ELECTROMYOGRAPHICAL ANALYSIS OF PLYOMETRIC EXERCISES

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The purpose of this study was to evaluate integrated electromyographic (IEMG) activity of the quadriceps (Q), hamstring (H), and gastrocnemius (G) muscle groups during the performance of 10 randomly ordered plyometric (P) exercises. Subjects included 23 adults who routinely performed P. A one way Repeated Measures ANOVA indicated Q-IEMG activity was significantly different ($p < 0.05$) across conditions. Similarly, G-IEMG was significantly different ($p < 0.05$) across conditions for males and subjects with vertical jumps greater than 50 cm. No significant differences ($p>0.05$) were found for the G-IEMG for female subjects and those with vertical jumps less than 50 cm, or for the H muscle group. Bonferonni adjusted pairwise comparisons of main effects revealed differences in IEMG between specific P exercises.

KEYWORDS: intensity, ACL, stretch-shortening-cycle

INTRODUCTION: Plyometric exercises are commonly used to develop muscular power, enhance athletic performance, and prevent injury. Like other forms of exercise, P training requires an understanding of a variety of program design variables such as exercise mode, frequency, volume, program length, recovery, progression and intensity (Potach & Chu, 2000). Intensity may be the most important of these variables. Typically, factors such as the number of points of contact during landing, the speed of the drill, the height of the jump, and the athlete's weight have been suggested as possible factors determining P intensity (Potach & Chu, 2000). Similarly, anecdotal recommendations exist for categories of low to high intensity P exercises (Chu, 1994; Potach & Chu, 2000). Attempts to evaluate the intensity of P exercises have often compared ground and knee joint reaction forces (GRF and K-JRF) of only a few exercises such as drop jumps versus pendulum jumps (Fowler & Lees, 1998), one-leg versus two-leg vertical jumps (Van Soest, et al., 1985), variations of an exercise such as drop jumps from multiple heights (Raynor & Seng, 1997), or loaded and unloaded drop jumps (Tsarouchas, et al., 1995). Jensen and Ebben (2002, 2005) evaluated several P exercises by analyzing GRF and K-JRF and impulse, and found differences in intensity between exercises, suggesting a course by which practitioners could progress P intensity in training programs. Motor unit recruitment, as assessed by IEMG, is another strategy which may be useful in quantifying the differences between P exercises. Therefore, the purpose of this study was to evaluate motor unit recruitment of a variety of P exercises using IEMG.

METHODS: Twenty-three adult subjects (12 female and 11 male; age = 22.65±3.42 years; body mass = 76.15±18.61 kg) volunteered to serve in the study. Subjects were of various training and ability levels, though all were familiar with and participated in P training. Subjects completed an informed consent form prior to participation in the study. Approval for use of human subjects was obtained from the institution prior to commencing the study.

Warm-up prior to the P exercises consisted of 5 minutes of low intensity work on a cycle ergometer followed by stretching which included one exercise for each major muscle group with stretches held for 15 seconds. Subjects then performed 5 repetitions each of the following exercises: walking forward lunge with arm circles (5 each leg), speed squats with body weight, and two repetitions at 75% intensity of the 10 P exercises to be performed in the test. Subjects were then allowed at least 5 minutes rest prior to beginning the test. During the test, the order of the exercises was randomly assigned and consisted of depth jumps (DJ) from 30.5 (DJ12) and 61cm (DJ24), pike jump (PIK), tuck jump (TUC), single leg vertical

jump and reach (SLJ), double leg vertical jump and reach (VJ), squat jump holding dumbbells equal to 30% of 1RM squat (SJ30), two-foot ankle hops (ANK), 15.24 cm cone hops (CON), and a box jump (BOX). One repetition of each exercise was performed with a one minute rest interval between each exercise.

Electromyographic data were recorded at 1024 Hz using bipolar surface electrodes placed on the bellies of the rectus femoris, biceps femoris, and gastrocnemius. Skin preparation included shaving hair and cleaning the surface with alcohol. The Q surface electrode was placed over the rectus femoris, halfway between the greater trochanter and medial epicondyle of the femur. The H surface electrode was placed over the biceps femoris halfway between the gluteal fold and the popliteal fossa. The G surface electrode was placed over the belly of the G, approximately one-third of the distance between the head of the fibula and the lateral malleolus. A reference electrode was placed between the medial condyle and medial malleolus of the tibia.

