power drop exercises with drop heights between 49 and 124 cm. Within-subject analyses demonstrated that vertical forces in power drop exercises were not correlated or were weakly ($r < 0.71$) associated with drop height. Other factors like technique and medicine ball properties determine the majority of the variance in peak forces in the power drop exercise. The data supported the utility of the method but did not support the validity of the Ebben et al. (1999) training load equations.

KEY WORDS: medicine ball, training, stretch-shorten cycle, muscle power

INTRODUCTION: Plyometric exercises are a common training method for improving athletic performance and in rehabilitation for high speed and high power events. While there has been considerable research on lower body plyometric training (Bobbert, 1990), there have been fewer studies on upper-body plyometric (UBP) exercise (Ebben et al. 1999; Newton et al. 1996, 1997). Forces and activation in UBP exercises are much higher than the small weight of the medicine ball (MB) because of the large accelerations during the movement (Newton et al. 1997).
In a recent study (Ebben et al. 1999) medicine balls were dropped on a force platform to create regression equations estimating possible training loads for the power drop exercise from MB mass and drop height. Appropriate training loads were based on the observation that loads between 30 and 45% of maximal strength maximize muscle power output (Kaneko et al. 1983; Newton & Kraemer, 1994; Wilson et al. 1993). While these equations provide an improved estimate on the peak force during upper body plyometrics beyond the weight of the MB, there are several reasons why these equations may not be accurate.
One reason these equations may be inaccurate is that the collision of a MB with the rigid surface of a force platform does not accurately model the eccentric loading on the upper extremities in UBP. Plyometric push-ups have total contact times of 0.3 to 0.5 sec. (Jones et al. 1999) while the initial impulse of MB impacts on a force platform lasts only 0.05 seconds for elastic MB designs. Consequently, the loads predicted by these equations may overestimate the peak forces and rate of force development in actual UBP exercises. This is a problem since the peak forces and force development in these equations may be larger than the 30-45% 1RM target and closer to injury-producing loads. Second, these equations might not be accurate because individual technique in the exercise has been found to influence loading in lower body plyometrics (Bobbert et al. 1986; Kovacs et al. 1999). The purpose of this study was to examine the accuracy of the Ebben et al. (1999) equations using a force platform and videographic method of actual power drop exercises.

METHODS: One female and two male students experienced in performing UBP exercise gave informed consent to participate in the study. All subjects were currently in a strength training program that included weekly UBP exercises. Subjects attended a single testing session where they performed power drop UBP exercises (Chu, 1992). Subjects warmed-up with two sets of 10 push ups and were oriented to the UBP by performing submaximal throws and practice power drops. Two of three MB masses (4.1 & 5.4 kg for females; 5.4 & 6.8 kg for males) were dropped 15 times from random distances between 49 and 124 cm for each subject. There was a 30 second rest period between power drops and a five minute rest between the two MB masses. Subjects performed the exercises in a supine position with flexed legs on a small (71 by 33 cm) bench placed on top of a Kistler 9286 force platform. After subtracting the weight of the subject and bench, the vertical force measured by the force platform represented the resultant vertical force applied by the subject to accelerate their arms and the MB. Force data (600 Hz) were collected and analyzed with Kistler Bioware® software. The MB were also dropped directly on the force platform from distances similar to those used with the subjects.

To document the drop distances, MB velocities, and subject movements during the power drops all trials were videotaped (60 Hz) in the sagittal plane. Motion of the MB and subjects hands were digitized from video records using Peak Performance Motus software. Kinematic data were smoothed with a Butterworth digital filter with automatic cut-off frequency selection. Vertical drop distance, duration of the eccentric and concentric phases of the UBP, and peak vertical velocity of the MB before release were calculated. For each subject the relationship between the UBP variables were analyzed with correlations, partial correlations, and linear regression. Descriptive statistics (mean, sd, and 95% CI) were calculated and dependent t tests were performed between MB masses for each subject.

