Regional Differences in Muscle Activation During Hamstrings Exercise

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Abstract

Schoenfeld, BJ, Contreras, B, Tiryaki-Sonmez, G, Wilson, JM, Kolber, MJ, and Peterson, MD. Regional differences in muscle activation during hamstrings exercise. *J Strength Cond Res* XX(X): 000–000, 2014—It is believed that regional activation within a muscle may lead to greater site-specific muscular adaptations in the activated portion of the muscle. Because the hamstrings are a biarticular muscle, it can be theorized that single-joint exercises where movement originates at the hip vs. the knee will result in differential activation of the muscle complex. The purpose of the present study was to assess electromyographic activity in the proximal and distal aspects of the medial and lateral hamstrings during performance of the stiff-legged deadlift (SLDL), a hip-dominant exercise, and the lying leg curl (LLC), a knee-dominant exercise. Ten young, resistance-trained men were recruited from a university population to participate in the study. Employing a within-subject design, participants performed the SLDL and LLC to muscular failure using a load equating to their 8 repetition maximum for each exercise. The order of performance of exercises was counterbalanced between participants so that approximately half of the subjects performed SLDL first and the other half performed LLC first. Surface electromyography was used to record mean normalized muscle activity of the upper lateral hamstrings, lower lateral hamstrings, upper medial hamstrings, and lower medial hamstrings. Results showed that the LLC elicited significantly greater normalized mean activation of the lower lateral and lower medial hamstrings compared with the SLDL ($p \leq 0.05$). These findings support the notion that the hamstrings can be regionally targeted through exercise selection. Further investigations are required to determine whether differences in activation lead to greater muscular adaptations in the muscle complex.

Key Words lateral hamstrings, medial hamstrings, nonuniform hypertrophy, muscular adaptations

Introduction

The hamstrings are a complex of 3 posterior lower-body muscles (biceps femoris, semitendinosus, semimembranosus) that combine to serve as both primary extensors of the hip and flexors of the knee (17). As such, these muscles are highly involved in all activities that require running, cycling, and jumping. Optimal performance in numerous athletic endeavors therefore requires substantial hamstrings strength and power. There also is evidence that weak hamstrings, often qualified as a strength imbalance compared with the quadriceps, predispose individuals to soft tissue injury of the posterior thigh (27). Hence, developing the hamstrings through targeted exercise is generally an important goal of strength and conditioning programs.

Although the hamstrings are synergists in multi-joint exercises, electromyographic (EMG) research shows that their activity is relatively modest during both the squat and leg press (23,26). This is consistent with the biarticular structure of the muscle complex. Because the hamstrings function both as hip extensors and knee flexors, their length remains fairly constant throughout performance of compound lower-body exercises, limiting their ability to produce dynamic force. Thus, the incorporation of single-joint movements is often recommended to supplement multi-joint exercise as part of a comprehensive training program. The stiff-legged deadlift (SLDL) and the prone lying leg curl (LLC) are 2 single-joint exercises commonly employed in resistance training programs. These exercises have been shown to produce approximately twice as much hamstrings activation compared with the squat (26), indicating they may help to optimize hamstrings development and performance.

It is well established that many large muscles can hypertrophy in a nonuniform manner, with increases in

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cross-sectional area (CSA) varying distally, proximally, and in the middle portion of the muscle pursuant to regimented resistance training (9,13). Emerging research shows that these variances may be related to region-specific activation of a given muscle. In a study using magnetic resonance imaging (MRI), Wakahara et al. (22) showed that regional differences in activation of the triceps brachii musculature as assessed by T2-weighted views were similar to increases in muscle CSA after 12 weeks of resistance training, with significantly greater hypertrophy seen in the middle and proximal portions compared with the distal region. More recent research from the same laboratory showed a similar correlation between muscle activation and hypertrophy in the triceps brachii (21). In this study, the researchers employed a multi-joint exercise (bench press) as compared with the single-joint exercise (lying triceps extension) used in the previous work, and found greater activation and subsequent hypertrophy of the middle aspect of the triceps compared with the most proximal region.

