CONTINUOUS WAVEFORM ANALYSIS OF FORCE, VELOCITY, AND POWER ADAPTATIONS TO A PERIODIZED PLYOMETRIC TRAINING PROGRAM

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This study assessed kinetic and temporal adaptations to the countermovement jump in response to a 6 week periodized plyometric training program. Twenty recreationally active women participated in this study (10 training and 10 control). Testing consisted of 3 maximal countermovement jumps on a force platform prior to and after six weeks of training. Analysis of characterizing phases (using a dependent t-test) was performed to assess differences between pre- and post-training sessions. Post-training force, velocity, and power were significantly different ($p < 0.05$). Periodized plyometric training altered the curves for force, velocity, and power. A combination of greater eccentric velocity and power followed by increased concentric power enhanced SSC and all three variables just before takeoff likely enhancing jump performance.

KEY WORDS: ground reaction forces, stretch-shortening cycle, program design

INTRODUCTION: Plyometric training is an effective training intervention to improve jumping performance (Markovic, 2007; de Villarreal et al., 2009; Markovic & Mikulic 2010). However little is known about how these improvements are manifested. By acquiring system characteristics (i.e. force, velocity and power) during the countermovement jump (CMJ), one can gain a holistic understanding of the complex motor system as well as the system adaptations. Previous studies have assessed system adaptations following training or factors determining jumping performance using discrete point analysis (Dowling and Vamos, 1993; Cormie et al., 2009; Petushek et al., 2010). However, this method inherently ignores the vast majority of data and important data can be discarded inadvertently (Dona et al., 2009). Due to the limitations in current discrete analysis procedures the understanding of the underlying source of performance improvement during the CMJ remains equivocal. The purpose of the study was to investigate the effectiveness of short-term periodized plyometric training examining continuous waveforms to better understand how CMJ technique/performance adapts in response to training.

METHODS: Ten women served as training subjects (mean ± SD; age = 19.00 ± 0.82 years; height = 1.68 ± 0.067 m; body mass = 62.72 ± 9.22 kg) while ten served as non-training controls (mean ± SD; age = 19.50 ± 1.18 years; height = 1.63 ± 0.065 m; body mass = 61.70 ± 9.90 kg). The University Ethics Committee approved the study and all participants were informed of any risk and signed an informed consent form before participation.

The training subjects trained twice per week for six weeks. The program was periodized by decreasing volume (100 to 60 foot contacts) and increasing intensity based on previous recommendations (Potach and Chu, 2008; Jensen and Ebben, 2007). Specifically, subjects initially performed low intensity plyometrics such as line/cone hops and low box height drop jumps and progressed to single leg bounds and higher box drop/depth jumps. Subject activity logs confirmed that all subjects refrained from other physical activity during the six weeks. Prior to data collection, every participant performed a standard warm-up routine consisting of low intensity jogging, stretching and five number of sub-maximal and maximal countermovement jumps. For initial and final testing, each participant performed 3 maximum effort countermovement jumps with an arm swing (CMJ), standing on a force platform (BP6001200, AMTI, Watertown, MA, USA). Participants rested for 30 seconds between trials. Vertical ground reaction force was captured at 1000 Hz. The captured force curves were used to generate velocity and power curves via numerical integration. The force, velocity and power curves of the three trials were averaged using a landmark registration (landmark=start concentric phase) (Ramsay 2006).

To assess the effect of the training intervention on jump height, a dependent *t*-test was used to examine subject scores generated during an analysis of characterising phases for significant differences (Richter et al., 2012). Analysis of characterising phases (ACP) detects key phases within the data to examine data determining phases in the time, magnitude and magnitude-time domain. The reader is referred to the previous publication for further reading (Richter et al., 2012). Participant scores for the statistical analysis were generated by the calculating the area between a participant's curve (p) and the mean curve across the data set (q) for every point (i) within the key phase (Equation 1 & 2).

$$score = \int p_i - q_i \qquad \text{Eq. (1)}$$

$$score = \int 0.5 * (\Delta_{time} p_{i,i+1} + \Delta_{time} q_{i,i+1}) * \Delta_{magnitude} p_i q_i \qquad \text{Eq. (2)}$$

