International Journal of EXERCISE SCIENCE

Original Research

Muscle Activation Patterns of the Proximal Medial and Distal Biceps Femoris and Gluteus Maximus Among 6 Hip Extension and Knee Flexion Exercises in Trained Women

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ABSTRACT

International Journal of Exercise Science 15(1): 1179-1189, 2022. The biceps femoris (BF) is a double-jointed muscle that performs both hip extension and knee flexion, making it a challenging muscle to train during common resistance training movements. An imbalance between the posterior and anterior chain increases the risk of lower-extremity injury. The purpose of this study was to compare BF proximal (BFprox), BF medial (BFmed), and BF distal (BFdist) peak and mean muscle activation among four hip hinging movements and two knee flexion movements. A secondary variable was gluteus maximus (GMax) muscle activation among the same six movements. Fifteen trained females completed three repetitions at 75% estimated 1-repetition max among the following exercises: Romanian-deadlift (RDL), step-up, hip-extension, kickbacks, Nordic hamstring curls (Nordics), and leg-curls. Repetition voltage was normalized to percent maximal voluntary isometric contractions. Eight separate one-way repeated measures ANOVAs with Sidak post hoc analysis indicated the BFprox elicited greater voltage in the kickback, Nordic, and leg-curl exercise compared to the RDL, step-up and hip-extension ($p < 0.05$), BFmed voltage was higher in the hip-extension, kickback, Nordic, and leg-curl vs. the step-up and RDL ($p < 0.05$), BFdist voltage was greater during the kickback, Nordic, and leg-curl exercise vs. the RDL, step-up and hip-extension ($p < 0.05$), while the GMax elicited the lowest voltage during the leg-curl vs. the other five exercises ($p < 0.05$). All eight ANOVAs reached statistical significance ($p < 0.01$). The Nordic exercises consistently elicited the highest voltage among the six exercises. Coaches, trainers, and therapist can use these findings to target different aspects of the BF for training purposes and hamstring injury management.

KEY WORDS: Muscle activation, electromyography, biceps femoris, gluteus maximus, trained women

INTRODUCTION

The posterior chain often refers to the gluteal muscles, hamstring muscles, and muscles comprising the lower back. An imbalance between the posterior chain and anterior chain increases the risk of lower-extremity injury (21). Injuries of the hamstrings account for 6 % to 29% of all injuries in track and field, soccer, Australian football, rugby, basketball, and cricket

(14, 18), and the biceps femoris (BF) specifically accounts for 80% of hamstring strain injuries (3). In addition, another study found hamstring strains are common and account for anywhere from 12-24% of all sporting injuries (22). Surface or needle electromyography electrodes (EMG) are commonly used to measure the percentage of muscle activity and may be able to identify imbalances.

The prevalence of hamstring injuries in active populations justifies a study measuring EMG differences between the gluteus maximus (GMax) and different regions of the hamstring musculature (6). Furthermore, there is a lack of literature investigating activation of specific regions of the hamstring complex during various common strength training movements, particularly as it pertains to resistance-trained women. It is important that females are reviewed in this study because previous research shows that when stabilizing the knee in an eccentric landing motion, females typically shorten their quadriceps more than their male counterparts (13). This suggests that females may preferentially activate their quadriceps more than the other lower body musculature which increases risk for hamstring-related injuries. However, another study found no differences in quadriceps and hamstring isometric strength and muscle activation during isometric knee flexion, knee extension, and isometric squat between men and women (19). Alternatively, Youdas et al. indicated men showed a hamstring to quad ratio via EMG approximately 3.5 times larger in males vs. females during a single leg squat indicating large differences between men and women (24). With data supporting the activation of different regions of the hamstring complex during various strength training exercises, coaches and trainers will be able to focus on strengthening regions of the BF which may be prone to injury.

Current literature suggests that most hamstring injuries occur at the proximal and middle portion of the hamstrings, with distal lesions being much less common (8). Knowing how exercises activate specific regions of individual muscles of the hamstrings may have implications in reducing the risk of injury and accelerating the rehab process. However, there is a lack of research analyzing the activation along the length of the commonly injured BF. Only few studies have examined region-dependent hamstrings activity. For example, Hegyi et al. (11) and Hegyi et al. (10) analyzed proximal, medial, and distal hamstring muscle activity across nine common hamstring prevention injury exercises. This study called for further investigation regarding which exercises would best reduce the risk of hamstring-related injuries (10). However, the authors concluded inter-muscular, and activation of the proximal and distal hamstring muscles are exercise-dependent and are affected by contraction types (10). Isolating actions at each joint may provide insight into how to properly train target targeted sections of the hamstring.

