ELECTROMYOGRAPHICAL ANALYSIS OF LOWER EXTREMITY MUSCLE ACTIVATION DURING VARIATIONS OF THE LOADED STEP UP EXERCISE

Christopher J. Simenz, Luke R. Garceau, Brittney N. Lutsch, Timothy J. Suchomel, William P. Ebben

Dept. Physical Therapy, Program in Exercise Science, Strength and Conditioning Research Laboratory
Marquette University, Milwaukee, WI, USA

This study evaluated the biceps femoris, gluteus maximus, gluteus medius, rectus femoris, semitendonosus, vastus lateralis, and vastus medialis activation during four variations of the step up exercise. The exercises included the step up, crossover step up, diagonal step up, and lateral step up. Fifteen women who regularly engaged in lower body resistance training performed the four exercises with 6RM loads on a 45.72cm plyometric box. Data were collected with a telemetered EMG system, and RMS values were calculated for EMG data for eccentric and concentric phases. Results of a repeated measures ANOVA ($p \leq 0.05$) revealed a variety of differences in muscle activation between the exercises.

KEYWORDS: gluteus medius, program design, ACL injury, women

INTRODUCTION: Quantification of muscle activation of lower body resistance training exercises allows practitioners to make informed decisions regarding which exercises are optimal for performance enhancement and rehabilitation. The hamstring muscle group is important in reducing ACL injury risk and training reduces hamstring inhibition and quadriceps to hamstrings ratio (Ebben, et al., 2009). While there is a growing body of literature on hamstring activation during resistance exercise and hamstring to quadriceps ratios, few have examined the eccentric and concentric phases (Wright, et al.,1999) or the role of the gluteus medius in closed chain resistance exercise (Ayotte, et al., 2007; Ekstrom, et al., 2007; Worrell, et al., 1993). Though data has indicated reduced firing of gluteus maximus during single leg activities (Zazulak, et. al., 2005), little data exists to describe the role of the gluteus medius. It is suggested that gluteus medius training improves both strength and timing of gluteus medius firing, which may reduce dynamic knee valgus during sport and exercise, reducing risk of ACL injury (Myer, et al., 2004).

Instead, research has commonly focused on the thigh musculature during variations of the step up exercise. The primary focus of previous studies has been the rehabilitation of the knee, with experimental procedures based on commonly utilized rehabilitation protocols such as step heights of 8 inches or lower (Ayotte, et al, 2007; Beutler, et al., 2002; Ekstrom, et al, 2007; Kerr, et al., 2007), and only body weight resistance (Ayotte, et al, 2007; Beutler, et al, 2002; Bolgla, et al, 2008; Brask, et al, 1984; Childs, et al, 2004; Cook, et al, 1992; Ekstrom, et al, 2007; Kerr, et al, 2007), thereby applying rehabilitative loads and conditions to non-rehabilitation populations. Those studies that did utilize additional resistance when assessing the step up loaded subjects arbitrarily with body weight plus an additional 25 percent of the subject's body weight (Selseth, et al, 2000; Worrell, et al, 1993; Worrell, et al, 1998) out of concern for the limited capacity of rehabilitation patients rather than using either RM testing or predictive regression tools (Ebben, et al., 2008). However, the existing literature has shown the benefits of using loaded single-leg exercises to improve functional and sport performance in athletes (McCurdy & Conner, 2003), since progressive overload is necessary (Fleck & Kraemer, 1997).

The purpose of this study is to examine muscle activation during 4 variations of the loaded step up exercise using prescribed 6RM loads to determine hip and knee muscle activation.

