Muscle Activation During Various Hamstring Exercises

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Abstract

McAllister, MJ, Hammond, KG, Schilling, BK, Ferreria, LC, Reed, JP, and Weiss, LW. Muscle activation during various hamstring exercises. *J Strength Cond Res* 28(6): 1573–1580, 2014—The dorsal muscles of the lower torso and extremities have often been denoted the "posterior chain." These muscles are used to support the thoracic and lumbar spine and peripheral joints, including the hip, knee, and ankle on the dorsal aspect of the body. This study investigated the relative muscle activity of the hamstring group and selected surrounding musculature during the leg curl, good morning, glute-ham raise, and Romanian deadlift (RDL). Twelve healthy, weight-trained men performed duplicate trials of single repetitions at 85% 1-repetition maximum for each lift in random order, during which surface electromyography and joint angle data were obtained. Repeated measures analysis of variance across the 4 exercises was performed to compare the activity from the erector spinae (ES), gluteus medius (GMed), semitendinosus (ST), biceps femoris (BF), and medial gastrocnemius (MGas). Significant differences ($p \leq 0.05$) were noted in eccentric muscle activity between exercise for the MGas ($p < 0.027$), ST ($p < 0.001$), BF ($p < 0.001$), and ES ($p = 0.032$), and in concentric muscle activity, for the ES ($p < 0.001$), BF ($p = 0.010$), ST ($p = 0.009$), MGas ($p < 0.001$), and the GMed ($p = 0.018$). Bonferroni post hoc analysis revealed significant pairwise differences during eccentric actions for the BF, ST, and MGas. Post hoc analysis also revealed significant pairwise differences during concentric actions for the ES, BF, ST, MGas, and GMed. Each of these showed effect sizes that are large or greater. The main findings of this investigation are that the ST is substantially more active than the BF among all exercises, and hamstring activity was maximized in the RDL and glute-ham raise. Therefore, athletes and coaches who seek to maximize the involvement of the hamstring musculature should consider focusing on the glute-ham raise and RDL.

Key Words surface electromyography, hamstrings, resistance training

Introduction

The dorsal muscles of the lower torso and extremities have often been denoted as part of the "posterior chain." These muscles are used to support the thoracic and lumbar spine and peripheral joints, including the hip, knee, and ankle on the dorsal aspect of the body (19). This terminology, apparently first coined by Françoise Mézières as far back as 1947, was used in the context of describing this musculature as "too short" and "too strong." Although many would still describe the posterior chain as too short (i.e., lacking adequate flexibility), it is seldom discussed as too strong. Although several exercises involve this musculature, many of those specifically target the hamstrings. Therefore, this study investigated relative muscle activity during 4 weight training exercises (stressing the hamstrings), which are widely used and typically available for both elite and recreational athletes.

The hamstrings muscle group is made up of 3 muscles in the posterior thigh, including the biceps femoris (BF), semitendinosus (ST), and semimembranosus (SM) (10). The hamstrings are responsible for actions at the hip and knee because they cross both joints at origin and insertion (5). This muscle group is typically recognized for producing flexion of the knee, but with the trunk flexed and knees extended, the hamstrings are powerful hip extensors (10). The actions and levels of activation of muscles have been posited as a method by which bodybuilders and athletes may prioritize certain exercises in an attempt to maximize regional hypertrophy (2).

Surface electromyography (sEMG) has been used to examine several aspects of muscle activity during various weight training exercises (4,6,8,14,15,18,20,21). Wright et al. (22) studied normalized, integrated EMG activity of the hamstrings (BF and ST) to compare the efficiency of 3 resistance training exercises, including the leg curl, stiff-leg deadlift (similar to the Romanian deadlift [RDL]), and back squat. That study found no significant differences in activation
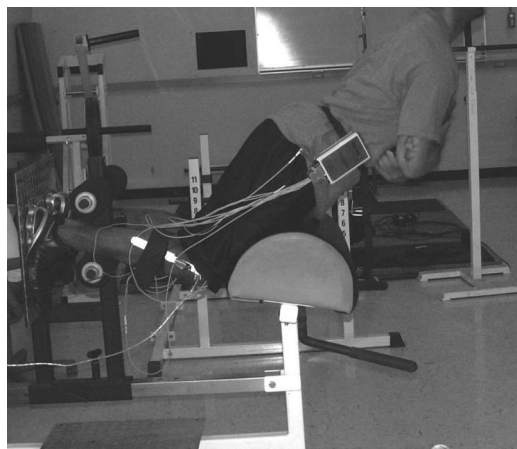
Figure 1. Mid–range of motion for the glute-ham raise. Subject was instructed to hold the weight at the level of the xiphoid process and maintain 0° at the hip for the entire range of motion.

between exercises but reported much greater activity and peak amplitudes on the concentric portions of the exercises compared with the eccentric (22). To date, no studies have investigated the glute-ham raise, which is another common exercise for the hamstrings.