There are several different mechanisms for hamstring injury, but previous researchers have proposed that injury is most likely to occur in the eccentric phase of muscular contraction (late swing phase of sprinting, resistance training, etc.). This may be due to insufficient eccentric strength/endurance or asymmetrical activation of the BF and semitendinosus. Hamstring injury may also occur during large moments of hip flexion where the knee is simultaneously extending (i.e., kicking movements) (6). Factors that increase the risk of hamstring strain include muscle imbalances, fatigue, inadequate warm-up, poor flexibility, improper running technique, and previous risk of injury (16, 22). Many studies have shown that strength training may reduce the risk of injury to the hamstring complex (1, 5, 17, 21). It is also well established that common strength exercises have different patterns of activation of the hamstring complex, with higher levels of BF long head and semimembranosus activation in hip-extension based movements, compared to preferential recruitment of semitendinosus and BF short head during knee flexion-based movements (4).

The purpose of the current study is to assess muscle activation of the proximal, medial, and distal BF and GMax among six lower body hip hinging and knee flexion exercises (Romanian deadlift, Step-up, hip extension, cable kickbacks, Nordic hamstring exercise, and machine leg curl) in resistance trained women. It was hypothesized that the hip hinging movements would elicit greater muscle activation of the GMax and proximal BF (BFprox), while the primary knee flexion exercises would elicit greater muscle activation of the medial BF (BFmed) and distal BF (BFdist) vs. the BFprox and GMax. Analysis of activation patterns will provide insight for coaches, trainers, and therapist on how to target and strengthen sections of the BF and GMax to reduce risk of injury, re-injury, or performance increases (5).

METHODS

Participants

A power analysis conducted with G*POWER 3.1 (Universitat Kiel, Germany) indicated that 14 participants were needed for a power of 0.80, with an effect size of 0.3 and an $\alpha = 0.05$. Participants consisted of 15 biological college females: age 20.8(1.1) yrs., height 167.5(4.9) cm, mass 64.2(8.1) kgs. Participants must have been involved in resistance training at least twice a week for the past 6 months. Individuals who had suffered hamstring injuries during the past year were excluded. In addition, inclusion criteria required participants' ability to perform a minimum of eight Nordic hamstring curls unassisted. All participants provided written informed consent prior to participation and the Institutional Review Board at the University of St. Thomas, MN approved this study (IRB # 1713733-4).

Protocol

Day 1: After completing the informed consent and health history questionnaire, height and weight were measured using a calibrated stadiometer and scale. Next, participants began with a general warmup and then a specific warm-up in accordance with the National Strength and Conditioning Association (NSCA) guidelines specifically targeting the hamstring and GMax complex. (9).

After the warm-up and mobilization tasks, participants completed 6 repetitions to failure of a Romanian deadlift (RDL), Step-up, prone leg curl, 45-degree hip extension, cable kickback, and Nordic hamstring exercises. The exercises were completed in the order listed to follow the NSCA guidelines which state that double joint and high intensity exercises should get priority for maximum safety and efficacy of training (9). Furthermore, 3-5 minutes rest was given between all exercise attempts according to NSCA guidelines. All exercises were performed with a spotter until muscle failure occurred. Based on the weight used and the number of repetitions successfully completed, an estimated 1 repetition maximum (1RM) was calculated using a load conversion chart.

Day 2: At least 72 hours after the first session, participants returned for day two of testing. Participants were instructed to refrain from lower body fatiguing exercises between day one and two of testing. Surface electrodes for electromyography were placed on the participants on GMax and the BF long head. Researchers palpated the ischial tuberosity and lateral head of the fibula which correspond to the origin and insertion of BF, respectively. Researchers measured the length of BF and placed an electrode at 25%, 50%, and 75% of the total length after thoroughly cleaning the area. An electrode was placed on the muscle belly of the GMax halfway between the greater trochanter and the sacral vertebrae according to SENIAM project guidelines (12).

