ELECTROMYOGRAPHICAL ANALYSIS OF HAMSTRING RESISTANCE TRAINING EXERCISES

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This study evaluated the EMG activity of the hamstring and quadriceps muscle groups during resistance training exercises commonly used for training the hamstrings. Subjects included 34 collegiate athletes. Hamstring and quadriceps MVIC and 6 repetition maximum loads were determined. Data were collected 72 hours later, during the performance of 6 randomly ordered exercises, including back squats, seated leg curls, stiff leg dead lifts, single leg dead lifts, good mornings, and “Russian curls.” Data were analyzed using RMS values normalized to MVIC. A one way repeated measures ANOVA revealed that significant differences existed between several exercises. Additionally, the ratio of hamstring to quadriceps co-activation was significantly different between all exercises.

KEY WORDS: strength, injury prevention, quadriceps, RMS

INTRODUCTION: The development of hamstring strength is important to ensure hamstrings/quadriceps muscle balance and to prevent hamstring muscle strains (Coole and Gieck, 1987; Wathen, 1994). Some sources suggest that the further the ratio is from 1:1, the greater the possibility of hamstring injury (Wathen, 1994). Previous reports indicate that the hamstring muscle group is frequently injured in athletic activities, possibly due to limited training or disproportionate training performed for the quadriceps (Coole and Gieck, 1987).

In addition to hamstring strains, weak hamstrings may also be part of the etiology of anterior cruciate ligament (ACL) injury. The co-contraction hypothesis states that hamstring activation may reduce the shear force associated with anterior tibial translation during some dynamic athletic movements. In fact, previous research has shown that subjects who were ACL deficient, yet able to return to athletic competition, demonstrated more compensatory EMG activity in the hamstrings, compared to ACL deficient subjects who were unable to compete (Boerboom et al., 2001). Thus, it appears that increased hamstring activation stabilizes the ACL deficient knee, aids ligaments in maintaining joint stability, equalizes articular surface pressure, and regulates the joints’ mechanical impedance (Baretta et al., 1988, Solomonov et al., 1987). Therefore, strengthening the hamstrings may be important to reduce both hamstring strains as well as ACL injuries.
Scientific evidence is limited about how to optimally train the hamstrings. In an attempt to quantify hamstring activation during resistance training exercises, researchers have used EMG to examine motor unit activity during variations of the deadlift (Escamilla et al., 2001), squat and leg press (Escamilla et al., 2001), and during variations in squat load or technique (Ebben and Jensen, 2002; Isear et al., 1996; Jensen and Ebben, 2000; McCaw and Melrose, 1999; Miller and Hendy, 2000; Wretenberg et al.,1996). However, these studies offer limited information regarding how to optimally train the hamstring, since the exercises assessed were predominantly characterized by hip and knee extension, which is unlikely to optimally activate the hamstrings (Ebben et al., 2000). Wright et al. (1999) demonstrated that the back squat yielded less than 50% of the concentric IEMG in the biceps femoris and semitendinosus compared to common hamstring training exercises such as the leg curl and stiff leg dead lift. Since hamstring strength is important for injury prevention and comprehensive information about how to optimally activate the hamstring is limited, the purpose of this study is to evaluate the hamstring motor unit activation of a variety of resistance training exercises that are commonly believed to train the hamstrings.

METHODS: This study used a randomized repeated measures research design to compare motor unit recruitment of the hamstring and quadriceps during six resistance training exercises believed to enhance hamstring strength. Independent variables included the resistance training exercise evaluated and dependent variables included hamstring and quadriceps EMG, hamstring and quadriceps EMG expressed as a percentage of MVIC, and the hamstring to quadriceps EMG ratio, for each of the exercises evaluated.

Twenty-one male and 13 female NCAA division-I or NCAA division-III athletes (20.38 ± 1.77 years) volunteered for this study. Subjects performed no resistance training for 72 hours prior to the study. All subjects provided informed consent prior to the study. This study was approved by the institutions' review board.

Prior to a pre-test orientation and the primary testing session, subjects participated in a general and dynamic warm up, consistent with the methods previously used in related studies (Ebben and Jensen, 2002). All subjects were familiarized with the test procedures during the pre-test orientating session, including performing an MVIC for the hamstring and quadriceps muscle groups, with the seated leg curl and squat, respectively. Each exercise was performed at 60 degrees of knee flexion, since pilot testing revealed that this position allowed the greatest MVIC. Additionally, each subject's 6 repetition maximum (6 RM) was assessed for the randomly ordered test exercises, including back squats, seated leg curls, stiff leg dead lifts, single leg dead lifts, good mornings, and the Russian curl.