Surface electrodes were connected to an amplifier and streamed continuously through an analog to digital converter (Delsys, Boston, MA, USA) to an IBM-compatible notebook computer. All data were filtered with a 10Hz high pass filter and saved with the use of computer software (EMGworks 3.1 data acquisition program, Delsys, Boston, MA, USA). Integrated electromyography (IEMG) was used for the analysis of all data and was calculated using root mean square across 50 samples. Data were analyzed for the entire repetition of each P exercise, including the takeoff and landing phases.

Statistical treatment of data was performed with SPSS 13.0 for Windows (Microsoft Corporation, Redmond, WA, USA) using a one-way, repeated measures ANOVA.

RESULTS: Separate analysis of all Q, H, and G data was conducted for all subjects, as well as for males, females, subjects with VJs greater than 50cm, and subjects with VJs less than or equal to 50cm. No significant main effects were found between any of the ten plyometric exercises with respect to H-IEMG or for G-IEMG for female subjects and for those with VJ less than or equal to 50cm (table 1). On the other hand, a significant main effect was found for the Q in all conditions of analysis. Similarly, a significant main effect was found for the G for all subjects. However, separate analysis by gender resulted in a finding of significance for only males and for subjects whose VJ was greater than 50cm (table 1). Data from Bonferonni adjusted pairwise comparisons of Q-IEMG for all subjects are presented in table 2. Data from Bonferonni adjusted pairwise comparisons of G-IEMG of males subjects are presented in table 3.

Table 1. Main effects of Analysis of Variance (ANOVA) for IEMG of the ten plyometric exercises

Total IEMG Quadriceps		Total IEMG Hamstrings		Total IEMG Gastrocnemius	
	Significance		Significance		Significance
All subjects	0.013*	All subjects	0.115	All subjects	0.000*
Males	0.000*	Men	0.444	Men	0.019*
Females	0.000*	Women	0.407	Women	0.143
VJ ≤50cm	0.003*	VJ ≤50cm	0.452	VJ ≤50cm	0.106
VJ >50cm	0.009*	VJ >50cm	0.407	VJ >50cm	0.016*

*Significantly different ($p<0.05$)

Table 2. Integrated EMG (mV) for the quadriceps muscle group for all subjects (mean ± SD)

(CON)	(BOX)	(TUC)	(VJ)	(SJ30)	(ANK)	(PIK)	(SLJ)	(DJ12)	(DJ24)
5.65 [a]	5.26 [b]	5.09 [b]	4.99 [b]	4.55 [b]	4.48 [c]	4.31 [c]	3.48 [d]	3.44 [d]	2.96 [e]
±2.35	±2.25	±2.41	±1.69	±1.77	±2.12	±2.14	±1.77	±2.21	±1.37

[a]Significantly different ($p<0.05$) from ANK, PIK, SLJ, DJ12, DJ24
[b]Significantly different ($p<0.05$) from SLJ, DJ12, DJ24
[c]Significantly different ($p<0.05$) from CON, DJ24
[d]Significantly different ($p<0.05$) from CON, TUC, VJ, SJ 30, BOX
[e]Significantly different ($p<0.05$) from ANK, CON, TUC, PIK, VJ, SJ30, BOX

Table 3. Integrated EMG (mV) for the gastrocnemius muscle group for males subjects (mean ± SD)

(CON)	(VJ)	(TUC)	(ANK)	(PIK	(BOX)	(SJ30)	(SLJ)	(DJ12)	(DJ24)
3.62 [a]	3.47 [b]	3.46	3.45 [b]	3.16 [b]	2.76	2.72	2.49[c]	2.37	1.93[c]
±1.85	±1.69	±2.23	±1.62	±1.46	±1.96	±1.23	±1.12	±1.47	±1.22

[a]Significantly different (p<0.05) from SLJ, DJ24
[b]Significantly different (p<0.05) from DJ24
[c]Significantly different (p<0.05) from CON
[d]Significantly different (p<0.05) from ANK, CON, PIK, VJ,

DISCUSSION: This is the first study to comprehensively evaluate motor unit recruitment during a variety of P exercises, demonstrating numerous differences in Q motor unit activity between exercises. Furthermore, some differences in G motor unit activity were found between exercises, particularly for males and subjects whose VJ exceeded 50cm. No significant differences were found for the H muscle group, suggesting that the response of this muscle group to P does not depend on the type of P performed, but on individual differences in H activation.

