QUANTIFYING THE ONSET OF THE CONCENTRIC PHASE OF THE FORCE-TIME RECORD DURING JUMPING

R.L. Jensen[1], S.K. Leissring[1], L.R. Garceau[2], E.J. Petushek[2], and W.P. Ebben[2]
Dept. HPER, Northern Michigan University, Marquette, MI, USA[1]
Dept. Physical Therapy, Program in Exercise Science, Marquette University, Milwaukee, WI, USA[2]

Knowledge of the onset of concentric movement is needed to determine many variables including rate of force development. This study sought to identify the onset of the concentric phase of the force-time record of a variety of jumps. Twelve subjects performed a depth jump, single leg countermovement jump, and a counter movement jump. Vertical ground reaction force (GRF) obtained via force plate and video analysis of a marker placed on the hip, was used to estimate the time of onset of the concentric phase on the force time record. Repeated Measures ANOVA indicated differences in the onset of the concentric phase for the different jumps. Results can be used to assist in the calculation of outcome variables based on the determination of the onset of the concentric phase of the force-time record, when motion analysis is unavailable.

KEY WORDS: positive acceleration phase, eccentric, plyometric

INTRODUCTION: Force plates, and the resultant force-time records, have often been used in the analysis of jumping and plyometric exercises (Ramey, 1983), producing numerous potential outcome variables (Schieb, 1986). The calculation of some variables, such as time to maximum rate of force development (RFD), time to peak force, time to take off, RFD for the first 100ms, and RFD to peak requires identification of the point of onset of the concentric (also known as positive or upwards) phase of the jump (Ebben et al., 2007; Ebben et al., 2008; Harrison and Bourke, 2009; Wilson et al., 1995).
The onset of the concentric phase may be determined via the synchronization of motion analysis systems with a force plate. In the absence of motion analysis, the start of the concentric phase has been estimated as a point at where GRF readings were 10 N greater than the subjects static starting GRF, or the first point where the GRF of the force-time record exceeded body mass, after the eccentric phase in which GRFs fell below body mass (Ebben et al., 2007; Ebben et al., 2008; Harrison and Bourke, 2009). Additionally, the RFD has been determined from the point of the minimum GRF value attained at the end of the eccentric and presumably the beginning of the concentric phase (Wilson et al., 1995). Finally, a point near the peak of the GRF from the force-time record has been proposed to be the beginning of the concentric phase of countermovement jump (CMJ) (Bosco et al., 1982; Linthorne, 2001). Thus, a number of different methods of determining the onset of the concentric phase of the force-time record have been proposed or used, likely producing variability in the results. Therefore, the purpose of the current study was to estimate the onset of the concentric phase of the force-time record during a variety of jumping conditions.

METHODS: Twelve NCAA Division II athletes and recreationally active college students (seven female and five male; mean ± SD; age = 24.6±4.4 years, height = 175.0±7.9 cm; body mass = 69.7±10.8 kg, vertical jump = 45.2±7.9 cm) 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 by the Institutional Review Board was obtained prior to commencing the study.
Warm-up prior to the study consisted of 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 5 repetitions of the CMJ followed by at least 5 minutes rest prior to beginning the test jumps. The test jumps included a depth jump (DJ) from a height equal to the subject’s vertical jump, a single leg jump from the left leg (SLJ), and a counter movement jump with arm swing

(CMJ) (Potach, 2004). Three test jumps were performed for each condition and the mean of the three used as the criterion value. The order of each test jump was randomly assigned. For the DJ, subjects were instructed to drop directly down off the box and immediately perform a maximum vertical jump. For the SLJ and CMJ, subjects were instructed to jump for maximal height. A one minute rest interval was maintained between each trial. Subjects performed no strength or plyometric training in the 48 hours prior to the study.

The test jumps were performed on a force platform (OR6-5-2000, AMTI, Watertown, MA, USA). Ground reaction force 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. Video of the exercises was obtained at 60 Hz from the saggital view using a 1 cm reflective marker placed on the greater trochanter. The marker was digitized using software (Motus 8.5, Vicon/Peak, Centennial, CO, USA) and data were smoothed using a fourth order Butterworth filter (Winter, 1990). The onset of the concentric phase was determined as the point where the marker moved vertically after the countermovement for the CMJ and SLJ or the landing of the DJ.

A signal was used to initialize kinetic data collection which also inserted as an audio tone in the video, in order to synchronize kinetic and kinematic data. Data were then combined into a single file and splined to create a file of equal length at 1000Hz.

The lowest point of vertical GRF during the countermovement for the CMJ and SLJ was determined from the force-time record. For the DJ the lowest point of vertical GRF was when contact was made with the force platform. In addition, the point where the vertical GRF equaled body mass following the countermovement was also determined. The time for each of these points on the force-time record was subtracted from the time determined from the onset of concentric movement as defined by upward movement of the marker on the greater trochanter. These times were used as the dependent variables for the study.

