RELIABILITY OF FORCES DURING VARIATIONS OF PLYOMETRIC EXERCISES

Sarah K. Leissring[1], William P. Ebben[2], Luke R. Garceau[2], Erich J. Petushek[2], Randall L. Jensen[1]

Dept. HPER, Northern Michigan University, Marquette, MI, USA[1]
Dept. Physical Therapy, Program in Exercise Science, Marquette University, Milwaukee, WI, USA[2]

Thirteen college students performed a drop jump from height equal to their peak vertical jump, single leg jumps from the left and right legs, and a counter movement jump. Vertical ground reaction force (GRF) obtained via an AMTI force plate and video analysis of markers placed on the hip, knee, lateral malleolus, and fifth metatarsal were used to estimate reaction forces on the knee joint. One-way Repeated Measures ANOVA indicated no differences for knee joint reaction forces relative to body weight or peak GRF for any of the jumps ($p > 0.05$). Average measures Intraclass Correlation Coefficients ranged from $r = 0.90$ to 0.97. Results indicate that peak GRF and knee joint reaction forces during the drop jump, counter movement jump, and single leg left and right leg jumps are reliable measures.

KEY WORDS: knee joint reaction forces, ground reaction forces, jumping

INTRODUCTION: Plyometric exercises have been demonstrated to improve athletic performance (Wilson *et al*., 1996) and enhance bone mass (Bauer *et al*., 2001). Ground reaction forces and knee joint reaction forces of plyometric exercises have been shown to vary depending on the type of jump performed or the height of a drop jump (Jensen & Ebben, 2002; 2007).

Evaluating the intensity of plyometric activity has been done using many variables (Bauer, *et al*., 2001; Ebben *et al*., 2008; Flanagan *et al*., 2008; Jensen & Ebben, 2002; 2007). However, the reliability of these variables while performing variations of plyometric exercises have not been extensively studied. Knowledge of a measure's reliability is important as it allows for comparisons across time as well as within various conditions. Without this knowledge it is difficult for researchers, practitioners, coaches, and/or athletes to know whether the measures of interest are changed via fatigue or training levels, or if they simply are not consistent. Therefore the purpose of the current study was to estimate the reliability of peak ground reaction forces and knee joint reaction forces while performing four variations of plyometric exercises.

METHODS: Thirteen active students (seven female and six male; mean ± SD; age = 24.3±4.3 years, height = 175.5±7.8 cm; body mass = 71.9±12.9 kg) volunteered to serve as subjects for the study. Subjects completed a Physical Activity Readiness-Questionnaire and signed an informed consent form prior to participating in the study. Approval for the use of human subjects was obtained from the institution prior to commencing the study. Subjects had performed no strength training in the 48 hours prior to data collection.

Warm-up prior to the plyometric exercises consisted of at least 3 minutes of low intensity work on a cycle ergometer. This was followed by dynamic stretching including one exercise for each major muscle group. Following the warm-up and stretching exercises, the subjects performed two trials of a maximal standing vertical jump (vertical jump = 46.2±8.4 cm) followed by at least 5 minutes rest prior to beginning the plyometric vertical jump tests. The order of plyometric exercises was randomly assigned and consisted of three trials each of drop jumps from a height equal to the subject's peak vertical jump (DJ), single leg jumps from the left and right legs (LLJ and RLJ respectively), and a counter movement jump (CMJ) with arm swing (Potach, 2004). For the drop jump subjects were instructed to drop directly down off the box and immediately perform a maximum vertical jump. For the other jumps they were asked to jump for maximal height. A one minute rest interval was maintained between each trial.