The purpose of this study was to identify the amount of involvement of specific muscles in the thigh, shank, and lower back during various weight training exercises. All 4 exercises being investigated (glute-ham raise, good morning, RDL, prone leg curl) are suggested as targeting the hamstring muscle group. The current study was designed to quantify the activity of the BF and ST and SM and the surrounding stabilizing muscles including the gluteus medius (GMed), longissimus subdivision of the erector spinae (ES), and medial gastrocnemius (MGas). This investigation was the first to compare the glute-ham raise, good morning, RDL, and prone leg curl exercises, which are all suggested to primarily activate the hamstrings and surrounding musculature. We hypothesized that there would be no difference in activation within muscles for the prone leg curl and glute ham because of the kinematic similarities between the 2 exercises. We similarly hypothesized no difference in activation within muscles for the good morning and RDL as a result of similar kinematics.

METHODS

Experimental Approach to the Problem

Four exercises that have been used to target the hamstrings include the glute-ham raise, good morning, RDL, and prone leg curl. Although there are numerous muscles involved in these exercises, 5 muscles were chosen for assessment, including synergistic musculature. Using a sample of experienced resistance-trained men, we used a cross-sectional design

TABLE 1. Descriptive characteristics of subjects ($N = 12$, mean ± SD), including 1 repetition maximum (1RM).

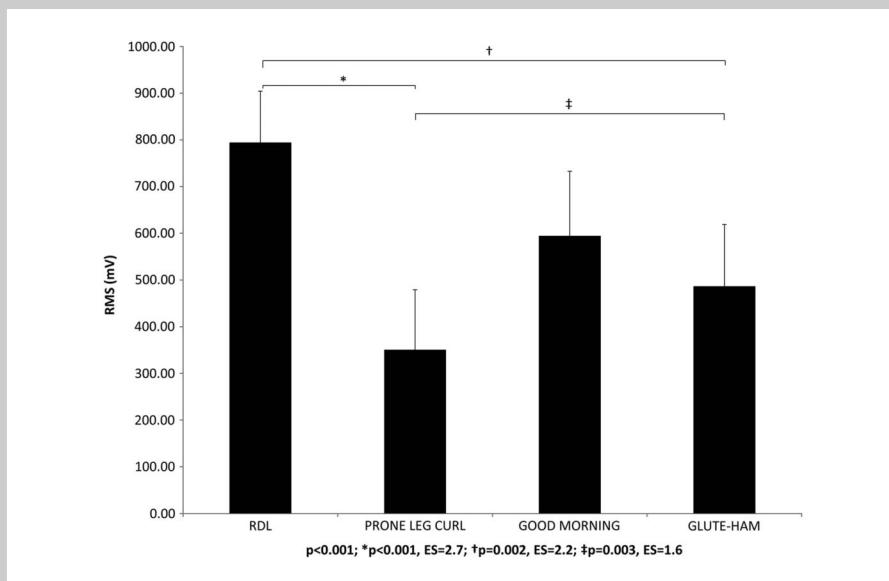| Age (y)	Height (cm)	Body mass (kg)	Estimated % body fat	Resistance training (y)	Glute-ham raise 1RM (kg)	Good morning 1RM (kg)	Romanian deadlift 1RM (kg)	Prone leg curl 1RM (kg)
27.1 ± 7.7	175.4 ± 3.9	88.7 ± 15.8	15.3 ± 7.1	8.6 ± 5.5	87.8 ± 25.8	113.1 ± 43.3	172.0 ± 34.2	68.5 ± 11.6
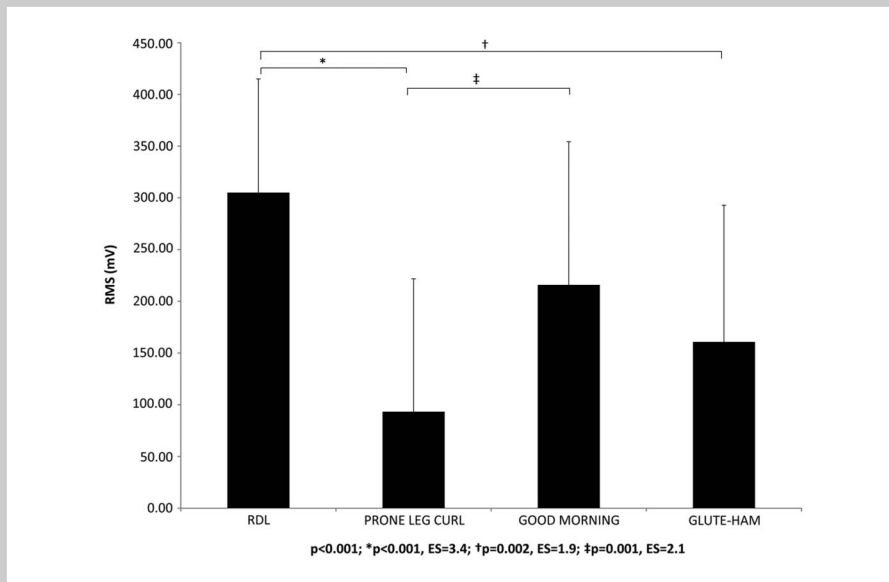
Figure 2. Omnibus test for eccentric activity of the biceps femoris ($p < 0.001$; $N = 12$.) Bonferroni correction showed significant pairwise differences ($p < 0.001$; effect size = 3.4) between RDL (305.1 ± 165.3 mV) and prone leg curl (93.3 ± 37.7 mV), glute-ham raise (160.7 ± 104.5 mV) and RDL ($p = 0.002$; effect size = 1.9), and between good morning (215.9 ± 97.1 mV) and prone leg curl ($p = 0.001$; effect size = 2.1). RDL = Romanian deadlift.