RESULTS: The training group increased their jump height by 21% (pre-training 0.24 ± 0.04 m to post-training 0.29 ± 0.03 m while the control group performance remained unchanged ($p>0.05$), therefore ACP was performed on the training group only. Analysis of characterising phases separated the captured waveforms in 12, 7 and 9 data characterizing phases (key phases) for the force, velocity, and power curves, respectively. The analysis of the separated key phases in the force curves found two phases (91-99% and 94-99%) being different between pre- and post-training in both the magnitude and magnitude-time domain ($p < 0.05$). Both occurred during 91-99% of the curve and indicated that the post-test condition produced higher a ground reaction force that occurred later in time than the pre-training condition (see Figure 1).

Examining the velocity curves, two key phases were found to differ significantly between pre- and post-training ($p < 0.05$). The first phase occurred at 32-51% of the velocity curves' duration, indicating that post-test downward velocity was greater than pre-test in both the magnitude and magnitude-time domain. The second phase occurred at 96-100% of the velocity curve. This phase revealed that the post-test peak velocity was higher and occurred later than Pre-training in both the magnitude and magnitude-time domain (see Figure 2).

The analysis of the power curves verified that three phases differed between the pre- and post-training ($p < 0.05$). The first phase occurred from 94-100% of the power curve, and revealed the post-training condition to result in higher and later peak power than pre-training in both the magnitude and magnitude-time domain. The second phase occurred from 68 to 72% of the curve and highlighted that the post-training generated a higher increase in power than the pre-training condition in solely the magnitude domain. The third phase occurred at 50-53% of the time through the jump, and indicated that at this time the subjects achieved more negative power post-training in the magnitude-time domain (see Figure 3).

DISCUSSION: The main findings of the current study were that six weeks of periodized plyometric training resulted in changes in the force, velocity, and power curve profiles during the CMJ. The use of ACP showed that the magnitude and magnitude-time domain of all three curves increased post-training during the latter part of the takeoff (> 90%). These findings are in agreement with Dowling and Vamos (1993) who showed that better jumpers attained a higher maximum force and power during the takeoff. While they only reported discrete values for peak power and force; examination of their figures indicate that curves of better jumpers were similar to the changes elicited due to training in the current study where peaks just prior to takeoff were higher. These increases are in agreement with Petushek and colleagues (2010); as well as Cormie and coworkers (2009), who state these changes are indicative of enhanced jump performance.

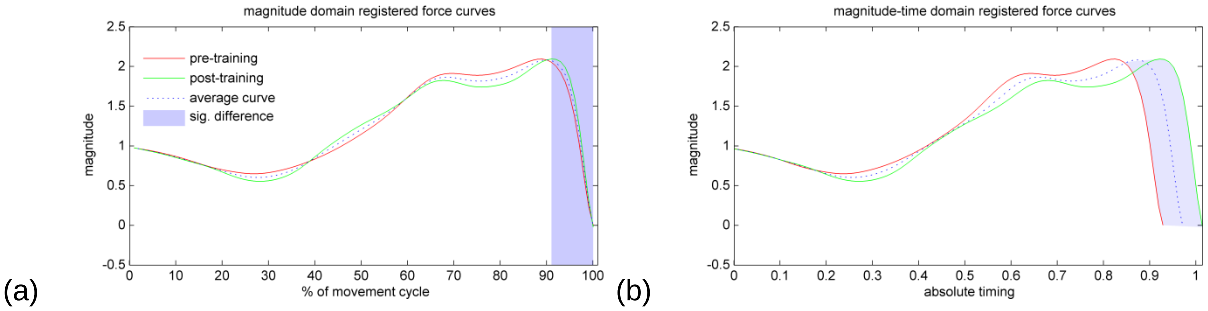

Figure 1. Differences between pre- and post-training in the force profiles for the (a) percent of the takeoff and (b) absolute time. Shading indicates the areas of the significantly different phases.