The participants completed the same warm-up and mobilization. One Maximal Voluntary Isometric Contraction (MVIC) data was collected using researchers' hands manually applied resistance for the knee flexion and hip extension actions prior to one practice MVIC, where participants were instructed to contract at self-induced "50%" power. Knee flexion MVIC was performed with participants prone on a training table, knee flexed at 90° to isolate the hamstrings, while the GMax MVIC was performed prone on a training table, knee flexed at 90°, and were instructed to drive the foot vertically isolating the GMax (15). Roughly two minutes rest was given between both muscles MVICs. Three repetitions of the RDL, Step-up, Hip extension, Kickback, Nordic hamstring curl, and Leg curl exercises were completed at 75% of the estimated 1RM and the associated EMG values were recorded (15). The repetitions were completed with a spotter and a metronome set to 60 beats per minute to control repetition speed between participants with a two second eccentric contraction, one second concentric contraction, and two seconds between repetitions (15). Each participant was given the same verbal coaching and demonstration of each exercise to ensure that coaching cues did not differ. All exercises were completed with at least 2 minutes rest in between different exercises (7). Researchers controlled foot internal/external rotation in the Leg Curl exercise via verbal coaching and close observation (2). Raw EMG values for the entirety of all three repetitions were normalized against the MVIC values to show percent activation for each movement.

Data Processing: Surface EMG data (Delsys Inc, Trigno™ EMG Wireless System, SP-W02A-242 Boston, MA USA) were band-pass filtered with high pass and low pass cut-off frequencies of 20 and 450 Hz, respectively with a sampling rate of 2000 samples/sec (23). The data was then full-wave rectified and smoothed using a root mean square (RMS) filter with a moving window of 250 ms (22). The average peak and mean muscle activation of all four surface electrodes during all three repetitions were normalized to the peak amplitude during the MVIC on the GMax and BF (20). Average mean muscle activation was pulled from the average activation during the eccentric and concentric phases, while average peak activation was pulled from the highest peak achieved during the full range of motion repetition (15, 23).

Statistical Analysis
All analyses were ran via SPSS (V.25) (Chicago, IL, USA). Eight separate one-way repeated-measures analysis of variance (ANOVA) using Hyunh-Feldt adjustment with exercise type as the within-subject factor (RDL, Step-up, Hip extension, Kickback, Nordic hamstring exercise, and leg curl) were conducted for peak and mean electromyography voltage for each four muscle sites (GMax, BFprox, BFmed, and BFdist) to compare muscle activity among exercises. Post hoc analyses were conducted using the Sidak method. An alpha level of 0.05 was used for all statistical methods. Lastly, effect sizes were calculated for all analysis performed using the partial eta squared (η_p^2). Effect sizes ranged from the following: .01: small, .06 medium, .14 large.

RESULTS

All eight separate one-way repeated measures ANOVAs performed were statistically different ($p < 0.01$) and produced large effect sizes.

There was a significant difference by exercise type on BFprox muscle activation $F(5.0, 65.0) = 5.94$, $p < 0.001$, $\eta_p^2 = 0.31$, where the cable kickbacks and Nordic hamstring exercise elicited higher muscle activation compared to the Step-up ($p < 0.05$). Exercise type significantly impacted mean BFprox muscle activation $F(4.85, 63.11) = 9.74$, $p < 0.001$, $\eta_p^2 = 0.42$, where the cable kickbacks, Nordic hamstring exercise, and leg curl had significantly higher muscle activation compared to the Step-up ($p < 0.01$) and the Nordic hamstring exercise elicited greater activation compared to the RDL ($p < 0.01$; Figure 1).

Exercise type had a significant effect on peak BFmed $F(3.33, 47.71) = 7.08$, $p < 0.001$, $\eta_p^2 = 0.33$, indicating the cable kickbacks and Nordic hamstring exercise had higher muscle activation compared to the RDL ($p < 0.05$), and the leg curl had higher muscle activation compared to the Step-up ($p < 0.05$). Results for the mean BFmed showed $F(2.90, 40.68) = 13.53$, $p < 0.001$, $\eta_p^2 = 0.49$, where the hip extension, cable kickbacks, Nordic hamstring exercise, and leg curl had greater muscle activation compared to the RDL and Step-up exercises ($p < 0.05$; Figure 2).

There was a significant difference by exercise type on peak BFdist $F(3.52, 49.37) = 10.46$, $p < 0.001$, $\eta_p^2 = 0.42$, where the cable kickbacks and Nordic hamstring exercise produced greater muscle activation vs. the Step-up ($p < 0.01$), the Nordic hamstring exercise was significantly greater compared to the hip extension ($p < 0.05$), and the leg curl was significantly higher compared to the RDL ($p < 0.05$). The ANOVA comparing the mean BFdist indicated $F(2.74, 38.38) = 17.2$, $p < 0.001$, $\eta_p^2 = 0.55$, where the hip extension, cable kickbacks, Nordic hamstring exercise, and leg curl showed significantly greater muscle activation compared to the Step-up, and RDL ($p < 0.01$; Figure 3).