RESULTS: Similar to the Ebben et al. study (1999) the MB drops directly onto the force platform had peak forces that were highly consistent and correlated ($r > 0.99$) with the height of the drop. The mean duration of direct force platform impact was 50 ± 5 ms. Peak vertical forces typically occurred 25 ms after impact creating very high rates of loading that were not similar those during the power drop exercises (Figure 1). Video data demonstrated that the power drop exercise had significantly larger mean contact times of 405 ± 83 ms (95% CI: 387 - 422) than the durations of the MB rebounds from the force platform. This major difference in the timing of the impulse of a bouncing MB and an UBP resulted in peak forces in the power drop exercises being 80% lower than the corresponding peak forces in direct force platform collisions.

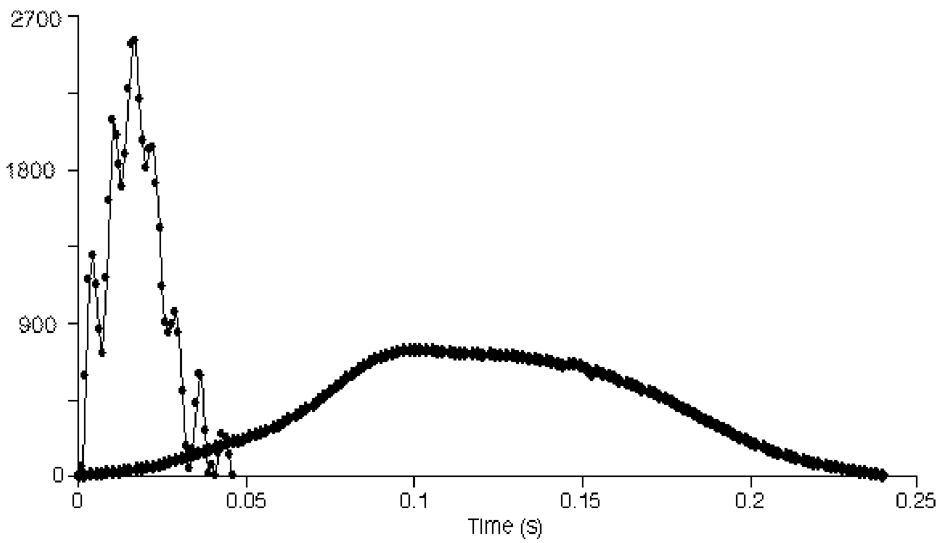

Figure 1 - Comparison of vertical force (N) in a power drop exercise (♦) and a direct force platform impact (•) for a 6.8 kg MB with a 124 cm drop.

Peak forces in the power drop exercises were significantly correlated with drop height in only two of the six subject-MB mass combinations. A female and male subject had significant ($p < 0.05$) associations ($r = 0.59$ and 0.71, respectively) between drop height and peak force using the 5.4 kg MB. These two correlations had little practical importance because they accounted for less than 50% of the variance in peak force. Figure 2 illustrates the scatterplots of these associations, the corresponding regression lines, and regression lines for the direct force platform impacts as well as for EE. The peak forces of direct force platform impacts were much larger than in the Ebben et al. (1999) study which was likely due to the use of different MB (Mediballs) in this study compared to the MB used by Ebben (D-Balls).