The plyometric exercises were performed by taking off from and landing on a force platform (OR6-5-2000, AMTI, Watertown, MA, USA). Ground Reaction Force (GRF) data were collected at 1000 Hz, real time displayed and saved with the use of computer software (Net Force 2.0, AMTI, Watertown, MA, USA) for later analysis. Peak GRF was the highest value attained during the movement and occurred during the landing.
Video of the exercises was obtained at 60 Hz from the sagittal view using 1 cm reflective markers placed on the greater trochanter, lateral knee joint line, lateral malleolus and the fifth metatarsal. Markers were digitized using automatic digitizing software (Motus 8.5 Peak Performance Technologies, Englewood, CO) and acceleration of the joint segment center of mass was determined after data were smoothed using a fourth order Butterworth filter (Winter, 1990).
To synchronize data a signal was used to initialize kinetic data collection which also inserted an audio tone in the video data. Data were then combined into a single file and splined to create a file of equal length at 1000Hz (see Figure 1). Knee joint reaction forces (KRF) were estimated according to Bauer *et al* (2001). Because GRF for the drop jump and counter movement jump would have been distributed across both feet (and therefore both knees) these GRF values were divided by two prior to calculation of KRF. Variables assessed were GRF, KRF/Body weight, and GRF/Body weight for the drop jump, counter movement jump, left leg jump, and right leg jump.

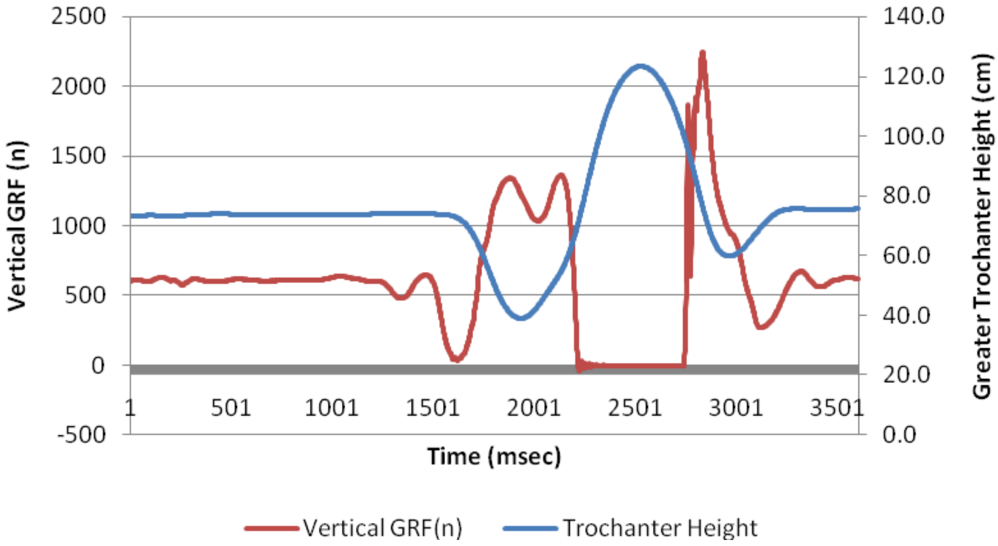

Figure 1. Illustration of vertical ground reaction forces and height of the greater trochanter marker relative to the force platform for the counter movement jump.

All statistical analyses of the data were carried out in SPSS © (Version 16.0). Trial-to-trial reliability analysis of recorded variables used both single (ICC_{single}) and average (ICC_{ave}) measures intra-class correlations. The ICC classifications of Fleiss (1986) (less than 0.4 was poor, between 0.4 and 0.75 was fair to good, and greater than 0.75 was excellent) were used to describe the range of ICC values. A repeated measures ANOVA was used to determine possible differences between trials. The criterion for significance was set at an alpha level of $p < 0.05$

RESULTS: Table 1 displays the Mean ± SD of peak vertical ground reaction force, GRF/BW and knee joint reaction force relative to body weight variables measured during three trials of DJ, LLJ, RLJ, and CMJ. As shown there were no differences across the trials for any of the variables ($p > 0.05$).

The trial-to-trial reliability of all dependent variables measured during drop jump, left and right legged single leg jumps, and countermovement jump as depicted by the single (ICC_{single}) and average (ICC_{ave}) measures intra-class correlation coefficients is illustrated in Table 2. Values for ICC_{ave} ranged from r = 0.90 to 0.97, while ICC_{single} ranged from r = 0.76 to 0.91

Table 1. Peak ground reaction force (GRF), peak GRF relative to body weight (GRF/BW), and Knee joint reaction force relative to body weight (KRF/BW) (mean ± SD) across the three trials for the DJ, LLJ, RLJ, and CMJ (n=13).

