THE EFFECT OF PLYOMETRIC TRAINING VOLUME ON JUMPING PERFORMANCE

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This study compared high and low daily volume periodized plyometric training programs and their effect on countermovement jump (CMJ) performance over a 2 week testing time course after training. Thirty-five male subjects participated. Subjects CMJ was tested on a force platform prior to and at 2, 6, 10 and 14 days post training. Peak vertical ground reaction force (GRF), reactive strength index-modified (RSI mod), jump height (JH), and body mass were assessed. No differences were found between the high and low volume training groups. Subjects GRF, RSI mod, and JH performance was improved in a range of 6 to 14 days post- training. Low and high volume periodized plyometric training programs produced equal results. Six to 14 days of recovery post training was required to accrue the training benefit.

KEY WORDS: stretch shortening cycle, taper, periodization, adaptations, program design

INTRODUCTION: Plyometric exercises are used to improve explosive power and prevent injury. While these exercises have been shown to be effective (de Villarreal et al., 2009), the details of program design are not well established. Research has quantified important program design variables such as plyometric intensity (Jensen & Ebben, 2007; Jensen et al., 2008; Ebben et al., 2011; Sugisaki et al., 2013) and the time course of post training recovery (Ebben et al., 2010; Petushek et al., 2010). However, recommendations for plyometric training volume remain unclear, as does the requisite amount of post-training recovery.

The training volume of lower body plyometrics is typically quantified as the number of foot contacts per exercise session. Previous training volume recommendations for beginner, intermediate, and advanced participants include 80-100, 100-120, and 120-140 foot contacts per plyometric training session (Potach & Chu, 2008), respectively. However, more recent recommendations suggest 80-100 foot contacts per session for novice adult athletes up to 200 foot contacts of high intensity plyometrics for trained adult athletes (Chu & Myer, 2013). In fact, recommendations have been made for up to 400 foot contacts of low intensity plyometrics per training session for trained adults (Chu & Myer, 2013). Thus, anecdotal recommendations for plyometric training volume range from 80 to 400 foot per training session. To date, no research has assessed the optimal plyometric training volume.

Previous research has examined the training effects of a six week periodized plyometric training program with volume that ranged from 100 to 60 foot contacts per training session (Ebben et al., 2010; Petushsek et al., 2010). These studies demonstrate that periodized plyometric training program is effective at improving vertical jump height, peak power, and peak eccentric and concentric velocity. Similarly, a six week plyometric training program that ranged from 90 to 140 foot contacts per training session resulted in improved agility test performance compared to a non-training control group (Miller et al., 2006). While anecdotal recommendations suggest plyometric training programs of 200 foot contacts per training session, programs with less volume have been shown to be effective at improving performance (de Villarreal et al., 2009).

The time course of recovery from plyometric training has recently been studied (Ebben et al., 2010). Some evidence suggests that the time course of recovery from other forms of training may influence the magnitude of the post training results (Gibala et al., 1994; Weis et al., 2003). Plyometric training is effective in a range of prescribed daily volume that was periodized from 100 down to 60 foot contacts (Ebben et al., 2010; Petushsek et al., 2010) and up to 140 foot contacts per session (Miller et al., 2006). Anecdotal recommendations have suggested a volume of up to 200 foot contacts of high intensity plyometrics per training session (Chu & Myer, 2013). However, no study has evaluated the effect of daily differences in plyometric training volume on performance or the time course of adaptations to the training. Therefore, the purpose of this study was to evaluate the effect of plyometric training volume on vertical jump performance and the time course of post training adaptations.

METHODS: Thirty five men served as subjects (mean ± SD; age 20.69 ± 1.39 yr; body mass 74.30 ± 11.09 kg). Each subject had previous experience training with the plyometric exercises use in this study. This study was approved by the Institutional Review Board. All subjects were informed of the possible risks associated with involvement in the study and provided written informed consent.

Subjects first attended a pre-test habituation session to ensure proper technique of each plyometric exercise in the training program as determined by a certified strength and conditioning specialist (CSCS) and to be randomly assigned to either the low volume (LV) or high volume (HV) periodized plyometric training program. The LV plyometric training program implemented in this study has been established as an effective periodized plyometric training program in previous research (Ebben et al., 2010; Petushek et al., 2010). This periodized program prescribed 75 foot contacts per workout in week one, increased foot contacts to 100 per workout week 2, and then performed 90, 80, 70, and 60 foot contacts per workout in weeks 3, 4, 5, and 6, respectively. The HV plyometric training program implemented in the current study required the subjects in the HV training group to perform exactly twice as many foot contacts as the LV training group. Both the LV and HV training programs required the subjects to attend two sessions per week for six weeks with 48-96 hours recovery between sessions.

The volume of foot contacts decreased, while the intensity of plyometric exercises increased through the training programs. The intensity of the prescribed plyometric exercises was based previous research that has either estimated (Potach & Chu, 2008) or known (Jensen & Ebben, 2007; Ebben et al., 2008, 2011) plyometric intensities. Subjects were given 30 seconds of rest between sets and 15 seconds of rest between single jumps, based on previous research (Read & Cisar, 2001).

Prior to the every training and testing session, subjects performed a standardized warm-up consisting of three minutes of light cycling followed by 5 slow bodyweight squats, 10 yard forward walking lunge, 10 yard backward walking lunge, 10 yard walking hamstring stretch, 10 yard walking quadriceps stretch, 20 yard skip, 40 yard sprint at 90% of maximal ability, and 5 vertical jumps.