METHODS: Fifteen women (mean ± SD; age 21.0 ± 1.41 yr; body mass 63.56 ± 6.89 kg, height 159.84 ± 28.99 cm) volunteer university students who regularly engaged in lower body resistance training served as subjects. The study was approved by the institution's internal review board. All subjects performed a habituation and testing session. Prior to each session, the subject warmed up and performed dynamic stretching. During the habituation session, all subjects were familiarized with the test procedures, including performing maximum voluntary isometric contractions (MVIC)s recorded in order to normalize the electromyographic (EMG) data. During this period, rectangular shaped, bipolar EMG surface electrodes with 1 x 10 mm 99.9% Ag conductors and an inter-electrode distance of 10 mm were placed on biceps femoris (BF), gluteus maximus (GMx), gluteus medius (GMe), rectus femoris (RF), semitendonosus (ST), vastus lateralis (VL), and vastus medialis (VM). Data were recorded using a four channel, fixed shielded cabled, DelSys Bagnoli-4 EMG system (DelSys Inc., Boston, MA, USA.) and an Elgon goniometer (DelSys Inc., Boston, MA, USA.). MVICs for the BF and ST groups were measured at 60 degrees of knee flexion using the seated leg curl (Hammer Strength, Schiller Park, IL, USA), at 60 degrees of knee flexion for the VL, VM, and RF on the leg extension machine (Magnum Fitness Systems, South Milwaukee, WI, USA), with subject lying prone at approximately 70 degrees hip flexion on a decline bench for the GMx (Magnum Fitness Systems, South Milwaukee, WI, USA), and GMe was tested with subject's leg abducted to approximately 25 degrees against a padded, immovable mass. Subjects also received instruction in and performed the four exercises including the step up (SU), crossover step up (CR), diagonal step up (DI), and lateral step up (LA). Subjects were then tested in order to determine their six-repetition maximum (6RM) for each step up variation. Six RM loads were chosen since this study sought to test muscle strength as opposed to muscle endurance. Approximately 72 hours after the habituation session, subjects returned for the testing session. During the testing session, subjects performed the same dynamic warm up session as in the habituation session, followed by 5 minutes of rest. Subjects then performed 2 repetitions of each of the step up test exercises in a randomized order with 6RM load, with 5 minutes of rest between each exercise. These exercises were selected for evaluation since they all are characterized by hip and knee extension, and DI, LA, and CR are additionally characterized by hip ab- and adduction in a dynamic, single-leg fashion, which is thought to elicit greater GMe activation (Kraus, et al., 2009).

The statistical analyses were undertaken with SPSS 17.0. A two way mixed ANOVA with repeated measures for step up exercise type was used to evaluate the main effects for step up variation and the interaction between step up variation and eccentric/concentric phase, for RMS EMG of the SU, CR, DI, and LA. Data were expressed as a percentage of MVIC for each muscle group. Bonferroni adjusted pairwise comparisons were used to identify the specific differences in muscle activation for each 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 power and effect size represented by d and η_p^2, respectively.

RESULTS: The analysis of EMG data revealed significant main effects ($p \leq 0.001$) for BF, GMx, GMe, RF, ST, and VL, but not for VM ($p=0.833$). Analysis revealed no significant interactions between exercise type and phase ($p \leq 0.05$) for the BF, GMx, RF, ST, VL, VM. A significant interaction ($p \leq 0.001$) was found for exercise type and phase for GMe.

Table 1. RMS EMG data for 7 muscles during eccentric and concentric phases of 4 step up variations (N=14)