	GRF (N)	GRF/BW ($N{\cdot}Kg^{-1}$)	KRF/BW ($N{\cdot}Kg^{-1}$)
DJ			
Trial 1	2710.7 ± 417.3	17.36 ± 2.70	4.67 ± 1.0
Trial 2	2734.2 ± 339.5	17.54 ± 2.30	4.81 ± 1.0
Trial 3	2650.3 ± 432.3	16.96 ± 2.70	4.93 ± 1.2
LLJ			
Trial 1	2134.0 ± 573.5	13.38 ± 2.20	5.86 ± 1.79
Trial 2	2240.2 ± 552.9	14.14 ± 2.41	5.70 ± 1.73
Trial 3	2256.4 ± 517.7	14.27 ± 2.26	5.70 ± 1.66
RLJ			
Trial 1	2097.3 ± 582.1	13.34 ± 3.35	7.30 ± 3.50
Trial 2	2255.8 ± 528.5	14.39 ± 3.09	7.21 ± 2.95
Trial 3	2139.0 ± 574.3	13.50 ± 2.69	6.90 ± 3.16
CMJ			
Trial 1	2500.9 ± 468.7	15.95 ± 2.09	3.52 ± 0.82
Trial 2	2502.8 ± 506.9	15.84 ± 1.95	3.64 ± 0.96
Trial 3	2432.3 ± 491.2	15.51 ± 2.45	3.57 ± 1.22

All trials within a specific jump were not different ($p > 0.05$)

Table 2. Intraclass Correlation Coefficient and 95% Confidence Interval (ICC:95% CI) for Peak ground reaction force (GRF), peak GRF relative to body weight (GRF/BW), and Knee joint reaction force relative to body weight (KRF/BW) across the three trials for the DJ, LLJ, RLJ, and CMJ (n=13).

	Average Measures (ICC:95% CI)				*Single Measure* (ICC:95% CI)			
	DJ	*LLJ*	*RLJ*	*CMJ*	*DJ*	*LLJ*	*RLJ*	*CMJ*
GRF	.94	.97	.97	.96	.84	.91	.91	.89
(N)	.85-.98	.92-.99	.92-.99	.91-.99	.66-.94	.80-.97	.78-.97	.76-.96
GRF/BW	.92	.91	.94	.91	.80	.78	.85	.77
($N{\cdot}Kg^{-1}$)	.81-.97	.78-.97	.86-.98	.77-.97	.58-.93	.55-..92	.67-.95	.53-.91
KRF/BW	.90	.97	.95	.96	.76	.91	.87	.88
($N{\cdot}Kg^{-1}$)	.76-.97	.92-.99	.88-.98	.89-.99	.52-.91	.78-.97	.71-.95	.73-.96

DISCUSSION: The major finding of the current study indicates that repeated measures of peak vertical GRF, peak GRF relative to body weight and KRF relative to body weight plyometric exercises can be reliably repeated on the same day for the exercises studied. The lack of difference across three trials and values for ICC_{ave} greater than r = 0.90 indicated a high level of reliability.

The findings for peak GRF are consistent with those of Stålbom *et al*. (2007) who found high reliability of forces in a single leg drop jump followed by a horizontal jump (ICC_{ave} r = 0.84). Though values for peak GRF (1880 ± 247 N) were less than those of the current study (2186 ± 554 N), subjects in the current study dropped from a mean height of 46 cm, while those of Stålbom and coworkers (2007) dropped from 20 cm. Similarly, Ford *et al*. (2007) found two legged drop jumps from the top of a 31 cm box were also highly reliable for kinematic variables, displaying values of ICC_{ave} r > 0.90. In addition, Flanagan and colleagues (2008) also found high reliability for the reactive strength index (height jumped/time spent on the ground between the landing and takeoff of a drop jump) when performing drop jumps (ICC_{ave} r >0.95).

CONCLUSION: The reliability of the current measures indicated that repeated measures of plyometric exercises can be reliably performed. Previous research has shown differences between the types of plyometric exercises (or jumps) for the studied variables (Jensen & Ebben 2002; 2007). Thus if researchers wish to compare plyometric exercises, the high reliability found in the current study would suggest that differences found between exercises would be due to the exercises themselves and not differences across the trials. As a result practitioners, coaches, and/or athletes may find these performance measures useful in assessing fatigue or training levels when performing drop, countermovement and single leg jumps.

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