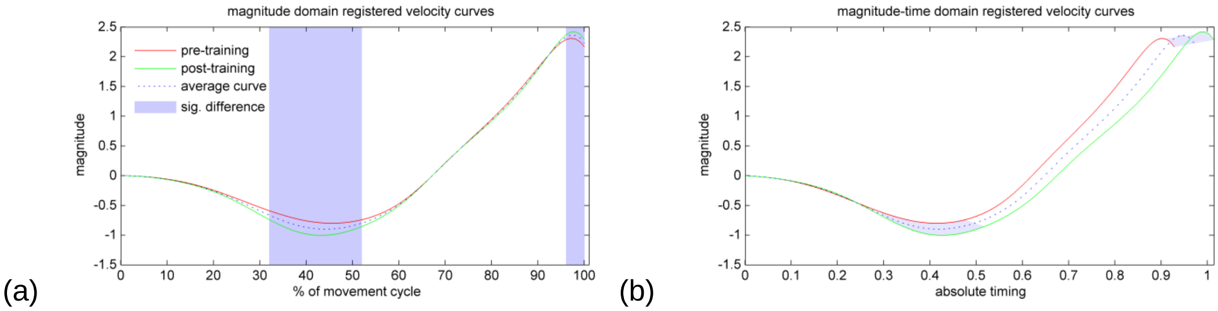

Figure 2. Differences between pre- and post-training in the velocity profiles for the (a) percent of the takeoff and (b) absolute time. Shading indicates the areas of the significantly different phases.

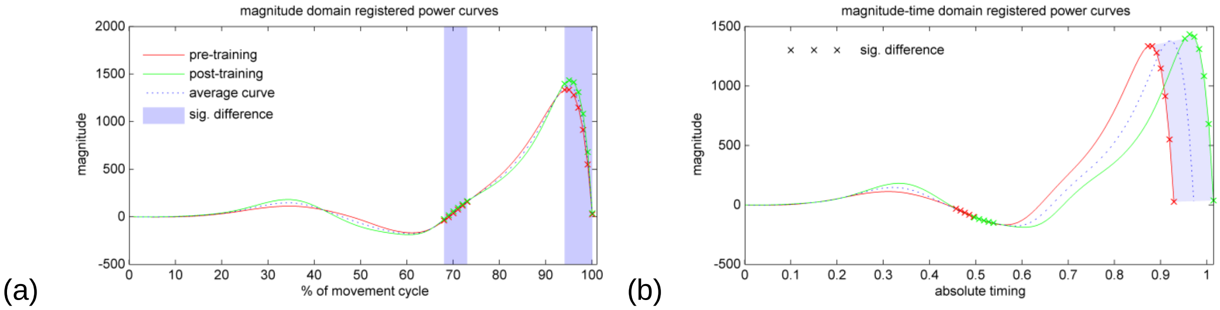

Figure 3. Differences between pre- and post-training in the power profiles for the (a) percent of the takeoff and (b) absolute time. Shading indicates the areas of the significantly different phases.

In addition, post-training downward velocity (~32-51% of the velocity curves' duration) was greater than pre-training. Post-training power also displayed a more negative value during the eccentric phase of takeoff (50-53% of the curve) and increased more rapidly during the early part of concentric movement (68-72% of the curve). These findings are similar to those of Cormie et al. (2009) and Petushek and colleagues (2010), who theorized that increased countermovement may enable subjects to optimize the stretch-shorten cycle mechanics (i.e., increasing the rate and magnitude of the stretch), which results in improved CMJ performance. Indeed the increase in power for the early and late portions of the concentric portion of the takeoff was likely a contributing factor in the increased jump height displayed post-training.

CONCLUSION: Six weeks of periodized plyometric training results in adaptations of the force, velocity, and power profiles during the CMJ. Specifically there is an increase in all three curves from ~91-100% of the curve duration. Furthermore, post-training, the velocity and power curves become more negative during the eccentric portion of the movement; and the power curve is increased during the early phase of the concentric contraction. These changes likely combine to enhance the SSC, thus augmenting jump performance.

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