examining 4 exercises: glute-ham raise (Figure 1), good morning, RDL, and prone leg curl. Because all subjects were experienced, resistance-trained athletes, 85% of their 1-repetition maximum (1RM) represents a common training load, and

Figure 3. Omnibus test for eccentric activity of the semitendinosus ($p < 0.001$; $N = 12$). Bonferroni correction showed significant pairwise differences ($p < 0.001$; effect size = 2.7) between RDL (794.4 ± 370.4 mV) and prone leg curl (350.7 ± 146.6 mV), glute-ham raise (486.6 ± 183.3 mV) and RDL ($p = 0.002$; effect size = 2.2), and between prone leg curl and glute-ham raise ($p = 0.003$; effect size = 1.6). RDL = Romanian deadlift; RMS = root mean square.

their 1RM values are believed accurate because of the reported reliability of the 1RM protocol used herein (7,17).

Subjects

Twelve healthy, weight-trained (experience, 8.6 ± 5.5 years) men (age, 27.1 ± 7.7 years; weight, 88.7 ± 15.9 kg) participated in the study for a total of 4 sessions. During the first session, subjects were informed of the procedures involved in the study, and after clarifying any possible questions, all gave written informed consent and filled out medical history and physical activity questionnaires. All procedures were approved by the University Human Subjects Review Board. Potential subjects were excluded if their medical history suggested a musculoskeletal or other issue that would prevent them from safely performing maximal weight training exercises.
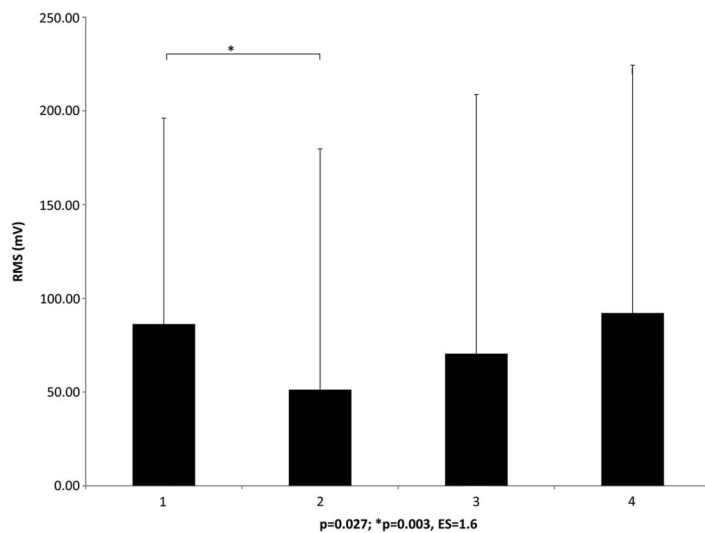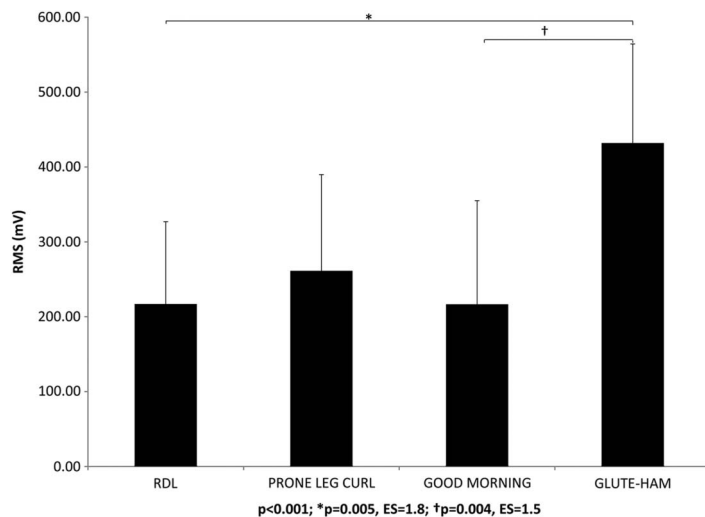
Procedures