		SU	CR	DI	LA
BF	Eccentric phase	$0.032 \pm 0.015^{a*}$	$0.031 \pm 0.015^{c*}$	$0.027 \pm 0.019^{c*}$	$0.019 \pm 0.009^{b*,c*,d*}$
	Concentric phase	0.092 ± 0.052	0.080 ± 0.047	0.090 ± 0.055	0.070 ± 0.038
	a= significantly different from LA		*c= significantly different from DI*		**= p ≤ 0.05*
	b= significantly different from SU		*d= significantly different from CR*		
GMx	Eccentric phase	0.040 ± 0.034	0.105 ± 0.297	0.036 ± 0.022	0.032 ± 0.018
	Concentric phase	0.098 ± 0.143	0.053 ± 0.024	0.061 ± 0.029	0.064 ± 0.047
GMe	Eccentric phase	$0.042 \pm 0.020^{a*,b*}$	$0.039 \pm 0.021^{a*,b*}$	$0.040 \pm 0.022^{b*,c*,d*}$	$0.038 \pm 0.023^{a*,c*,d*}$
	Concentric phase	0.070 ± 0.028	0.077 ± 0.035	0.065 ± 0.022	0.054 ± 0.022
	a= significantly different from DI		*c= significantly different from SU*		**= p ≤ 0.05*
	b= significantly different from LA		*d= significantly different from CR*		
RF	Eccentric phase	$0.054 \pm 0.019^{a*,b*}$	$0.053 \pm 0.018^{a*,b*}$	$0.062 \pm 0.019^{c*,d*}$	$0.060 \pm 0.022^{c*,d*}$
	Concentric phase	0.084 ± 0.024	0.087 ± 0.020	0.092 ± 0.030	0.093 ± 0.030
	a= significantly different from DI		*c= significantly different from SU*		**= p ≤ 0.05*
	b= significantly different from LA		*d= significantly different from CR*		
ST	Eccentric phase	$0.046 \pm 0.024^{a*,b*}$	$0.036 \pm 0.012^{c*,d*}$	$0.039 \pm 0.015^{a*,b*}$	$0.028 \pm 0.011^{c*,d*}$
	Concentric phase	0.093 ± 0.036	0.071 ± 0.033	0.089 ± 0.039	0.069 ± 0.028
	a= significantly different from CR		*c= significantly different from SU*		**= p ≤ 0.05*
	b= significantly different from LA		*d= significantly different from DI*		
VL	Eccentric phase	0.116 ± 0.066	0.104 ± 0.067	$0.110 \pm 0.061^{a*}$	$0.099 \pm 0.053^{b*}$
	Concentric phase	0.183 ± 0.099	0.186 ± 0.104	0.191 ± 0.110	0.178 ± 0.083
	a= significantly different from LA		*b= significantly different from DI*		**= p ≤ 0.05*
VM	Eccentric phase	0.084 ± 0.044	0.085 ± 0.044	0.088 ± 0.047	0.079 ± 0.037
	Concentric phase	0.144 ± 0.077	0.145 ± 0.073	0.150 ± 0.085	0.144 ± 0.081

SU= Step up	LA= Lateral Step up	GMe= Gluteus medius	VL= Vastus Lateralis
CR= Crossover Step up	BF= Biceps femoris	RF= Rectus femoris	VM= Vastus medialis
DI= Diagonal Step up	GMx= Gluteus maximus	ST= Semitendonosus	

DISCUSSION: This is the first known study to use systematically tested RM loads to analyze EMG activity of the GMe musculature along with other hip and thigh musculature during variations of the loaded step up exercise. Significant differences were found between exercises as well as between concentric and eccentric phases for the GMe, contrary to findings of Ayotte, et al., (2007) who found no significant differences in GMe activation between front step up and lateral step up exercises in unloaded subjects. Specifically, the crossover step up was found to elicit the greatest concentric activation of the GMe, while the step up elicited the greatest eccentric activation, which we conclude was due to the starting position of CR, which placed the lead leg of the subject into femoral adduction. As a result, GMe showed greater activation during the concentric phase of the CR, as the position likely forced the muscle to fire in an attempt to abduct the femur. This finding suggests the CR should be included in resistance training programs for court and field sport athletes in an attempt to reduce incidence of dynamic knee valgus, a common injury position due to unplanned changes of direction and cutting maneuvers (Hewitt, et al., 2010). In this study, the GMx showed no significant differences in activation regardless of exercise, suggesting similar strengthening effects as determined by Ayotte, et al. (2007) during various single leg exercises. In the current study the RF, interestingly, showed greatest activation during the LA and DI exercises, both of which were performed with relatively lighter loads when compared to the SU and CR. Significant differences were found for the hamstring musculature (BF, ST) during concentric and eccentric phases of the step up variations, with more activation occurring during SU and DI up variations. It is suspected that the requirement of more sagittal plane movement of the limb coupled with the advantageous line of pull of the hamstrings in that position increase activation. Activation levels for the BF and ST were relatively low when compared to VL and VM musculature for the selected exercises, consistent with existing literature (Ayotte, et al., 2007; Brask, et al., 1984; Cook, et al., 1992; Isear, et al., 1997). The VL and VM showed no significant differences between concentric and eccentric phases, contrary to findings of Selseth and colleagues (2000), who found significant differences in activation between concentric and eccentric phases for the LA exercise.

CONCLUSION: There are several practical applications that can guide the use of variations of the step up exercise for maximal muscle activation. For maximal GMe activation, the CR should be used, while the SU and DI should be used for maximal hamstring activation. To best activate the rectus femoris, the LA and DI should be utilized. Ultimately, it appears that a varied resistance program employing all variations of the step up exercise would be the most effective approach in maximally activating the hip and thigh musculature.

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