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KINETIC QUANTIFICATION OF PLYOMETRIC TAKE OFF, FLIGHT, AND LANDING CHARACTERISTICS

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This study assessed the kinetic characteristics of a variety of plyometric exercises and assessed gender differences therein. Twenty-six men and 23 women performed a variety of plyometric exercises including line hops, 15.24 cm cone hops, squat jumps, tuck jumps, countermovement jumps, loaded countermovement jumps equal to 30% of 1 RM squat, depth jumps normalized to the subjects jump height, and single leg jumps. All plyometric exercises were performed on a force platform. Outcome variables associated with the takeoff, airborne, and landing phase of each plyometric were assessed including the peak ground reaction force during takeoff, time to takeoff, jump height, peak power, peak ground reaction force during landing, and landing rate of force development. A number of differences were found between plyometric exercises.

KEYWORDS: stretch shortening cycle, power, program design, periodization, jump

INTRODUCTION: Explosive exercises such as plyometrics are often used to enhance athletic performance and prevent injury. Results of a meta-analysis demonstrate that plyometric training is effective, though considerable variation exists in the design of plyometric programs employed by researchers (Divillereal et al., 2009). The design of plyometric programs requires an understanding of a variety of variables including exercise intensity (Potach & Chu, 2008).

The intensity of resistance training is easily quantified since most forms of resistance have clearly labeled masses. Resistance training programs are typically progressed using some percentage of an athlete's repetition maximum (RM) or 1RM. Unlike resistance training, plyometric intensity has been defined as the amount of stress placed on involved muscles, connective tissues and joints and is dictated by the type of plyometric exercise that is performed (Potach & Chu, 2008). Based on this definition, it is possible to quantify the intensity of a variety of plyometric exercise based on the kinetic characteristics of the takeoff phase, airborne phase, and landing phase of each exercise.

Previous research has examined ground reaction forces (GRF) and joint reaction forces of a limited number of plyometric exercises such as drop-jumps and pendulum jumps (Fowler & Lees, 1998), unloaded and loaded drop jumps (Tsarouches et al., 1995), drop jumps of varying heights (Raynor & Seng, 1997), and of one-legged and two-legged counter-movement jumps (Van Soest et al., 1985). Research assessing the intensity of a larger number of plyometric exercises is limited to studies quantifying exercise impulse and GRF (Jensen & Ebben, 2007; Jensen et al., 2008), knee joint reaction forces (Jensen & Ebben, 2007), or electromyography (Ebben et al., 2008). Of these studies, some did not assess kinetic variables (Ebben et al., 2008) and those that did used a limited number of subjects (Jensen & Ebben, 2007). The purpose of this study was to quantify plyometric exercise intensity by evaluating kinetic variables associated with the takeoff, airborne, and landing phase of each exercise.

METHODS: Twenty-six men (mean ± SD; age 20.23 ± 1.63 yr; body mass 79.41 ± 9.03 kg) and 23 women (mean ± SD; age 20.39 ± 1.50 yr; body mass 65.35 ± 9.81 kg) athletes served as subjects. The study was approved by the institution's internal review board.

All subjects performed a habituation and testing session. Prior to each session, the subject warmed up and performed dynamic stretching and jumping. During the habituation session, subjects' 5 RM back squat was assessed along with countermovement jump height using a Vertec. Subjects were given instruction, a demonstration, and practiced the correct performance of the plyometric exercises to be tested. The plyometric exercises included line hops (LH), 15.24 cm cone hops (CH), squat jumps (SJ), tuck jumps (TJ), countermovement jumps (CMJ), depth jumps from a box height that was equal to the subjects CMJ height as determined by a Vertec (DJ), loaded countermovement jumps with handheld dumbbells equal to 30% of the subjects estimated 1 RM squat based on their 5RM squat test results (DBJ), and single leg jumps (SLJ). These plyometric exercises were included in this study since they represent a variety of estimated (Potach & Chu, 2008) and researched (Jensen & Ebben, 2007; Ebben et al., 2008) exercise intensities.

During the testing session, subjects performed 3 repetitions of each of the plyometric test exercises in a randomized order with 1 minute of rest between each exercise. The test exercises were assessed with a force platform (BP6001200, Advanced Mechanical Technologies Incorporated, Watertown, MA, USA) which was calibrated with known loads to the voltage recorded prior to the testing session. Kinetic data were collected at 1000 Hz, real time displayed and saved with the use of computer software (BioAnalysis 3.1, Advanced Mechanical Technologies, Inc., Watertown, MA USA) for later analysis. All values were averaged for three trials for each plyometric exercise.