The authors are aware of only 2 studies that have examined regional activation of the hamstrings during exercise training, both of which used functional MRI as a proxy for measuring site-specific muscle activation. Kubota et al. (8) examined 3 different sections of the hamstring muscles during eccentric knee flexion exercise and found that only the semitendinosus saw significant differences between the proximal and distal sections of the muscle in the days following exercise, perhaps because of the tendinous intersection that divides the semitendinosus neuroanatomically. Mendiguchia et al. (12) examined 15 different sections of the hamstring muscles during the lunge and eccentric leg curl. Results showed that the leg curl preferentially targeted the semitendinosus, whereas the lunge preferentially targeted the proximal portion of the long head of the biceps femoris. This finding, although novel, might be expected given that the lunge is a multi-joint movement and the eccentric leg curl is a single-joint movement. To date, no study has investigated whether different single-joint hamstrings exercise variations elicit regional differences in activation of the muscle complex. This information could potentially have important implications for resistance training program design. Therefore, the purpose of the present study was to assess EMG activity in the proximal and distal aspects of the medial and lateral hamstrings during performance of the SLDL, a hip-dominant exercise, and the LLC, a knee-dominant exercise. We hypothesized that the SLDL would promote greater activation of the proximal aspect of the hamstrings because the action takes place at the hip and that the LLC would promote greater activation of the distal hamstrings because the action takes place at the knee.

Materials and Methods

Experimental Approach to the Problem

The LLC and SLDL are popular exercises for strengthening the hamstrings muscles. Although these exercises are often used interchangeably, it is not clear whether they elicit regional activation of the target musculature. It is conceivable that the SLDL, which involves hip extension, may generate greater activity in the upper aspect of the hamstrings given that this is where movement is initiated. Conversely, given that the LLC involves knee flexion, the possibility exists that its performance will result in greater activation of the lower aspect of the musculature. This study was designed to investigate whether significant differences in hamstrings muscle activity are in fact seen between performances of the SLDL vs. the LLC as determined by surface EMG. A within-subject counterbalanced design was used to answer the following research question: Can regional differences in hamstrings muscle activity be achieved by varying exercise selection?

Subjects

Ten young men (age = 23.5 ± 3.1 years) were recruited from a university population to participate in this study. All subjects were experienced with resistance training of the lower extremities, defined as performing resistance exercises targeting the thigh musculature for a minimum of 1 day a week for 1 year or more. Inclusion criteria required that subjects could read and speak English as well as pass a physical activity readiness questionnaire. Those receiving care for any lower back or hamstrings-related injury at the time of the study or those with an amputation of a lower extremity limb were excluded from participation. Each subject was provided with and signed a written informed consent before participation. The research protocol was approved by the institutional review board at Lehman College, Bronx, New York. AU4

Repetition Maximum Testing

Before EMG analysis, 8 repetition maximum (RM) testing was carried out for the SLDL and LLC. Repetition maximum testing was consistent with recognized guidelines as established by the National Strength and Conditioning Association (1). The LLC exercise was performed on a Life-Fitness (Brunswick Corporation, Rosemont, IL, USA) v-shaped leg curl machine as described by Stiggins (19). Briefly, the subject lied prone on the machine with legs extended and the lever arm adjusted so that it rested just proximal to the heels. The subject flexed his knees until the pad stopped just short of contacting the buttocks and then reversed direction until the pad returned to the start position. Stiff-legged deadlifts were performed as described by Graham (6). Briefly, subjects grasped an Olympic bar from a power rack with a pronated grip, hands spaced slightly wider than shoulder width. The subject stepped out from the power rack and assumed a shoulder width stance with weight hanging at arm's length, torso erect and scapulae adducted. While maintaining a neutral spine (natural lordotic curvature) and knees very slightly flexed, the subject flexed forward at the hips until the torso was approximately parallel to the floor or as far as comfortably possible and then returned to the start position.

