P03-7 ID64

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 profile adaptations to the countermovement jump in response to a six week periodized plyometric training program. Twenty recreationally active women participated in the study (10 training, 10 control). Testing consisted of 3 maximal countermovement jumps on a force platform prior to and after six weeks of training. Key phases of the jumps were examined to assess differences in the profiles pre- and post-training using Analysis of Characterizing Phases. Periodized plyometric training significantly altered the profiles for force, velocity, and power ($p < 0.05$). A combination of greater eccentric velocity and power followed by increased concentric power enhanced the stretch shortening cycle and all three variables just before takeoff likely enhancing jump height.

KEY WORDS: plyometric training, stretch-shortening cycle, program design

INTRODUCTION: Plyometric training can be an effective training intervention to improve jumping performance (Markovic, 2007; de Villarreal et al., 2009). However, little is known about how these improvements manifest. 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 attempted to assess system adaptations following training using discrete point analysis [e.g. peak power] (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 discrete point analysis procedures, the understanding of the underlying sources that enhance performance during the CMJ remains equivocal. The purpose of the study was to investigate the effectiveness of short-term periodized plyometric training on CMJ technique and performance by examining continuous waveforms via an Analysis of Characterizing Phases.

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 a variety of low intensity plyometrics such as line/cone hops and low box height drop jumps and progressed to higher intensity plyometrics including 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 sub-maximal and maximal CMJs. For initial and final testing, each participant performed 3 maximum effort CMJs with an arm swing, 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 of the concentric phase) (Ramsay, 2006).

To assess the effect of the periodized plyometric training on jump technique and height, a dependent *t*-test was used to examine subject scores generated during an Analysis of Characterising Phases of the force, velocity, and power curves (Richter et al., 2012). Analysis of Characterising Phases (ACP) detects phases of variance (key phases) within a sample of curves, which are used to examine differences between groups in the time, magnitude and magnitude-time domains. A functional principal component analysis (retaining 99% of the data's variance) was used to identify the key phases that were then used to generate subject scores (Richter et al., 2012). Subject scores for the statistical analysis were generated by calculating the area between a subject's curve (p) and the mean curve across the data set (q) for every point (i) within the key phase (Equations 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 & DISCUSSION: This study demonstrated that six weeks of periodized plyometric training increased CMJ height by 21% (pre-training 0.24 ± 0.04 m to post-training 0.29 ± 0.03 m) ($p < 0.05$) while control group performance remained unchanged ($p>0.05$), therefore ACP was performed on the training group only. ACP identified adaptations in force, velocity and power curves. For force curves, periodized training resulted in higher ground reaction force that occurred later in time during the 91-99% phase of the jump (see Figure 1).

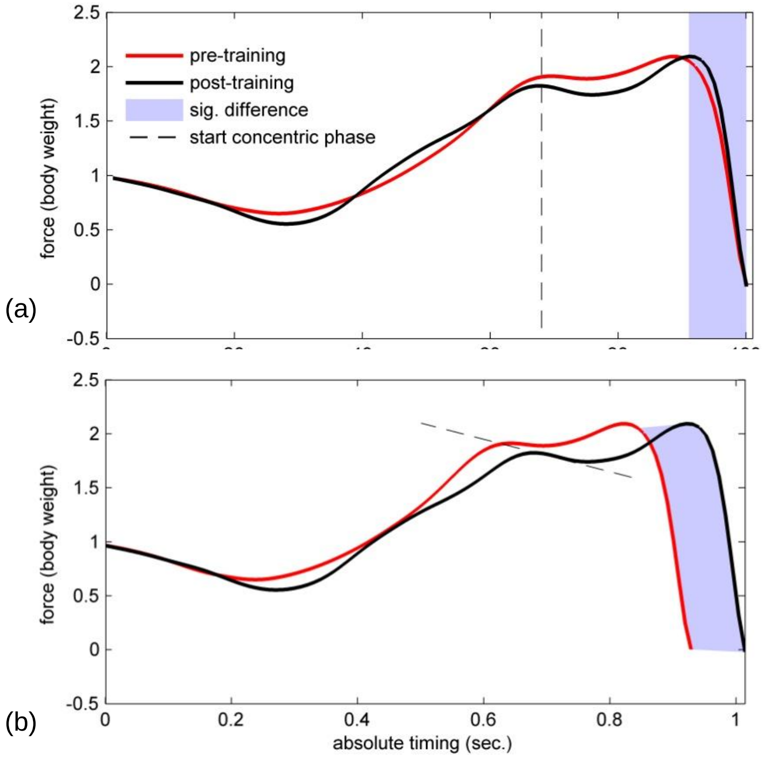

Figure 1. Differences between pre- and post-training in the force profiles for the (a) percent of the takeoff and (b) absolute time. Shading indicates the areas of the significantly different phases.