Subjects were tested prior to and at four times after the cessation of the training program, (2, 6, 10, and 14 days after). Subjects were tested at multiple times post training to assess the time course of adaptations. During these testing sessions, each subject performed 3 maximal CMJ with arm swing on a force platform (BP6001200, Advanced Mechanical Technologies Incorporated, Watertown, MA, USA), with 30 seconds rest between each jump.

All CMJ were performed on a force platform which was calibrated with known loads to the voltage recorded prior to each 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. Subject's peak vertical ground reaction force (GRF) (Jensen & Ebben, 2007), reactive strength index-modified (RSI Mod) (Ebben & Petushek, 2010c), jump height (JH) (Moir, 2008), and body mass (BM) were assessed using previously published methods. The three trial average of each variable was used for analysis.

The statistical analyses were performed with SPSS 20 (IBM, New York, NY, USA). A two-way mixed ANOVA with repeated measures for testing time course was used to evaluate the main effects for testing time course and the interaction of testing time course and plyometric training volume for GRF, RSI Mod, JH, and BM. Bonferroni adjusted pairwise comparisons were used to identify the specific differences between the testing time course. 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 effect size and power represented by η^2_p and d, respectively.

RESULTS: The analysis of GRF revealed significant main effects for testing time course ($P \leq 0.001$, $\eta^2_p = 0.18$, $d = 0.83$). Analysis of RSI Mod showed significant main effects for testing time course ($P \leq 0.05$, $\eta^2_p = 0.19$, $d = 0.84$). Analysis of JH showed significant main effects for testing session in the time course. ($P \leq 0.05$, $\eta^2_p = 0.15$, $d = 0.68$). Finally, analysis of BM showed no significant main effects for testing time course ($P > 0.05$). The statistical analysis showed no interaction between the any dependent variable and training volume for any of the sessions in the testing time course (P > 0.05). Results of Bonferroni adjusted pairwise comparisons for each significant dependent variable, as well as BM, are presented in Table 1. Intraclass correlation coefficients assessing the trial to trial reliability ranged from 0.41 to 0.99, with most ICC's over 0.80, for the dependent variables.

Table 1. Pre and post-test data from both training groups for ground reaction force (GRF), reactive strength index modified (RSI Mod), jump height (JH), and body mass (BM) from both training groups.

Testing Time Course	GRF (N)	RSI Mod	JH (m)	BM (kg)
Pre-Test	926.61 ± 204.60	0.44 ± 0.12	0.35 ± 0.11	72.30 ± 11.53
2 Days Post Training	977.45 ± 260.76	0.49 ± 0.17	0.36 ± 0.11	73.08 ± 11.92
6 Days Post Training	1000.56 ± 268.90[a]	0.51 ± 0.19[b]	0.37 ± 0.11[c]	73.10 ± 11.83
10 Days Post Training	980.25 ± 261.51	0.51 ± 0.19[b]	0.37 ± 0.12	73.32 ± 11.56
14 Days Post Training	999.01 ± 271.89[a]	0.50 ± 0.17	0.36 ± 0.11	73.08 ± 12.14

[a]GRF 6 Days Post-Training and 14 Days-Post Training is significantly different (P≤0.05) than the Pre-Test
[b]RSI Mod 6 Days Post-Training and 10 Days-Post Training is significantly different (P≤ 0.05) than the Pre-Test
[C]JH 6 Days Post-Training is significantly different (P≤ 0.05) than the Pre-Test .

DISCUSSION: This is the first study to assess the differences in the prescribed daily volume of plyometric training and its' effect on performance, as well as the time course of adaptations to the training. This study shows that higher volume periodized programs of double the volume are no more effective than the lower volume program. This study is also assessed the time course of recovery from plyometric training. This study also shows that plyometric training is effective at enhancing jumping ability, consistent with previous research (de Villarreal et al., 2009; Ebben et al., 2010).

The present study showed that plyometric training programs with lower daily volume were equally effective compared to higher volume programs. This finding is consistent with previous research demonstrating similar results when comparing low and high weekly volume programs (de Villarreal et al., 2009). Thus, lower volume programs are more time efficient, yet equally effective.

The current study also shows that performance is enhanced if there is a period of recovery after the training stimulus. This finding differs from the results of a previous study showing that periodized plyometric training with reduced volume produced post training test results that were not different over a 10 day post-test time course (Ebben et al., 2010). Similarly, studies assessing forms of training other than plyometrics have shown superior performance in torque, strength, and power with tapered training compared to a 10 day non-training recovery period (Gibala et al., 1994). Furthermore, the amount of requisite post-training

recovery has been shown to be dependent on the strength measure being tested (Weis et al., 2003).
The current study demonstrates that 6 to 14 days of recovery was more optimal than 2 days of recovery for athletes who were participating in other forms of sports training as well. As a result, the total volume of fatigue producing stimulus present in the athletes comprehensive training program may necessitate both a periodized reduction in training volume and a post training recovery period. Subjects jumping ability in the present study were somewhat lower than the ability of subjects in previous studies (de Villarreal et al., 2009; Ebben et al., 2010). The magnitude of the mean post-training adaptation in jumping ability was less for subjects in the current study as well. Unlike subjects who were more highly trained (Ebben et al., 2010), subjects in the current study may have needed both a periodized program and a post training recovery period to manifest adaptations.

CONCLUSION: Practitioners who design plyometric programs should prescribe low to moderate volume periodized plyometric training since higher volume programs offer no additional benefit. Higher volume programs are less time efficient. Post training testing, and possibly sport participation, should occur more than 2 days after the training period, with the optimal benefits of training being expressed between 6 days and 2 weeks after training.

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