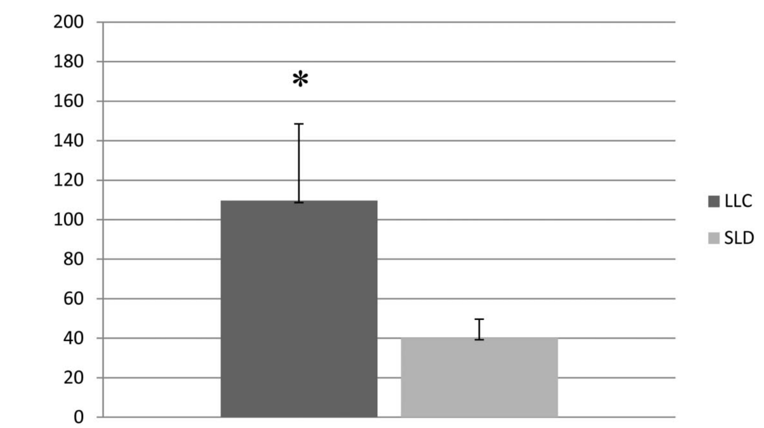

Figure 1. Graphical representation of lower lateral hamstrings activation for LLC and SLDL expressed as %maximal voluntary isometric contraction, mean (±*SE*). *Significant difference ($p \leq 0.05$). LLC = lying leg curl; SLDL = stiff-legged deadlift.

Procedure

Following consent, subjects were prepared for testing by lightly shaving and then wiping the skin with an alcohol swab in the desired areas of electrode attachment to ensure stable electrode contact and low skin impedance. After preparation, self-adhesive disposable silver/silver chloride pre-gelled dual snap surface bipolar electrodes (Noraxon Product #272; Noraxon USA Inc, Scottsdale, AZ, USA) with a diameter of 1 cm and an interelectrode distance of 2 cm were attached parallel to the fiber direction of the upper and lower aspects of the medial hamstrings (semitendinosus) and lateral hamstrings (biceps femoris) muscles. Electrode placement was made on the right side of each subject. The upper medial hamstrings electrode was centered approximately 6 cm below the gluteal fold in line with the ischial ramus. The lower medial hamstrings electrode was placed 4 cm above the popliteal fold in line with the medial epicondyle of the femur. The upper lateral hamstrings electrode was centered approximately 6 cm below the gluteal fold in line with the head of the femur. The lower lateral hamstrings electrode was placed 4 cm above the popliteal fold in line with the lateral epicondyle. A neutral reference electrode was placed over the patella. These methods are consistent with the recommendations of Criswell (4), Rainoldi et al. (16) and the SENIAM (Surface EMG for Non Invasive Assessment of Muscles) project (18). Electrode placement was far enough away from the tendons so that end effects of potentials near the tendons would not impact the EMG signal. After all electrodes were secured, a quality check was performed to ensure EMG signal validity.

Instrumentation

Raw EMG signals were collected at 2000 Hz by a Myotrace 400 EMG unit (Noraxon USA Inc), and filtered by an eighth order Butterworth bandpass filter with cutoffs of 20–500 Hz. Data were sent in real time to a computer through Bluetooth and recorded and analyzed by MyoResearch XP Clinical Applications software (Noraxon USA Inc). Signals were rectified (by root mean square [RMS] algorithm) and all 8 repetitions were smoothed in real time (by mean algorithm).

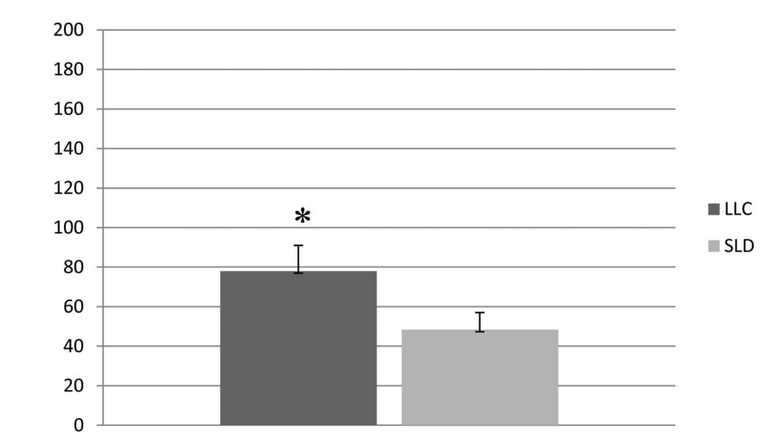

Figure 2. Graphical representation of lower medial hamstrings activation for LLC and SLDL expressed as %maximal voluntary isometric contraction, mean (±*SE*). *Significant difference ($p < 0.01$). LLC = lying leg curl; SLDL = stiff-legged deadlift.