Subjects reported to the laboratory on 4 separate occasions to complete the study. During the first session, anthropometric measures, such as height, body mass, and estimated body fat percentage via 3-site skinfold (1), were measured. Also in this session, the subjects were tested on their 1RM (3) on the glute-ham raise and good morning exercises, in order, with approximately 10 minutes of rest between the exercises. During the glute-ham raise, each subject held the resistance load against his or her chest, making sure that the center of the weight was aligned with the xiphoid process. Range of motion (ROM) was predetermined as 90° of extension and flexion at the knee while maintaining a neutral hip (Figure 1). The good morning exercise was initiated from 180° hip extension (upright position) with a York

Figure 4. Omnibus test for eccentric activity of the medial gastrocnemius ($p = 0.027$; $N = 12$). Bonferroni correction showed significant pairwise differences ($p = 0.003$; effect size = 1.6) between RDL (213.0 ± 86.3 mV) and prone leg curl (105.6 ± 51.3 mV). RDL = Romanian deadlift; RMS = root mean square.

Olympic barbell (20 kg) rested on the superior aspect of the trapezius. Eccentric hip flexion was performed until the torso was parallel with the floor (approximately 90° hip flexion). Concentric hip extension completed the lift until each subject returned to an upright position. All lifts were visually monitored to ensure appropriate joint actions and ROM. At session