After approximately 72 hours, subjects returned for the primary testing session. Each subject performed a MVIC for the hamstring and quadriceps. Subjects then performed 2 full range of motion repetitions, with their 6 RM loads, for each of the randomly ordered test exercises. Limited repetitions, randomization, and 5 minutes of recovery were provided between all exercise in order to reduce order and fatigue effects. Data were analyzed for the second repetition of each exercise and compared to each muscle groups' MVIC. Data were collected for the first third of the reps of each resistance training set, consistent with previous work by Escamilla et al. (2001).

Electromyographic data were recorded at 1024 Hz using bipolar surface electrodes placed on the biceps femoris (BF) and semitendinosis (S). Skin preparation included shaving hair and cleaning the surface with alcohol. The hamstring electrode was placed over the biceps femoris halfway between the gluteal fold and the popliteal fossa. The quadriceps surface electrode was placed over the rectus femoris, halfway between the greater trochanter and medial epicondyle of the femur. Reference electrodes were 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 Inc. Boston, MA, USA) to an IBM-compatible notebook computer. All data were filtered with a 10Hz high pass filter and saved and analyzed with the use of computer software (EMGworks 3.1, Delsys Inc., Boston, MA, USA). Root mean square (RMS) signal processing was used on all EMG data and normalized to each subjects' MVIC.

Data were analyzed with SPSS 13.0 for Windows (Microsoft Corporation, Redmond, WA, USA) using a one way repeated measures ANOVA with Bonferonni's post hoc test of significant findings.

RESULTS: No significant interaction was found between gender and exercise type (p=.88). Significant differences in RMS, normalized as a percentage of MVIC, were found between several of the exercises evaluated (Table 1). Additionally, the ratio of hamstring to quadriceps co-activation was statistically different between all exercises (Table 2).

Table1. Percentage of Hamstring MVIC for Each of the Resistance Training Exercises

	Russian Curl (RC)	**Seated Leg Curl (SLC)**	**Stiff Leg Deadlift (SGLDL)**	**Single Leg Deadlift (SLDL)**	**Good Morning (GM)**	**Squat (S)**
RMS Mormalized as % MVIC	.981±0.39[a]	.808±0.28[a]	.494±0.27[a]	.483±0.39[c]	.430±0.16[d]	.266±0.20[a]

[a]Significantly different (p<0.001) from all other exercises
[b]Significanlty different (p<0.05) than RC, SLC, and S.
[c]Significantly different (p<0.05) than RC, SLC, GM and S
[d]Significantly different (p<0.05) than RC, SLC, SGLDL, S

Table 2. Ratio of Hamstring (% MVIC) to Quadriceps (% MVIC) Co-Activation for Each of the Resistance Training Exercises.

	Russian Curl (RC)	**Seated Leg Curl (SLC)**	**Stiff Leg Deadlift (SGLDL)**	**Single Leg Deadlift (SLDL)**	**Good Morning (GM)**	**Squat (S)**
Hamstring/ Quadriceps Ratio[a]	25.09±14.4	14.85±9.77	8.23±5.18	2.91±1.56	4.87±3.15	0.37±0.21

[a]All exercises are significantly different (p<0.05) from each other.

DISCUSSION: This is the first study to assess hamstring activation during a variety of resistance training exercises. Results indicate that the Russian curl is the optimal hamstring exercise for motor unit recruitment followed by the leg curl. The stiff leg deadlift was superior to the squat and statistically similar to the single leg dead lift and the good morning. The single leg deadlift was statistically similar to the stiff leg dead lift, and the good morning was statistically similar to the stiff leg deadlift, perhaps due to their biomechainc similarities. These findings are consistent with those of Wright et al. (1999), who demonstrated that the leg curl and stiff leg deadlift elicited more EMG activity than the squat. Unlike the findings of Wright et al. (1999), the present study yielded significant difference in EMG between the leg curl and stiff leg deadlift. Previous studies assessing exercise variations of the dead lift, leg press and/or squat found differences in motor unit recruitment, though the practical significance for training the hamstring is mitigated by the fact that knee and hip extension exercises such as the squat offer a suboptimal hamstring stimulus according to Wright et al., (1999) and confirmed in the present study. Previous finding demonstrated that exercise load affects EMG (Isear et al.,1996; Miller and Hendy, 2000), emphasizing the importance of equating load as a percentage of maximum in studies that use EMG to assess a variety of resistance training exercises. Finally, the present study suggest that hamstring to quadriceps co-activation ratio is considerably higher for open kinetic chain exercises such as the Russian curls and seated leg curl, than for the closed kinetic chain exercises such as the stiff leg dead lift, single leg dead lift, good morning and squat.

CONCLUSIONS: Hamstring training should be included in programs designed to increase leg strength, reduce muscle imbalances, prevent hamstring strains, and potentially reduce ACL injuries. Findings of this study help determine the optimal exercises for inclusion. Consideration should also be given to including a number of hamstring exercises for program variation, and follow the principle of biomechanic specificity, particularly with respect to closed kinetic chain and ground based exercises for sports or activities that require hamstring strength, under such conditions.

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