Maximal Voluntary Isometric Contraction

Maximal voluntary isometric contraction (MVIC) data were obtained for the hamstrings muscles by performing a manually resisted isometric contraction as outlined by Hislop and Montgomery (7). Testing was carried out as follows: After an initial warm-up consisting of 5 minutes of light cardiovascular exercise and slow

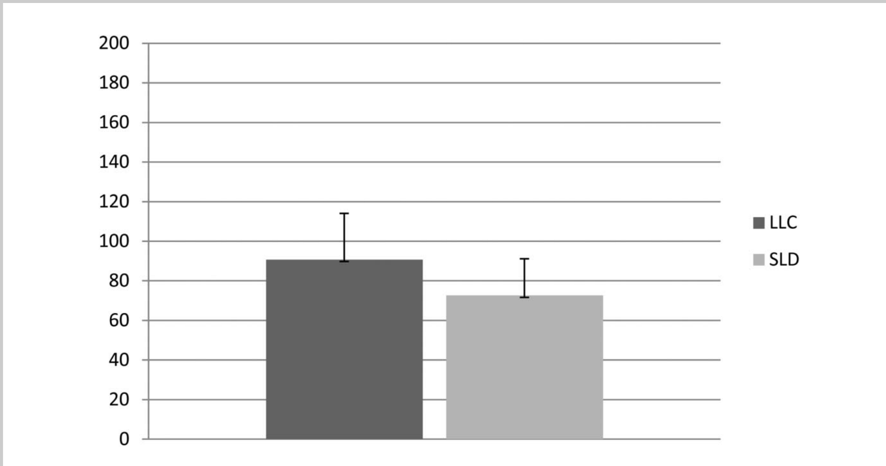

Figure 3. Graphical representation of upper lateral hamstrings activation for LLC and SLDL expressed as %maximal voluntary isometric contraction, mean (±*SE*). LLC = lying leg curl; SLDL = stiff-legged deadlift.

dynamic stretching in all 3 cardinal planes, subjects assumed a prone position on a floor mat with lower limbs extended. Resistance was applied manually at the posterior surface of the leg just above the ankle. Starting from a position of full knee extension, subjects were instructed to flex the knee by slowly increasing the force of the contraction so as to reach a maximum effort after approximately 3 seconds. Subjects then held the maximal contraction against resistance for 3 seconds before slowly reducing force over a final period of 3 seconds. The same process was repeated for prone hip extension, with subjects laying prone with knees fully extended and attempting to extend the hip against manual resistance provided at the posterior surface of the leg just above the ankle. The highest MVIC EMG value was used as the reference with which to normalize EMG signals.

Exercise Description

Five minutes after MVIC testing, subjects performed 1 set of the LLC and SLDL with a resistance equating to their 8RM for each exercise, respectively. The order of performance of the exercises was counterbalanced between participants so that half of the subjects performed the LLC first and the other half performed the SLDL first at their 8RM. Five-minute rest was provided between exercise bouts, which was found sufficient to ensure that fatigue does not compromise results (24). Concentric actions were performed as forcefully as possible (velocity of ∼1 second) and eccentric actions were performed at a 2 count (velocity of ∼2 seconds). Technique instruction and verbal encouragement was provided to each subject before and during performance by the primary investigator who is a certified strength and conditioning specialist to ensure that exercise was carried out in the prescribed manner.