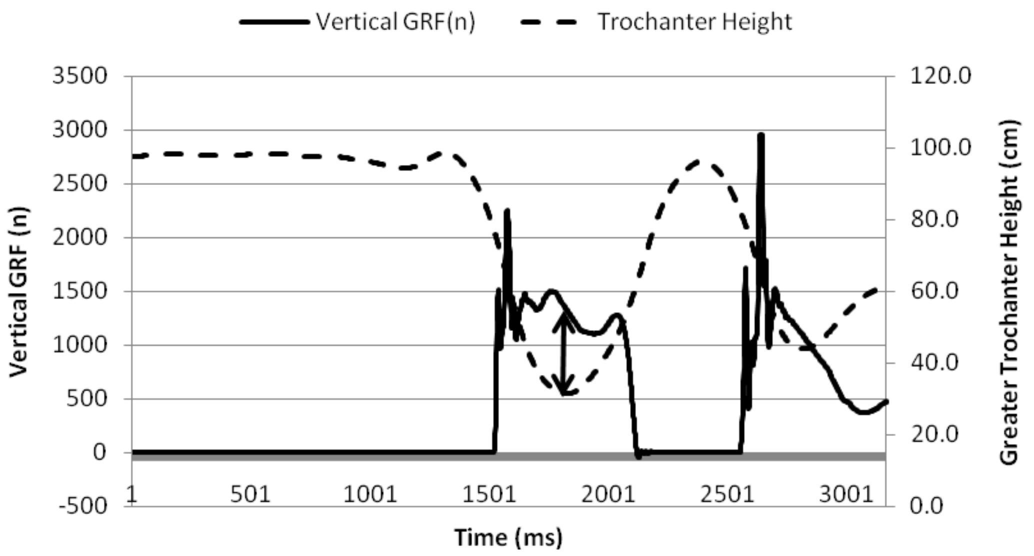
All statistical analyses of the data were carried out in SPSS © (Version 16.0). A repeated measures ANOVA was used to determine possible differences between trials. Bonferroni adjusted pairwise comparisons identified the specific differences between the test jumps. The criterion for significance was set at an alpha level of $p \leq 0.05$. Effect sizes were determined using partial eta squared (η_p^2).

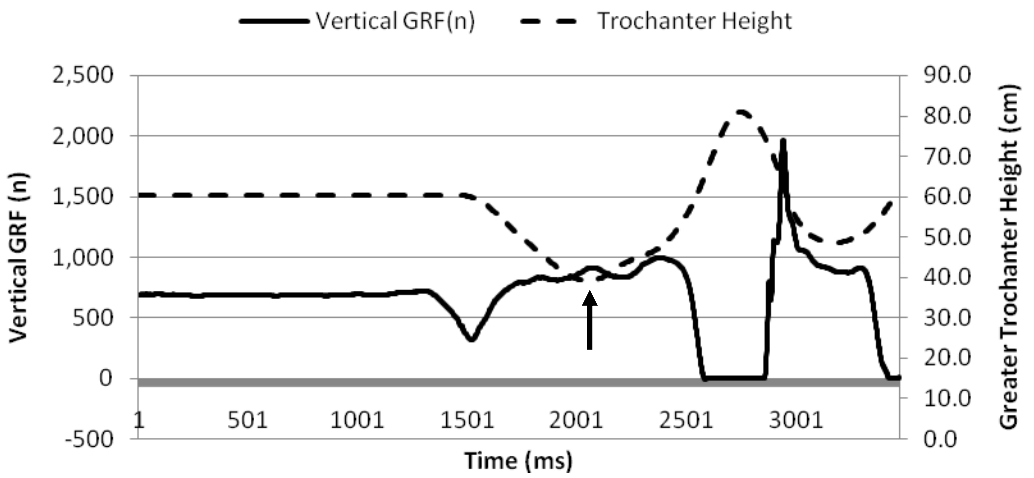
RESULTS: Results of the ANOVAs are shown in Table 1. There was a significant main effect for the onset of the concentric phase as assessed by the point when vertical force equaled body mass ($p < 0.05$) with a medium effect size of $\eta_p^2 = 0.281$. However, post hoc Bonferroni comparisons found no significant differences between the different jumps ($p > 0.075$). For the onset of the concentric phase as assessed by the lowest point of the vertical force to the start of the vertical rise of the hip, there were significant main effects ($p < 0.05$) with a medium effect size of $\eta_p^2 = 0.391$. Post hoc analysis revealed the time of onset of the concentric phase for DJ was significantly less than the CMJ and SLJ ($p < 0.05$). The CMJ and SLJ did not differ ($p > 0.10$). Sample force-time records and approximate point of onset of the concentric phase for the DJ, SLJ, and CMJ are shown in Figures 1-3.