For velocity curves, ACP revealed that the post-test CMJ peak eccentric and concentric velocities were more pronounced and occurred later than pre-training in both the velocity and velocity-time domain ($p < 0.05$). (Figure 2).

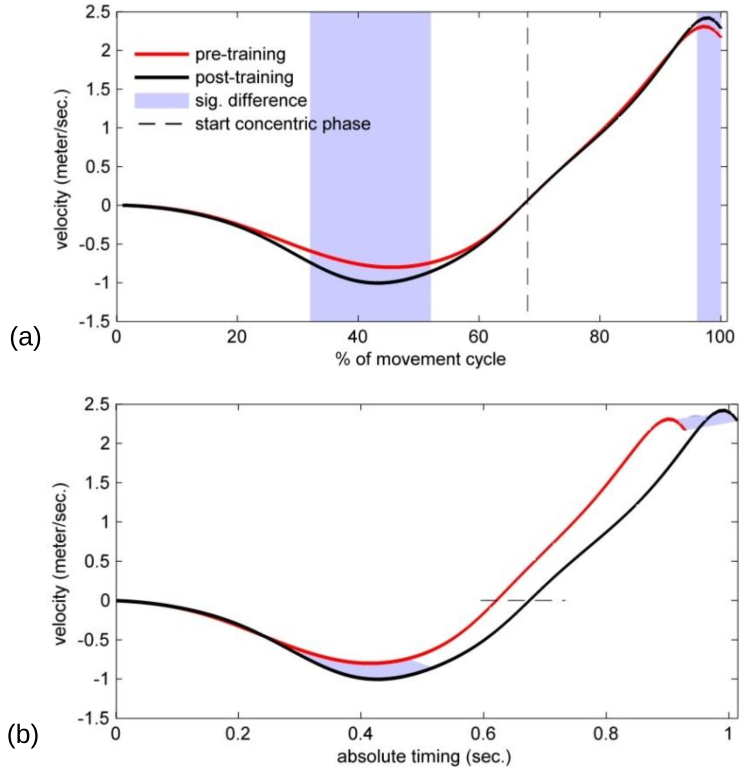

Figure 2. Differences between pre- and post-training in the velocity profiles for the (a) percent of the takeoff and (b) absolute time. Shading indicates the areas of the significantly different phases.

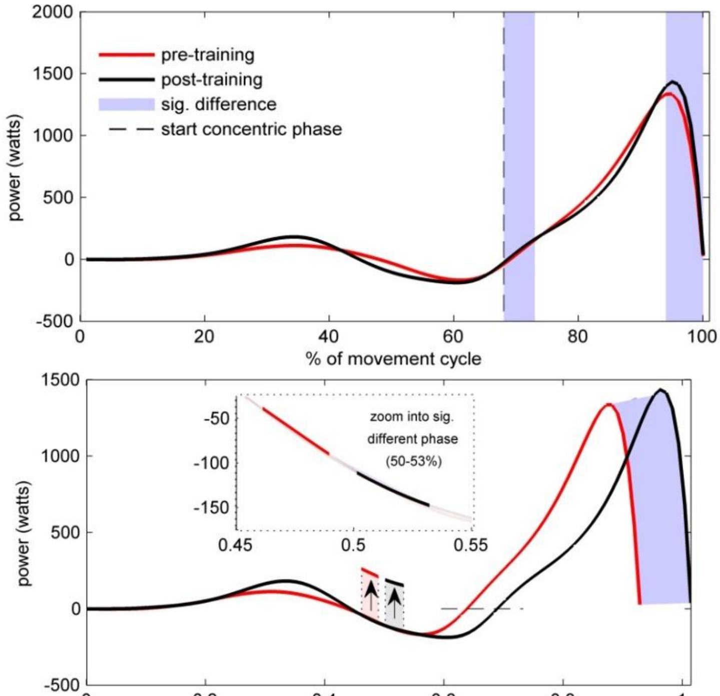

Figure 3. Differences between pre- and post-training in the power profiles for the (a) percent of the takeoff and (b) absolute time. Shading indicates the areas of the significantly different phases.

Post-training power curves 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). In addition peak power occurred at 94-100% of the power curve, and was higher and later than pre-training in both the power and power-time domain. The findings of greater changes in velocity and power are similar to those of Cormie et al. (2009) and Petushek et al. (2010), who theorized that an increased countermovement resulted in greater changes in velocity both eccentrically and concentrically. These changes may enable subjects to optimize the stretch-shortening cycle mechanics (i.e., increasing the rate and magnitude of the stretch), resulting in greater power and improved CMJ performance. 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. As shown in the figures above, peak force, velocity, and power profiles were all higher just prior to takeoff. Indeed the increase in power for the early 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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Acknowledgements:

This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE-1051031 (EJP).