HAMSTRINGS, QUADRICEPS, AND GLUTEAL MUSCLE ACTIVATION DURING RESISTANCE TRAINING EXERCISES

McKenzie L. Fauth[1], Luke R. Garceau[1], Brittney Lutsch[1], Aaron Gray[1], Chris Szalkowski[1], Brad Wurm[1], and William P. Ebben[1,2]

Department of Physical Therapy, Program in Exercise Science, Strength and Conditioning Research Laboratory, Marquette University, Milwaukee, WI, USA[1]
Department of Health, Exercise Science & Sport Management, University of Wisconsin-Parkside, Kenosha, WI, USA[2]

This study evaluated hamstrings, quadriceps, and gluteal muscles activation during the back squat, deadlift, step-up, and lunge. Root mean square electromyographical data were analyzed for the eccentric and concentric phases during each exercise. Subjects included 16 women who performed 2 repetitions of each of the exercises at a 6 repetition maximum load. A repeated measures ANOVA revealed significant main effects ($P \leq 0.05$) representing differences in muscle activation between the resistance training exercises all muscle groups ($P \leq 0.05$) except for the rectus femoris, during the concentric phase ($P = 0.22$). Based on these results, resistance training exercises can be prescribed based on how they best train the desired musculature.

KEYWORDS: women, strength training,

INTRODUCTION: The quadriceps, hamstrings, and gluteal muscles are important in sport performance and injury prevention. The quadriceps group raises as well as controls the descent of the body's center of mass during athletic movements, such as running and jumping (Neumann, 2010). However, some evidence indicates that strong quadriceps forces cause anterior translation of the tibia and increase the risk of injury to the anterior cruciate ligament (ACL) (Baratta et al., 1988). Hamstring training may reduce hamstrings inhibition, hamstrings to quadriceps imbalance, and ACL injuries (Baratta et al., 1988).

Training the quadriceps disproportionately to the hamstrings may inhibit hamstrings co-activation, reduce joint stability, increase anterior tibial translation in response to strong quadriceps forces (Hewett et al., 2001), and potentially increase the incidence of hamstring strains (Yamamoto, 1993). Understanding hamstrings to quadriceps activation ratios is potentially important for performance and injury prevention during a variety of athletic movements such as jump landings, single leg support, and cutting maneuvers (Yamamoto, 1993). Such athletic movements also place a large demand on the hip musculature.

The gluteus medius and maximus have attachments on both the femur and pelvis, and therefore contribute not only to movements of the lower extremity, but also to pelvic and trunk stabilization. Insufficient strength or recruitment of these muscles may contribute to poor core stability, as well as to malalignment of the lower extremity. Training hip muscles increases lower extremity alignment, improves landing technique, and decreases risk of ACL injury by reducing valgus force to the knee (Myer et al., 2008).

Few studies have evaluated lower body muscles activation during a variety of resistance training exercises. Studies have assessed unloaded single leg squats, lunges and a 20.32 cm step-up exercise (Bourdreau et al., 2009) and hamstrings and quadriceps activation during a variety of loaded resistance training exercises (Ebben, 2009; Ebben et al., 2009). At present, no study has evaluated the activation of hip and knee muscles groups for several lower body resistance training exercises that incorporate hip and knee extension. Therefore, the purpose of this study was to quantify muscle activation of the quadriceps, hamstrings, and gluteal muscles during the back squat, deadlift, step-up, and lunge.