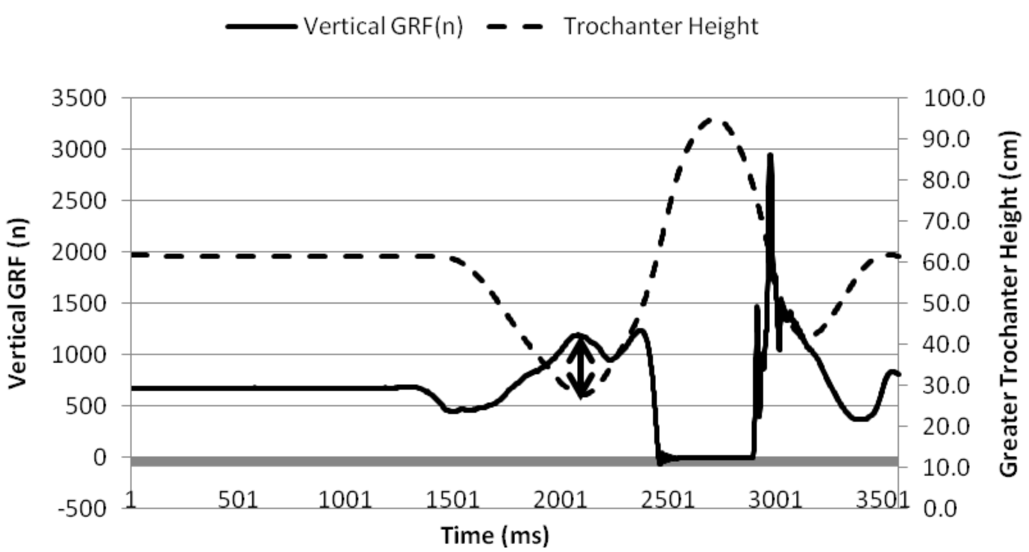
Table 1. Point of onset of the concentric phase of the force-time record, expressed in milliseconds after the point at which body mass is attained and after the eccentric phase of each jump. Data are expressed in ms. All data are expressed as mean ± SD for 12 subjects.

	Onset of concentric phase (ms after body mass achieved)	Onset of concentric phase (ms after the low point of vertical force)
DJ	248.4 ± 54.0	257.1 ± 55.1 [a]
SLJ	287.8 ± 52.8	445.6 ± 81.8
CMJ	306.3 ± 48.9	439.6 ± 64.4

[a] DJ was lower than CMJ and SLJ ($p < 0.05$)







Figures 1-3. Figures 1-3 show the force-time record for the DJ, SLJ and CMJ with arrows identifying the approximate point of onset of the concentric phase.

DISCUSSION: This study demonstrates that the onset of the concentric phase of the force-time record occurs between 248.3 to 306.3 seconds after the force-time record reaches a value equal to body mass, subsequent to falling below body mass during the eccentric phase. Values were not statistically different between the three jumps, when assessed this way. Differences were found between the jumps when the onset of the concentric phase was assessed as the difference in time from the lowest point of the force-time record. Thus, the point of onset of the concentric phase may be dependent on the type of jump performed. The present study demonstrated that the onset of the concentric phase of the force-time record during jumping is different than the methods used in previous studies which attempted to approximate the start of the onset of the concentric phase from force-time records. These previous studies included estimations of this value as the point at where GRF readings were 10 N greater than the subjects static starting GRF, or the first point where the GRF of the force-time record exceeded body mass, after the eccentric phase in which GRFs fell below body mass (Ebben et al., 2007; Ebben et al., 2008; Harrison and Bourke, 2009; Wilson et al., 1995). Results of the present study are most similar to previous assertion that a point near the peak of the GRF from the force-time record was the beginning of the concentric phase of the CMJ (Bosco et al. 1982; Linthorne, 2001). Thus, the onset of the concentric phase may be estimated as the first GRF peak for the SLJ and the CMJ. However further research should be performed with additional subjects from a variety of heights for the DJ. Never-the-less, data from the present study can be used to approximate point of onset of the concentric phase of the force-time record, in order to calculate outcome variables that require the knowledge of this value in the absence of motion analysis.

CONCLUSION: Kinetic analysis provides useful information for the quantification of a variety of aspects of jumping. In the absence of motion analysis to determine the onset of the concentric phase, the results of this study provide an approximate measure of this value. Outcome variables that require knowledge of the onset of the concentric phase of the force-time record can be calculated based on this measure.

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Acknowledgement: Funded by NMU Freshman Fellows and College of Professional Studies grants.