2, subjects' 1RM in the prone leg curl and RDL exercises were tested as in session 1. The RDL was performed with a York Olympic barbell held with a pronated grip at the anterior aspect of the thighs and slight bend in the knee (near full extension). This lift was mechanically similar to the good morning, with the difference being the resting position of the barbell. The prone leg curl was conducted on a modified plate-loaded leg curl machine. The subject was placed on the machine so that the axis of rotation on the lever arm was at the center of the knee joint. The required ROM was from the start position on the machine until the lever arm contacted the back of the leg, approximately 110°.
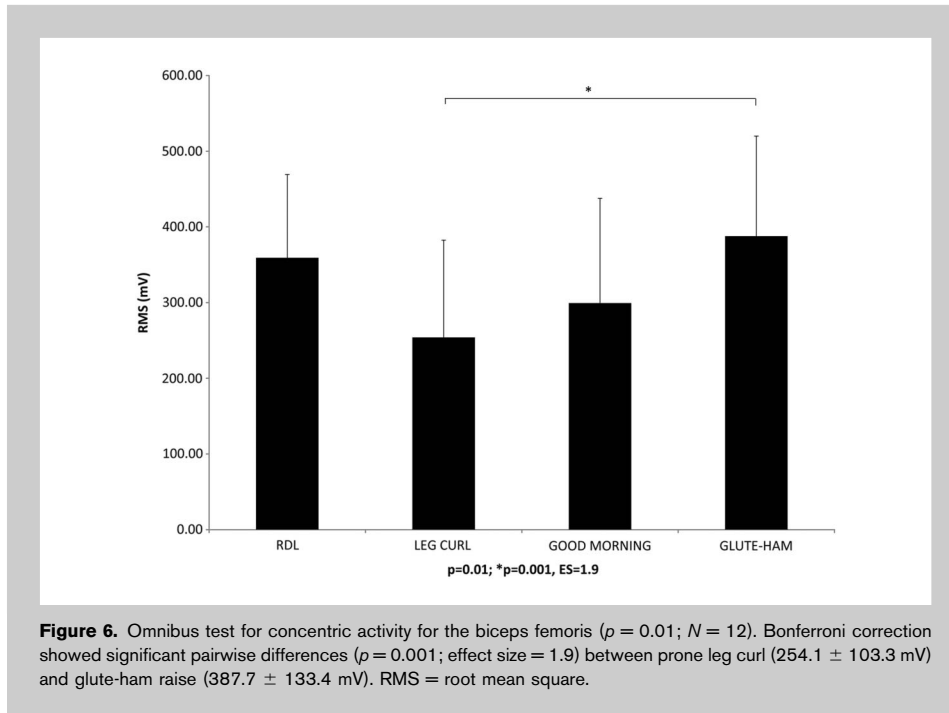
On the third and fourth visits, subjects performed duplicate trials of single repetitions at 85% 1RM for each lift in random order, during which sEMG and joint angle data were obtained. A standardized warm-up protocol was performed before lifting during all sessions, similar to the warm-up for the 1RM tests. One test repetition was performed before the 2 experimental repetitions to ensure sensor viability. Two to 3 minutes of rest were given between trials to ensure fatigue was minimized without reducing the effects of the warm-up. Each subject was given 2–5 days of rest between the sessions.
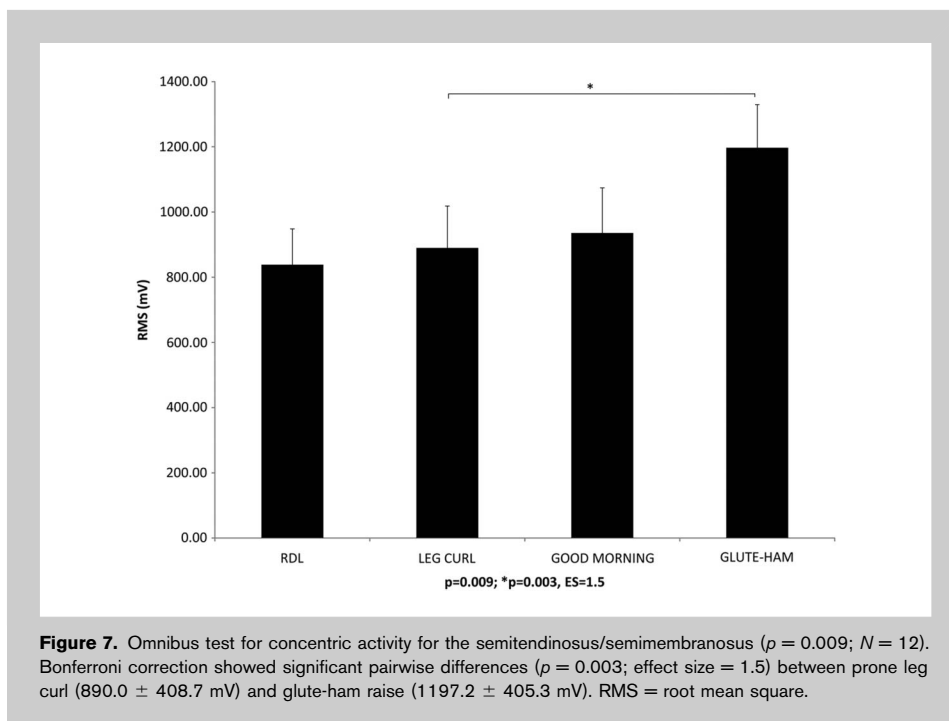
Surface Electromyography

To determine muscle activity during each lift, surface sensors were placed on the right side of the body, over the ES, GMed, ST and SM, BF, and MGas, according to Hermens et al. (11). These sensor placements are suggested to reduce cross talk in the EMG signal. Because of the deep position of the SM (10) and some discrepancy in the ability to obtain separate sEMG data from the SM and ST (9,12,16,22), we elected to use the ST placement of Hermens

Figure 5. Omnibus test for concentric activity for the erector spinae ($p < 0.001$; $N = 12$). Bonferroni correction showed significant pairwise differences ($p = 0.005$; effect size = 1.8) between RDL (217.0 ± 105.6 mV) and glute-ham raise (432.0 ± 162.0 mV), and between good morning (216.6 ± 164.8 mV) and glute-ham raise ($p = 0.004$; effect size = 1.5). RDL = Romanian deadlift; RMS = root mean square.