METHODS: Subjects included 16 women (mean ± SD; age = 21.19 ± 2.17 years; height = 169.39 ± 7.54 cm; body mass = 66.08 ± 9.91 kg) who participated in either NCAA Division I or club or intramural sports and lower body resistance training. All subjects provided informed consent and the university's internal review board approved the study.
Subjects attended one pre-test habituation session and one testing session. Prior to each, subjects participated in a standardized general and dynamic warm up. During the pre-test habituation session, subjects were familiarized with and performed their 6 repetition maximum (6 RM) for the back squat, deadlift, step-up, and forward lunge. All exercises were performed according to the methods previously described (Earle & Baechle, 2000) with the exception that the step-up began on top of the box so that all exercises started with the eccentric phase and ended with the concentric phase.
Following the 6 RM testing, subjects were familiarized with 4 maximum voluntary isometric contraction (MVIC) tests for the hamstrings, quadriceps, gluteus medius, and gluteus maximus.
Approximately 1 week after the pre-test habituation session, subjects returned for the testing session. During this session, subjects performed MVICs for the hamstrings, quadriceps, gluteus medius, and gluteus maximus with contractions held for 6 seconds each. Subjects then were tested by performing 2 full range of motion repetitions of their previously determined 6 RM loads, for each of the test exercises. Randomization of the exercises, limited repetitions, and 5 minutes of recovery were provided between MVICs as well as each test exercise.
Surface electromyography (EMG) was used to quantify muscle activation using a fixed shielded cabled, telemetered EMG system (Myomonitor IV, DelSys Inc. Boston, MA, USA). Data were recorded at sample rate of 1024 Hz using bipolar surface electrodes with 1 x 10 mm 99.9% Ag conductors, and an inter-electrode distance of 10 mm. Electrodes were placed on the longitudinal axis of the medial and lateral hamstrings (MH and LH, respectively) the rectus femoris (RF), the vastus lateralis and medialis (VL and ML, respectively), and the gluteus medius and maximus (GMD and GMX, respectively). A common reference electrode was placed on the lateral malleolus. Electrode placement was chosen in order to assess uni-articular and bi-articular knee extensor and flexor muscles, as well as hip abductors and extensors. Additionally, an electric goniometer was placed on the lateral aspect of the right knee in order to distinguish between the eccentric and concentric phases of the test exercises. Skin preparation included shaving, abrasion and cleansing with alcohol. Elastic tape was applied to ensure electrode placement and provide strain relief for the electrode cables. Surface electrodes were connected to an amplifier and streamed continuously through an analog to digital converter (DelSys Inc. Boston, MA, USA) to an IBM-compatible notebook computer.
All data were filtered with a 10-450 Hz band pass filter, saved, and analyzed with the use of software (EMGworks 3.1, DelSys Inc., Boston, MA, USA). The input impedance was 1015 Ohms and the common mode rejection ratio was >80 dB. Raw data were acquired and processed using root mean square (RMS) EMG with a moving window of 125 ms. Electromyographic data were analyzed for seconds 2-3 of the MVICs, and for eccentric and concentric phases for each of the 4 test exercises using the average of both test repetitions. All RMS EMG values for each muscle were normalized to the average RMS EMG of the 2 trials of the MVIC.
Data were evaluated with a repeated measures ANOVA to test main effects of RMS EMG for each muscle assessed. Bonferroni adjusted post hoc analyses were used to assess the specific differences in muscle activation between the resistance training exercises. The *a priori* alpha level was set at $P \leq 0.05$ and all data are expressed as means ± SD.

RESULTS: Significant main effects representing differences in muscle activation between the resistance training exercise were found for all muscle groups ($P \le 0.05$) except for the RF, during the concentric phase ($P = 0.22$). Table 1-7 shows the differences in muscle activation between the exercises. Subjects' mean squat, deadlift, lunge and step-up estimated 1 RMs were 88.98, 83.66, 67.38 and 38.48 kg, respectively.

Table 1. RMS EMG data for the lateral hamstring (LH) during the eccentric (ECC) and concentric (CON) phases of the 4 study exercises. (N=14)

	Deadlift	Lunge	Step-Up	Squat
LH ECC	0.55 ± 0.51[a]	0.38 ± 0.27[b]	0.35 ± 0.27[b]	0.28 ± 0.20[b]
	Deadlift	Step-Up	Lunge	Squat
LH CON	1.29 ± 0.72[a]	0.87 ± 0.54[b]	0.86 ± 0.66[b]	0.62 ± 0.40[b]

a = significantly different than all other exercises ($p \le 0.05$); b = significantly different than DL ($p \le 0.05$).