Dependent variables were selected in order to comprehensively evaluate each plyometric exercise including the takeoff phase using vertical ground reaction forces (GRF-T). Data were also assessed for the flight phase using jump height (JH) and power (P). The landing phase of each plyometric exercise was assessed using the landing rate of force development (L-RFD) and landing vertical ground reaction force (GRF-L). These variables were calculated from the force time records of each plyometric exercise consistent with methods previously used (Canavan & Vescovi, 2004; Jensen & Ebben, 2007; Moir, 2008; Raynor & Seng, 1997; Tsarouches et al., 1995; Van Soest et al., 1985). Peak GRF-T was defined as the highest value attained from the force time record for the take off phase of each jump. Jump height and power were calculated based in part on flight time using previously published equations (Moir, 2008). The L-RFD was defined as the first peak of GRF minus the initial GRF upon landing divided by the time to the first peak of GRF minus the time of initial ground reaction force and normalized to one second (Jensen & Ebben, 2007). Peak GRF-L was defined as the highest GRF value attained during the landing phase of the plyometric exercise (Jensen & Ebben, 2007).

The statistical analyses were undertaken with SPSS 17.0. A two way mixed ANOVA with repeated measures for plyometric exercise type was used to evaluate the main effects for plyometric exercise type and the interaction between plyometric exercise type and gender, for GRF-T, JH, P, L-RFD, and GRF-L. Bonferroni adjusted pairwise comparisons were used to identify the specific differences between the plyometric exercises. The trial to trial reliability of each dependent variable was assessed for each plyometric exercise using average measures intraclass correlation coefficient (ICC). In addition, a repeated measures ANOVA was used to confirm that there was no significant difference ($P > 0.05$) between three trials of each plyometric exercise. Assumptions for linearity of statistics were tested and met. An *a priori* alpha level of $P \leq 0.05$ was used with post hoc power and effect size represented by d and η_p^2, respectively.

RESULTS: The analysis of GRF-T revealed significant main effects for plyometric exercise type ($P \leq 0.001$, $\eta_p^2 = 0.60$, $d = 1.00$). Analysis of P showed significant main effects for plyometric exercise type ($P \leq 0.001$, $\eta_p^2 = 0.95$, $d = 1.00$). Analysis of JH showed significant main effects for plyometric exercise type ($P \leq 0.001$, $\eta_p^2 = 0.94$, $d = 1.00$). Analysis of GRF-L showed significant main effects for plyometric exercise type ($P \leq 0.001$, $\eta_p^2 = 0.53$, $d =$

1.00). Finally, analysis of L-RFD showed significant main effects for plyometric exercise type ($P \leq 0.001$, $\eta_p^2 = 0.25$, $d = 1.00$). Results of Bonferroni adjusted pairwise comparisons for each dependent variable are presented in Tables 1 to 5. Intraclass correlation coefficients assessing the trial to trial reliability ranged from 0.34 to 0.99, with most ICC's over 0.80, for the plyometric exercises and dependent variables.

Table 1. Takeoff GRF in Newtons (mean ± SD)

	CH	TJ	CMJ	LH	DBJ	SJ	SLJ
Mean	1311.50[a]	1168.73[b]	1021.33[c]	949.19[d]	864.28[e]	840.55[d]	735.62[c]
SD	353.25	408.33	303.75	284.70	251.90	214.52	238.51

[a]Significantly different (p≤0.001) than all plyometrics except for the TJ
[b]Significantly different (p≤0.001) than all plyometrics except for the CH
[c]Significantly different (p≤0.01) than all other plyometrics
[d]Significantly different (p≤0.05) than all plyometrics except for the DBJ
[e]Significantly different (p≤0.001) than all plyometrics except for the SJ and LH

Table 2. Power in watts (mean ± SD)

	DBJ	DJ	CMJ	TJ	SJ	SLJ	CH	LH
Mean	3946.39[a]	3555.71[b]	3554.81[b]	3497.03[c]	3087.51[a]	2442.88[a]	1989.27[a]	1783.31[a]
SD	983.64	851.75	858.74	804.84	782.85	705.56	569.83	462.85

[a]Significantly different (p<0.001) than all other plyometrics
[b]Significantly different (p<0.05) than DBJ, TJ, SJ, SLJ, CH, LH
[c]Significantly different (p<0.05) than all other plyometrics

Table 3. Jump height in meters (mean ± SD)

	DJ	CMJ	TJ	SJ	DBJ	SLJ	CH	LH
Mean	0.38[a]	0.38[a]	0.37[b]	0.30[c]	0.20[d]	0.20[d]	0.12[c]	0.04[a]
SD	0.08	0.08	0.07	0.07	0.04	0.05	0.04	0.03

[a]Significantly different (p<0.05) than TJ, SJ, DBJ, SLJ, CH, LH
[b]Significantly different (p<0.05) than all other plyometrics
[c]Significantly different (p<0.001) than all other plyometrics
[d]Significantly different (p<0.001) than DJ, CMJ, TJ, SJ, CH, LH

Table 4. Landing rate of force development in N·m^{-1} (mean ± SD)

	DJ	CMJ	DBJ	SJ	TJ	SLJ	CH	LH
Mean	62025.19[a]	56672.28[b]	48922.91[c]	46271.89	44619.92[d]	31007.34[e]	26811.47[e]	17942.71[f]
SD	53699.83	72354.88	39549.69	51560.76	39615.93	20576.40	32067.62	5201.70