Figure 6. Omnibus test for concentric activity for the biceps femoris ($p = 0.01$; $N = 12$). Bonferroni correction showed significant pairwise differences ($p = 0.001$; effect size = 1.9) between prone leg curl (254.1 ± 103.3 mV) and glute-ham raise (387.7 ± 133.4 mV). RMS = root mean square.

et al. (11) to represent the combined activity of the ST and SM group. Two round Ag-AgCl bipolar surface sensors (2-cm intersensor distance, Ambu Blue Sensor SP, Ambu Inc., Glen Burnie, MD, USA) were used for each muscle. Sensors were placed on a line between anatomical landmarks (11) so that the same fibers intersected both sensors, distal to the 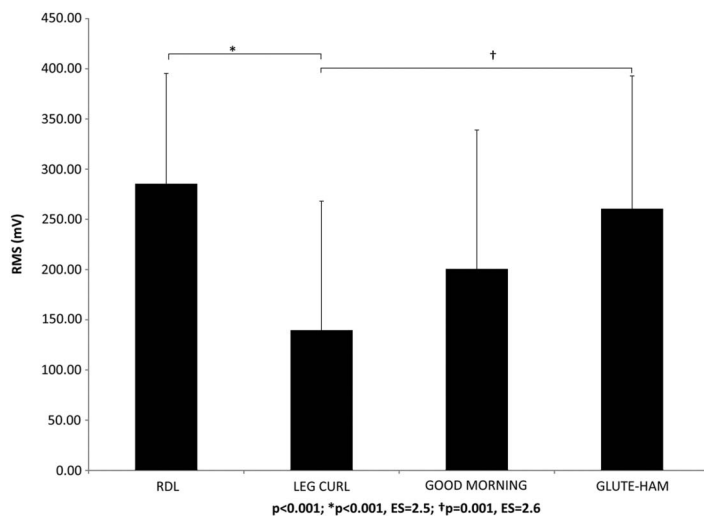motor point. A ground sensor was placed on the patella for signal noise reduction, and all sensor placement was standardized between sessions by tracing the outline of the sensors with a permanent marker. The sensors used were passive; therefore, preamplification was not possible. A common mode of rejection of 90 dB, a band pass filter (10–450 Hz), and input impedance of 10MΩ were applied to incoming data. Before the placement of sensor, the subject's skin was shaved, abraded with fine sandpaper, and cleaned with alcohol. Signals were recorded and processed using a Myopac Jr (RUN Technologies; Mission Viejo, CA, USA) via 5 dual-lead channels. Synchronized data were collected at 2 kHz (Datapac 5) and channeled through a 12-bit analog-to-digital converter (DAS1200 Jr; Measurement Computing; Middleboro, MA, USA). During offline analysis (Datapac 5), raw sEMG signals were band-pass filtered using a fourth-order Butterworth digital filter (10–450 Hz cutoff). Data were quantified using a root mean square over a 125-millisecond moving window for the entire ROM. A laboratory-made rotary potentiometer was strapped to the lateral side of the leg centered on the joint in question to determine joint position of the active hip or knee during each exercise and allowed determination and separate analysis of eccentric and concentric actions. General EMG procedures are similar to those of McAllister et al. (15).

Statistical Analyses

Data are expressed as mean ± (SD). Repeated measures analysis of variance across the 4 exercises was performed for each muscle group (1×4), and the a priori significance was set at $p \leq 0.05$. Bonferroni correction was used for pairwise comparisons in the instance of significant main effects, and standardized effect sizes for repeated measures were calculated.