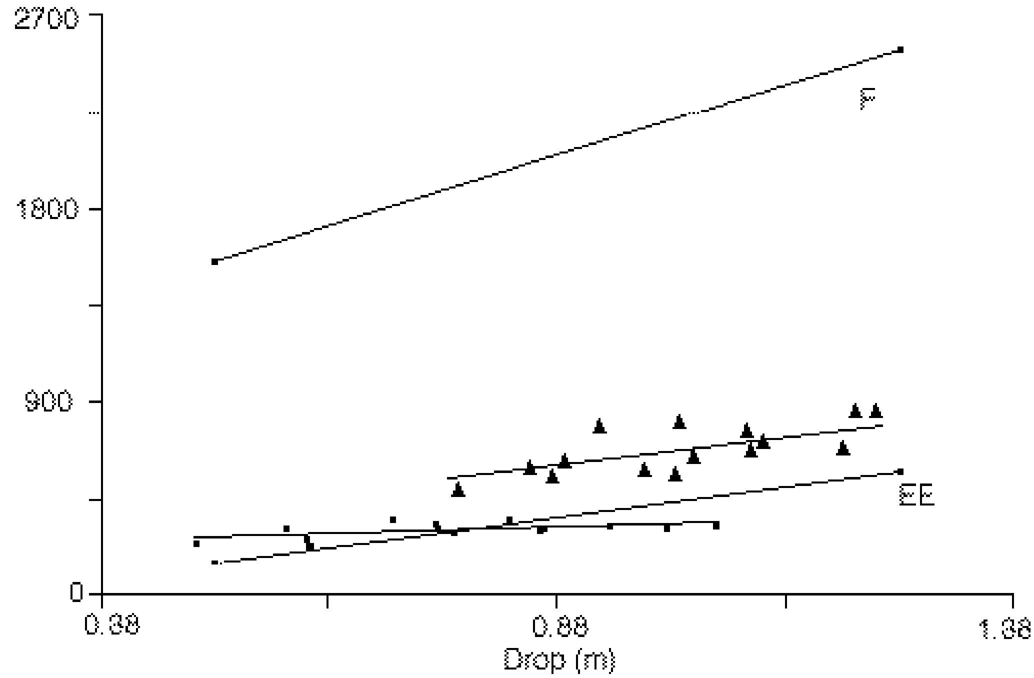

Figure 2. Scatterplots of the significant ($p < 0.05$) associations between drop height and peak force (N) in a 5.4 kg power drop exercise for a female (·) and a male subject. The corresponding regression lines, the regression line for the direct force platform impacts (F), and the EE are illustrated.

Inspection of Figure 2 also illustrates that there were systematic differences between the peak forces for these two subjects and the EE. At low drop heights the female subject had peak forces 70% larger than those from EE, becoming 40% lower than EE when the drop heights neared one meter. The male subject had peak forces that were between 50 and 80 percent larger than the load predicted by EE. It was clear that peak forces in actual power drop exercises were quite variable (between 4 and 20 times the weight of the MB) and could be substantially larger or smaller than the EE.
The descriptive data for the peak forces and durations of the power drop exercises (Table 1) supported the dominant effect of MB mass and technique interactions over variations in the drop height. Dependent t tests showed significant ($p < 0.016$) increases in exercise duration as MB load increased for each subject. The second male subject (M2) had the largest increase in duration and consequently had a surprising trend ($t = 1.13$, $p = 0.28$) of smaller peak forces using the largest (6.8 kg) MB compared to the 5.4 kg MB.

DISCUSSION: The force platform and video measurements were effective in examining the associations between peak forces and power drop exercise conditions. The majority of the variance in peak force in the power drop conditions studied was not related to the height of the drop, but were related to other factors like variations in technique, hand positioning, and in physical properties of the medicine balls. The partial correlations did not show a consistent pattern in the intercorrelations of drop height, eccentric duration, or total contact time across subjects, suggesting that there were unique trial to trial combinations of factors affecting peak forces for each subject. Previous research on lower body plyometrics has shown similar interactions of technique effects on loading and performance (Bobbert et al. 1986; Kovacs et al. 1999).

Table 1 Peak Forces (N) and Durations (ms) of the Power Drop Exercise

	MB Mass (kg)					
	4.1		5.4		6.8	
	F_p	t	F_p	t	F_p	t
F1	249	469	294*	537**		
	(58)	(30)	(40)	(38)		
M1			596	326	699**	351**
			(67)	(13)	(71)	(13)
M2			668	327	623	418**
			(111)	(37)	(147)	(29)

Data are Mean (sd). Significant within-subject difference from the smaller mass medicine ball at * $p < 0.02$ or ** $p < 0.007$.

CONCLUSION: The generalizability of the results of this study are limited but the data clearly show the utility of this method for the study of UBP forces. The data also call into question the EE because the majority of the variance in UBP peak forces seems to be related to subject, technique factors, and physical properties of MB.

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