Statistical Analyses

All statistical analyses were performed using SAS software version 9.3 (SAS Institute, Cary, NC, USA). Descriptive statistics were used to explore the distribution, central tendency, and variation of each measurement, with an emphasis on graphical methods such as spaghetti plots and boxplots. Regression analysis was used to predict difference between muscle activation with generalized estimating equations (GEEs) to account for the correlations between repeated measures. Generalized estimating equations are considered marginal models with partial (or quasi)-likelihood methods. In GEE, the correction for within-subject correlations is carried out by assuming a priori a correlation structure for the repeated measurements. One primary advantage of GEE models is that they provide an exchangeable correlation structure to examine the association between exposures and responses. This is an attractive feature when you cannot assume that the underlying

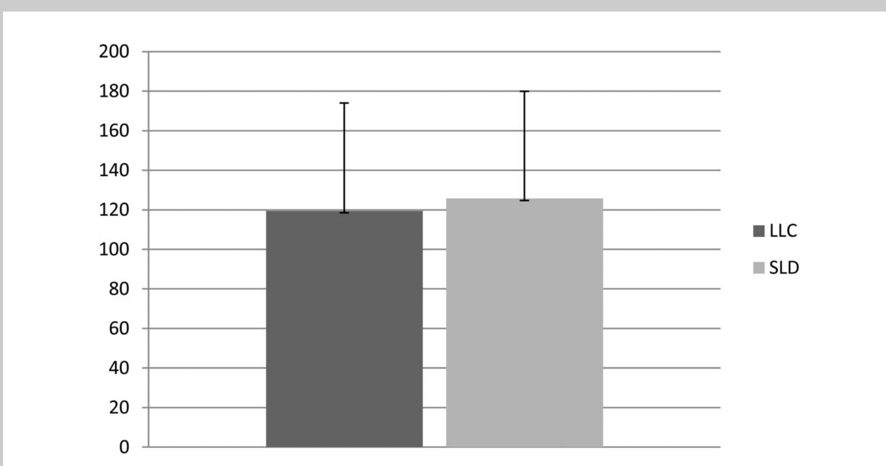

Figure 4. Graphical representation of upper medial hamstrings activation for LLC and SLDL expressed as %maximal voluntary isometric contraction, mean (±*SE*). LLC = lying leg curl; SLDL = stiff-legged deadlift.

distribution is multivariate normal, and/or predict the consequences of a misspecified distribution. Because data were collected for the same individuals across successive time points and tests, these repeat observations were highly correlated. If this correlation is not considered, then the standard errors of the parameter estimates will be invalid and hypothesis testing results will be nonreplicable.

Results

The mean reported resistance training experience of the subjects was 4.6 ± 2.2 years. This is consistent with their 1RM values for the SLDL and LLC (297 ± 59 and 108 ± 25 lbs, respectively).

Significantly greater normalized mean activation of the lower lateral ($\beta = 69.4$; $p = 0.01$) and lower medial ($\beta = 29.6$; $p < 0.0001$) hamstrings was noted during the LLC compared with the SLDL (Figures 1 and 2). In contrast, normalized mean activation of the upper medial and upper lateral hamstrings were similar between the LLC and SLDL (Figures 3 and 4).

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In the SLDL, mean normalized activation of the upper lateral hamstrings was significantly greater than that of the lower lateral hamstrings ($\beta = 32.4$; $p < 0.01$) and there was a trend for greater activation of the upper medial vs. lower medial hamstrings ($\beta = 77.4$; $p = 0.12$). No significant differences in normalized mean activation of the lateral vs. medial hamstrings were noted either within or between exercises.

Discussion

To the authors' knowledge, this is the first study to examine regional differences in muscle activation during the performance of different single-joint hamstrings exercises. The primary and novel finding of the study was that the LLC produced significantly greater normalized mean activation of the distal portion of the hamstrings muscle complex both medially (semitendinosus) and laterally (biceps femoris) compared with the SLDL. With respect to the lower lateral hamstrings, this result might be predicted given that the short head of the biceps femoris does not cross the hip joint and thus would not be activated in a hip-dominant exercise such as the SLDL. However, the semitendinosus crosses both the hip and knee joints, so the greater activity in the lower medial hamstring region during LLC may be considered an unexpected finding.