Figure 7. Omnibus test for concentric activity for the semitendinosus/semimembranosus ($p = 0.009$; $N = 12$). Bonferroni correction showed significant pairwise differences ($p = 0.003$; effect size = 1.5) between prone leg curl (890.0 ± 408.7 mV) and glute-ham raise (1197.2 ± 405.3 mV). RMS = root mean square.
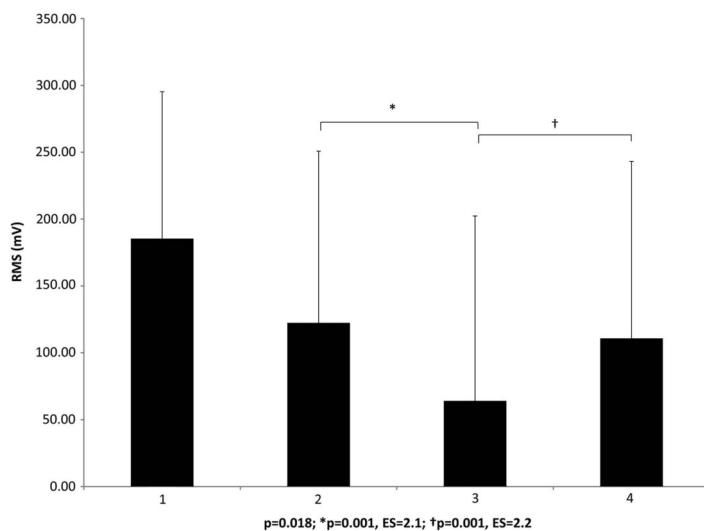
Figure 8. Omnibus test for concentric activity of the medial gastrocnemius ($p < 0.001$; $N = 12$). Bonferroni correction showed significant pairwise differences ($p < 0.001$; effect size = 2.5) between RDL (285.5 ± 119.4 mV) and prone leg curl (139.7 ± 85.4 mV), and between glute-ham raise (260.7 ± 149.8 mV) and prone leg curl ($p = 0.001$; effect size = 2.6). RDL = Romanian deadlift; RMS = root mean square.

Statistical procedures were conducted with SPSS 20 (IBM Corporation Software Group, Somers, NY, USA).

RESULTS

The training status of the subjects is substantial based on the reported training history, and the 1RM values achieved (Table 1). With regards to the analysis of eccentric muscle actions, the GMed and MGas did not meet the assumption of sphericity. During the analysis of concentric actions, the GMed did not meet the assumption of sphericity. The Greenhouse-Geisser adjustment was used to correct all violations of the assumption of sphericity. Significant differences ($p \leq 0.05$) were noted in eccentric muscle activity for the MGas ($p < 0.027$), ST and SM ($p < 0.001$), BF ($p < 0.001$), and ES ($p = 0.032$), and in concentric muscle activity, for the ES ($p < 0.001$), BF ($p = 0.010$), ST and SM ($p = 0.009$), MGas ($p < 0.001$), and GMed ($p = 0.018$). No significant differences ($p > 0.05$) were noted in eccentric activity for the GMed. Bonferroni corrections revealed significant pairwise differences during eccentric actions for the BF (Figure 2), with the RDL showing significantly more activity than other exercises. Pairwise comparisons for the ST and SM also showed significantly more activity during the RDL (Figure 3), but the MGas was only significantly greater in the RDL compared with the prone leg curl (Figure 4). Post hoc analysis also revealed significant ($p \leq 0.05$) pairwise differences during concentric actions for the ES with the activity during the glute-ham being significantly greater than the good morning and the RDL (Figure 5). There was a significantly greater concentric activity during the glute-ham compared with the prone leg curl for the BF (Figure 6), ST and SM (Figure 7), and MGas (Figure 8), and the MGas activity for the RDL was also greater than the prone leg curl. The GMed activity was significantly greater during the leg curl and glute-ham vs. the good morning (Figure 9). Each of the aforementioned pairwise comparisons had effect sizes that are considered large or greater (13). In addition, there were

Figure 9. Omnibus test for concentric activity of the gluteus medius ($p = 0.018$; $N = 12$). Bonferroni correction showed significant pairwise differences ($p = 0.001$; effect size = 2.1) between prone leg curl (194.1 ± 122.4 mV) and good morning (43.1 ± 64.1 mV), and between glute-ham raise (220.7 ± 110.9 mV) and good morning ($p = 0.001$; effect size = 2.2). RMS = root mean square.

several muscles that did not display significant pairwise differences between exercises but did show large or greater effect sizes (13). These include eccentric contractions from ES (between prone leg curl and good morning), BF (between prone leg curl and glute-ham), and MGas (between prone leg curl and glute ham) and concentric actions from the ES (between prone leg curl and good morning) and GMed (between RDL and good morning).