[a]Significantly different (p<0.01) than SJ, TJ, SLJ, CH, LH
[b]Significantly different (p<0.01) than SLJ, CH, LH
[c]Significantly different (p<0.001) than SLJ, CH, LH
[d]Significantly different (p<0.01) than DJ, SLJ, CH, LH
[e]Significantly different (p<0.01) than DJ, CMJ, DBJ, SJ, TJ, LH
[f]Significantly different (p<0.05) than all other plyometrics

Table 5. Landing GRF in Newtons (mean ± SD)

	DJ	DBJ	CMJ	TJ	SJ	SLJ	CH	LH
Mean	2589.54[a]	2506.76[b]	2462.35[c]	2285.89[d]	2255.69[d]	1855.47[e]	1458.45[e]	1052.36[e]
SD	995.91	1041.29	1065.21	939.08	929.09	538.67	676.13	453.40

[a]Significantly different (p<0.05) than TJ, SJ, SLJ, CH, LH
[b]Significantly different (p<0.05) than SJ, SLJ, CH, LH
[c]Significantly different (p<0.001) than SLJ, CH, LH
[d]Significantly different (p<0.01) than DJ, SLJ, CH, LH
[e]Significantly different (p<0.05) than all other plyometrics

DISCUSSION/CONCLUSION: A variety of differences in kinetic characteristics between plyometric exercises were found. A number of previous studies assessing plyometric exercises only included one (Raynor & Seng, 1997; Tsarouches et al., 1995) or two plyometric exercises (Fowler & Lees, 1998; Van Soest et al., 1985) in the analysis. Results of the present study can be used to further understand plyometric exercises and prescribe them based on this assessment of the exercise intensity. Practitioners should determine the physical ability they are trying to develop and progress plyometric intensity according to the variables assessed in this study. For example, if developing athletic power is the goal, a plyometric program can be guided by the assessment of power, progressing from low intensity plyometric exercises such as line hops and cone hops, to squat jumps and tuck jumps, to countermovement jumps and depth jumps, and finally to dumbbell jumps and single leg jumps. Similarly, if a practitioner desires to improve and athletes ability to manage the rate and magnitude of landing forces a plyometric program should be progressed from exercises with low L-RFD and GRF-L such as line hops and cone hops, to squat and tuck jumps, to countermovement jumps, dumbbell and depth jumps, and finally single leg jumps. Plyometric exercises can be similarly progress based on other variables assessed in this study.

REFERENCES:

Canavan, P.K., & Vescovi, J.D. (2004). Evaluation of power prediction equations: peak vertical jumping power in women. *Medicine and Science in Sports and Exercise,* 36, 1589-93.

De Villarreal, E.S.S., Kellis, E., Kraemer, W.J., & Izquierdo, M. (2009). Determining variables of plyometric training for improving vertical jump height performance: a meta-analysis. *Journal of Strength and Conditioning Research,* 23, 495-506.

Ebben, W.P., Simenz, C., & Jensen, R.L. (2008). Evaluation of plyometric intensity using electromyography. *Journal of Strength and Conditioning Research,* 22, 861-868.

Fowler, N.E., & Lees, A. (1998). A comparison of the kinetic and kinematic characteristics of plyometric drop-jump and pendulum exercises. *Journal of Applied Biomechanics,* 14, 260-275.

Jensen, R.L., & Ebben, W.P. (2007). Quantifying plyometric intensity via rate of force development, knee joint and ground reaction forces. *Journal of Strength and Conditioning Research,* 21, 763-767.

Jensen, R.L., Flanagan, E.P. Jensen, N.L., & Ebben, W.P. (2008). Kinetic responses during variations in plyometric exercises. In: *Proceedings of the XXVI Congress of the International Society of Biomechanics in Sports;* Y.-H. Kwon, J. Shim, J. K. Shim and I.-S. Shin, (eds). p. 393-396.

Moir, G. (2008). Three different methods of calculating vertical jump from force platform data in men and women. *Measurements in Physical Education and Exercise Science,* 12, 207-218.

Potach, D.H., & Chu, D.A. (2008). Plyometric Training. In: Beachle, T.R, & Earle, R.W, editors. *The Essentials of Strength Training and Conditioning. (pp 413-427).* Champaign: Human Kinetics.

Raynor, A.J., & Seng, T.Y. (1997). Kinetic analysis of the drop jump: the effect of drop height. In: *AIESEP Singapore 1997 World Conference on Teaching, Coaching and Fitness Needs in Physical Education and the Sports Science Proceedings;* Walkusji J.J., (ed). Singapore. p. 480-486.

Tsarouchas. L., Giavroglou, A., Kalamaras, K., & Prassas, S. (1995). The variability of vertical ground reaction forces during unloaded and loaded drop jumping. In: *Biomechanics in Sports: 12th symposium of the International Society of Biomechanics in Sports.* Budapest: International Society of Biomechanics in Sports; p. 311-4.

Van Soest, A.J., Roebroeck, M.E., Bobbert, M.E., Huijing, M.F., Van Ingen P.A., & Schenau, G.J. (1985). A comparison of one-legged and two-legged counter-movement jumps. *Medicine and Science and Exercise,* 17, 635-639.

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