Previously, P have been categorized according to their estimated level of intensity. Jumps in place were thought to be least intense, followed by standing jumps of maximal effort, multiple hops and jumps, box jumps and depth jumps (Chu, 1992). Additionally, single leg P and those performed with added weight were thought to increase exercise intensity (Potach and Chu, 2000).

Results of the present study contrast with a number of these aforementioned anecdotal recommendations. For example, CON resulted in the highest Q-IEMG and G-IEMG for all subjects and males, respectively, despite the fact they were previously considered low intensity (Chu, 1992). In fact, in the present study, subjects demonstrated less mean Q-IEMG during depth jumps and single leg jumps than all other P, despite the previous belief that these were among the highest intensity P (Potach and Chu, 2000). Previous work by Jensen and Ebben (2002) indicated that SLJ, DJ, VJ were among the P demonstrating the highest impulse. Thus, as a measure of intensity, these findings are more consistent with previous anecdotal recommendations than the present study. Plyometrics that were anecdotally thought to provide the greatest overload, such as the SLJ, jumps with added mass and DJ's (Potach and Chu, 2000), that offered the highest GRF such as the SLJ, DJ24 and SJ 30 (Jensen and Ebben, 2005) and that yielded the greatest K-JRF such as TUC, PIK, and SLJ (Jensen and Ebben, 2005), resulted in relatively low levels of Q-IEMG activity in the present study.

Surprisingly, these findings indicate that P exercises previously thought to provide the greatest intensity and overload resulted in less motor unit recruitment than exercises believed to be of lower intensity. For example, DJ12, DJ24, SLJ, resulted in less Q-IEMG than exercises such as the CON. The SLJ also produced less Q-IEMG than the VJ, despite the fact that only one Q as opposed to both, were responsible for overcoming all of the body mass. Furthermore, SJ30 elicited less mean Q-IEMG than the VJ, even though the SJ30 represents a jump with an added load of 30% of the subject's squat repetition maximum. Finally, the DJ from 61cm resulted in less mean Q-IEMG than the DJ from 30.5cm.

Two hypotheses are suggested for why P that most likely offer greater overload resulted in less Q-IEMG. First, the P exercises with the greatest overload may trigger the hamstring-muscle reflex arc (Solomonow, 1987), resulting in inhibition of the Q, as demonstrated by less Q-IEMG. Second, greater overload during stretch shortening cycle activity may preferentially activate passive elastic force producing biomaterials rather then active contractile mechanisms.

Plyometric intensity can be evaluated in a number of ways. In the present study, mean differences for the H-IEMG were as great as threefold, yet due to large standard deviations and Bonferonni correction during pairwise comparison, no significance was found. While it is important to evaluate numerous P exercises, the familywise error rate likely inflates the type II error. Previous work by the authors (Jensen and Ebben, 2002, 2005) suggests that there is less variability when evaluating P with GRF, K-JRF and impulse. As a result, these

measures may be preferable for evaluating large numbers of P. Electyromyography may be more useful to further evaluate and understand smaller number of P exercises or to compare exercises from various anecdotal categories.

CONCLUSION: Quantifying P exercise intensity is important in order to optimally progress this form of exercise for developing athletic ability, rehabilitation and preventing injury. Quadriceps IEMG, and to a lesser degree G IEMG, particularly for males and subjects with VJ over 50cm, demonstrate qualitative differences between P exercises. Practitioners are encouraged to incorporate P exercises that offer greater motor unit recruitment in the progression of the P program.

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