Despite its biarticular structure, there is a physiological basis for nonuniform muscle activation of the medial hamstrings complex. The fibers of both the semitendinosus and semimembranosus are partitioned, with each subdivision innervated by a singular muscle nerve or a primary nerve branch (25). Thus, the possibility exists that proximal or distal portions of the muscle can be preferentially recruited during exercise performance. Importantly, such preferential recruitment may translate into increased hypertrophy in the region of activation. Wakahara et al. (21) recently demonstrated that nonuniform muscle growth from resistance training is a function of region-specific muscle activation during a given exercise. Similar findings have been noted by other researchers (11,22). One may postulate that the distal region of the hamstrings would be activated to a greater degree with the LLC as a result of movement directed at the knee, which could therefore lead to greater hypertrophy in this aspect of the hamstrings muscle compared with the SLDL. However, it would seem logical that the SLDL would promote greater activation of the upper portion of the hamstrings given that movement originates at the hip, but this was not noted in the present study. From a practical standpoint, it remains speculative to infer that muscle activation is necessarily consistent with local muscular adaptations. Further research is needed to determine whether a cause-effect relationship does indeed exist in this regard.

Previous research comparing general hamstrings muscle activity between single-joint exercises is conflicting. Ebben et al. (5) found that knee flexion exercises (leg curl and Russian curl) produced greater activation of the hamstrings compared with exercises initiated at the hip joint (SLDL and good morning). Conversely, McAllister et al. (10) found hamstrings activity was significantly greater in the Romanian deadlift, a hip-dominant exercise, compared with the knee-dominant leg curl. The results of the present study adds to the current literature by showing that while activation between the LLC and SLDL was similar in the upper aspect of the hamstrings, the LLC elicits significantly greater activity in the distal portion of the muscle.

Given the capacity of the hamstrings musculature to reflexively protect the knee joint (2,3,20) (via ligamentous mechanoreceptors), one may postulate that exercises known to preferentially recruit the distal hamstrings would be desirable for sports or activities linked to a high incidence of capsuloligamentous injuries at the knee. Moreover, evidence suggests that the hamstrings musculature may serve to reactively protect the knee joint among individuals with knee injuries such as anterior cruciate ligament deficiency through increased activation (3). Essentially, it has been reported that increased hamstrings force is thought to serve as a protective mechanism that compensates for mechanical instability through decreasing tibiofemoral shear forces and opposing tibial translations (2,3). Although it is not clear, given the paucity of regional activation studies on the hamstrings musculature, one may surmise that recruitment in the proximity of the joint would be desirable for a protective effect. Further research would be needed to determine this.

Several studies have shown differential activation patterns of the lateral vs. medial hamstrings during performance of different exercises. Zebis et al. (28) found that the kettlebell swing and Romanian deadlift targeted the semitendinosus, whereas the LLC and hip hyperextension targeted the biceps femoris. In contrast, McAllister et al. (10) found that the activity of the semitendinosus was higher in all exercises studied, including the leg curl. Ono et al. (15) found that performing eccentric knee flexion at 120% of 1RM produced significantly greater activation in the semitendinosus compared with the semimembranosus. A follow-up study by Ono et al. (14) found that the eccentric phases of hip extension exercise elicited the greatest activation in the semimembranosus followed by the biceps femoris and then the semitendinosus, whereas the concentric action produced similar activation of the semimembranosus and biceps femoris, which were both significantly greater than that of the semitendinosus. Our results showed no evidence of within-exercise differences between activation of the lateral vs. medial hamstrings in either the LLC or SLDL. Further investigation is warranted to elucidate possible reasons for discrepancies between findings.

Practical Applications

AU5 The results of this investigation support the notion that one can regionally target different domains of the hamstring musculature through exercise selection. Specifically, the distal hamstring musculature is preferentially recruited during the LLC when compared with the SLDL. In regard to the proximal hamstrings, there appears to be no preferential activation pattern when comparing the aforementioned exercises at a consistent load. Although exercise selection is often multimodal and based on fitness goals such as hypertrophy, performance-based criteria, and injury prevention, it seems reasonable to consider activation patterns. Individuals seeking distal stability and strength at the knee or distal hypertrophy of the posterior thigh may benefit from exercises that target the distal hamstring musculature such as the LLC. The findings from this study provide insight into practical applications for exercise selection when selectively targeting hamstring activation at the knee.

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