Table 2. RMS EMG data for the medial hamstring (MH) during the eccentric (ECC) and concentric (CON) phases of the 4 study exercises. (N=14)

	Deadlift	Lunge	Step-Up	Squat
MH ECC	0.43 ± 0.31[a]	0.41 ± 0.33[a]	0.31 ± 0.24[b]	0.24 ± 0.21[b]
	Deadlift	Step-Up	Lunge	Squat
MH CON	0.90 ± 0.41[c]	0.59 ± 0.36[d]	0.57 ± 0.49[d]	0.49 ± 0.29[d]

a = significantly different than SU and S ($p \le 0.05$); b = significantly different than DL and L ($p \le 0.05$); c = significantly different than all other exercises ($p \le 0.01$); d = significantly different than DL ($p \le 0.05$)

Table 3. RMS EMG data for the rectus femoris (RF) during the eccentric (ECC) phase of the 4 study exercises. (N=14)

	Squat	Lunge	Step-Up	Deadlift
RF ECC	0.81 ± 0.35[a]	0.66 ± 0.38[b]	0.63 ± 0.27[c]	0.54 ± 0.49[d]

a = significantly different than DL ($p \le 0.05$); b = significantly different than S and DL ($p \le 0.01$); c = significantly different than DL and SU ($p \le 0.01$); d = significantly different than S, L, SU ($p \le 0.01$);

Table 4. RMS EMG data for the vastus lateralis (VL) during the eccentric (ECC) and concentric (CON) phases of the 4 study exercises. (N=14)

	Lunge	Squat	Step-Up	Deadlift
VL ECC	0.98 ± 0.47[a]	0.94 ± 0.40[a]	0.90 ± 0.41[a]	0.61 ± 0.28[b]
VL CON	1.37 ± 0.59[a]	1.33 ± 0.68[a]	1.31 ± 0.82[a]	0.63 ± 0.32[b]

a = significantly different than DL ($p \le 0.05$); b = significantly different than all other exercises ($p \le 0.05$)

Table 5. RMS EMG data for the vastus medialis (VM) during the eccentric (ECC) and concentric (CON) phases of the 4 study exercises. (N=14)

	Lunge	Step-Up	Squat	Deadlift
VM ECC	1.27 ± 0.54[a]	1.22 ± 0.61[a]	1.17 ± 0.49[a]	0.78 ± 0.34[b]
VM CON	1.77 ± 0.63[a]	1.73 ± 0.94[a]	1.49 ± 0.54	1.32 ± 0.68[c]

a = significantly different than the DL ($p \le 0.001$); b = significantly different than all other exercises ($p \le 0.01$); c = significantly different than SU and L ($p \le 0.01$)

Table 6. RMS EMG data for the gluteus medius (GMD) during the eccentric (ECC) and concentric (CON) phases of the 4 study exercises. (N=14)

	Step-Up	Lunge	Deadlift	Squat
GMD ECC	0.56 ± 0.27[a]	0.55 ± 0.30[a]	0.25 ± 0.09[b]	0.23 ± 0.11[b]
GMD CON	0.85 ± 0.27[a]	0.84 ± 0.35[a]	0.56 ± 0.34[b]	0.38 ± 0.15[b]

a = significantly different than S and DL ($p \le 0.001$); b = significantly different than SU and L ($p \le 0.001$)

Table 7. RMS EMG data for the gluteus maximus (GMX) during the eccentric (ECC) and concentric (CON) phases of the 4 study exercises. (N=14)

	Lunge	Step-Up	Deadlift	Squat
GMX ECC	0.95 ± 0.45[a]	0.87 ± 0.31	0.76 ± 0.36[b]	0.62 ± 0.34[b]
	Step Up	Lunge	Deadlift	Squat
GMX CON	1.99 ± 0.91[c]	1.88 ± 0.69[c]	1.79 ± 0.88[c]	1.18 ± 0.50[d]

a = significantly different than DL and S ($p \leq 0.05$); b = significantly different than L ($p \leq 0.05$); c = significantly different than S ($p \leq 0.05$); d = significantly different than all other exercises ($p \leq 0.05$)