DISCUSSION

The main findings of this investigation demonstrate that there are significant differences in activation within muscles when comparing all exercises. Although one might expect similar activation for a given muscle for activities of similar kinematics, such as the prone leg curl and glute-ham raise, this is not the case with the data herein. These findings may also indicate that the kinematics are not as similar as they appear to be, especially when you consider possible variance of internal and external rotation. For instance, the ST and SM insert at the upper medial surface of the tibia, and the BF inserts at the head of the fibula (10). The greater amount of activity from ST may be related to the fact that ST contributes to the internal rotation of the knee, whereas BF contributes to the external rotation of the knee (10). Although the potential impact is unclear, the absence of control for hip rotation (internal or external) may have obviated the identification of specific patterns of muscle recruitment. Foot position was not standardized in this study because the investigators felt that the subjects' experience would allow foot position to be habitual and consistent. This delimitation must be considered when interpreting our results.

EMG activity for the BF was similar for the concentric prone leg curl and concentric RDL. These results are consistent with a previous investigation (22) that reported no significant difference in activity from the concentric actions of the BF between the leg curl and stiff-leg deadlift. Wright et al. (22) also reported that the eccentric action from the BF was significantly more active during the leg curl in comparison with the stiff-leg deadlift. Our findings partially conflict with those reported by Wright et al. (22) because our investigation showed significantly greater activity from the BF during the eccentric RDL as compared with the eccentric prone leg curl. We also noted that qualitatively, each of the tested muscles were more active during the concentric vs. eccentric action, consistent with Wright et al. (22).

It has been previously reported that the concentric leg curl and stiff-leg deadlift produced greater activity for the ST in comparison with a deadlift and back squat (22). Our investigation showed that the concentric action during the prone leg curl and RDL were actually the least active for the ST and SM compared with the good morning and glute-ham raise. The glute-ham raise also elicited the greatest activity during the concentric contraction of the BF and was significantly more active compared with the concentric portion of the prone leg curl. These results suggest that when considering the concentric actions of the BF, and ST and SM, the glute-ham raise is the most effective exercise for maximizing sEMG activity of these muscles. Oliver and Dougherty (16) reported no significant difference in EMG activity from the medial hamstrings, BF, gluteus maximus, and GMed when comparing the razor curl with the prone leg curl but reported that 90° of both hip and knee flexion (as seen at the completion of the razor curl) is optimal for increasing hamstring contractibility. This statement is best supported by the finding that the razor curl demonstrated elevated activity compared with the prone leg curl when EMG activity was expressed as a percent maximal voluntary isometric contraction (16). The suggestion that simultaneous hip and knee flexion is optimal for producing hamstring contractibility (16) is not supported by our findings because our data demonstrate significantly greater concentric activity from the BF, and ST and SM during the glute-ham raise compared with that seen during the prone leg curl, despite no motion at the hip.

It has been suggested that the position of the more medial hamstring muscles allow them to resist shear tibial forces that are likely to contribute to anterior cruciate ligament injuries. Therefore, it may be optimal to maximize involvement from the more medial hamstring musculature to reduce the likelihood of ACL injuries (16), but this hypothesis has yet to be thoroughly supported. It was also noted that ES involvement was greatest during the glute-ham raise. The elevated activity during the glute-ham raise could be related to the possibility that there is greater torque about the knee and thus greater demands from the hamstring and ES muscles when considering the mechanical actions during these exercises.

This investigation has expanded upon previous analyses of muscle activation during lower-body resistance exercise (8,22) by including analysis of GMed and MGas. For both eccentric and concentric actions, GMed was significantly more active during RDL compared with the good morning. Medial gastrocnemius was also significantly more active during RDL in comparison with good morning and prone leg curl during both concentric and eccentric actions. Escamilla et al. (9) evaluated the MGas during the deadlift, but many researchers failed to analyze activity from the MGas during various lower-body exercises (8,22), which is a major limitation because this biarticular muscle crosses at the ankle and knee joints (10). Additional research is needed to determine MGas activity relative to the RDL and other exercises that are meant to stress the MGas specifically.

PRACTICAL APPLICATIONS

Because each of the tested lifts are performed with the intention of stressing the hamstrings, it is important to note that activity was maximized for the BF during the RDL and glute-ham raise. The concentric action from the ST and SM was highest in the glute-ham raise, whereas the eccentric action of the ST and SM was highest in the RDL. Therefore, the current findings suggest that athletes and coaches who seek to maximize involvement of different regions of the hamstring musculature should consider specific exercises.

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