DISCUSSION: This study is the first to assess GMD and GMX activation during a variety of lower body resistance training exercises and further investigates hamstrings and quadriceps muscle activation during eccentric and concentric phases of a variety exercises. Results indicate that exercises such as the step-up and lunge are best for GMD and GMX activation, potentially due to the unilateral nature of these exercises. As a result, exercises such as these should be included in a training program for sports that require hip extension and abduction for dynamic performance or stabilization. Previous research demonstrated that single leg squat produced more GMX and GMD than lunges or 20.32 cm step-up exercises (Bourdreau et al., 2009). However, these exercises were performed without any added resistance (Bordreau et al., 2009). Of the exercises assessed in the present study, the deadlift appears the be the best MH and LH activator, producing 55 and 43 percent of the MVIC, respectively, during the eccentric phase, and 129 and 90 percent of the MVIC, respectively, during the eccentric phase. Previous research demonstrated biceps femoris activation of approximately 55 percent of the MVIC during the deadlift (Ebben et al., 2010). Results of the present study demonstrate mean rectus femoris and vastus lateralis activation ranged from highest to lowest during squat, lunge, step-up and deadlift. This finding is identical to previous research (Ebben et al., 2010).
VM activation has not been previously assessed during a variety of lower body resistance training exercises. In the present study, VM activation was highest during the lunge and step-up while the deadlift produced significantly lower levels of VM activation.

CONCLUSION: Results of this study demonstrated that the step-up and lunge are the best exercises for activating the GMD, GMX, and VM. The squat best activates the RF and the lunge, squat, and step-up are equally effective at activating the VL. The deadlift is the best exerciser for activating the MH and LH. Resistance training exercises should be prescribed based on how they best train the desired musculature.

REFERENCES:

Baratta, R., Solomonow, M., Zhou, B.H., Letson, D., Chuinard, R., & D'Ambrosia, R. (1988). Muscular coactivation: the role of the antagonist musculature in maintaining knee stability. *American Journal of Sports Medicine*, 16, 113-122.

Bourdreau, S.N., Dwyer, M.K., Mattacola, C.G., Lattermann, C., Uhl, T.L., & McKoen, J.M. (2009). Hip muscle activation during the lunge, single leg squat, and step-up-and over exercises. *Journal of Sport Rehabilitation.* 18, 91-103.

Earle, R.W. & Baechle, T.R. (2008). *Essentials of Strength Training and Conditioning* (3rd ed., pp. 325-359). Champaign, IL: Human Kinetics.

Ebben, W.P. (2009). Hamstring activation during lower body resistance training exercises. *International Journal of Sports Physiology and Performance*, 4(1), 84-87.

Ebben, W.P., Feldmann, C., Mitsche, D., Dayne, A., Knetzger, K., & Alexander, P. (2009). Quadriceps and hamstring activation and ratios of lower body resistance training exercises. *International Journal of Sports Medicine*, 30, 1-7.

Hewett, T.E., Myer, G.D., & Ford, K.R. (2001). Prevention of anterior cruciate ligament injuries. *Current Women Health Reports*, 1, 218-224.

Meyer, G.D., Chu, D.A., Brent, J.L., & Hewett, T.E. (2008). Trunk and hip control neuromuscular training for prevention of knee injury. *Clinics in Sports Medicine*, 27, 425-448.

Neumann, D.A. (2010). Kinesiology of the musculoskeletal system: Foundations for rehabilitation. 2nd ed., St. Louis, MO, Mosby, Inc.

Yamamoto, T. (1993). Relationship between hamstring strains and leg muscle strength. A follow-up study of collegiate track and field athletes. *Journal of Sports Medicine and Physical Fitness*, 33, 194-199.

Acknowledgement
Travel to present this study was funded by a Green Bay Packers Foundation Grant.