Lastly, there was a significant difference by exercise type for the peak GMax $F(3.67, 47.76) = 14.86$, $p < 0.001$, $\eta_p^2 = 0.53$, where the Step-up and cable kickbacks produced significantly greater muscle activation compared to the Nordic hamstring exercise and leg curl ($p < 0.05$), and the RDL, hip extension, and Nordic hamstring exercise elicited significantly greater muscle activation vs. the leg curl ($p < 0.05$). Exercise type differed for mean GMax $F(3.33, 43.39) = 12.09$, $p < 0.001$, $\eta_p^2 = 0.48$, where the hip extension and cable kickbacks produced significantly greater muscle activation compared to the Nordic hamstring exercise and leg curl ($p < 0.05$), and the RDL and Step-up elicited significantly greater muscle activation vs. the leg curl exercise ($p < 0.05$; Figure 4).

Sidak Post hoc analyses were performed for all eight separate one-way repeated measures ANOVAs. Figures 1 through 4 present means and standard deviations and indicate areas of statistical significance of peak and mean muscle activation amongst the six exercises.

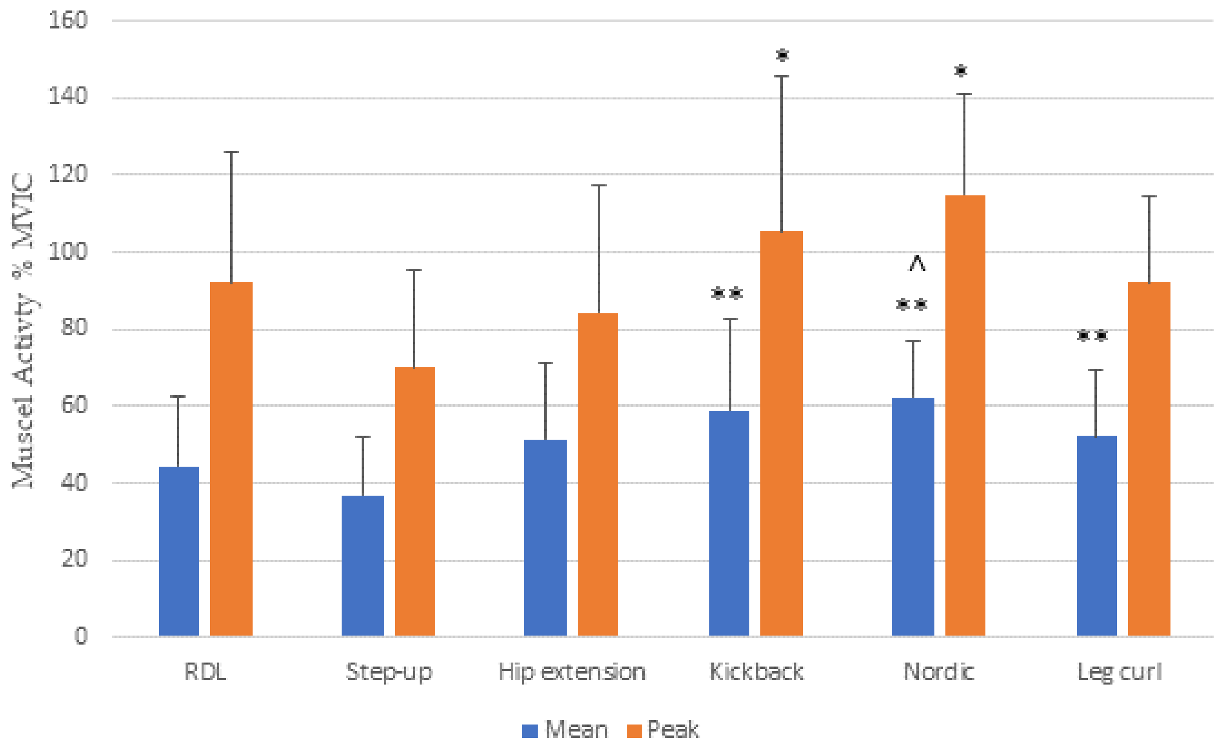

Figure 1. BFprox peak and mean muscle activity among the six exercises as a percentage to the MVIC. Note: * greater vs. Step-up ($p < .05$), ** greater vs. Step up ($p < .01$), ^ greater vs. RDL.

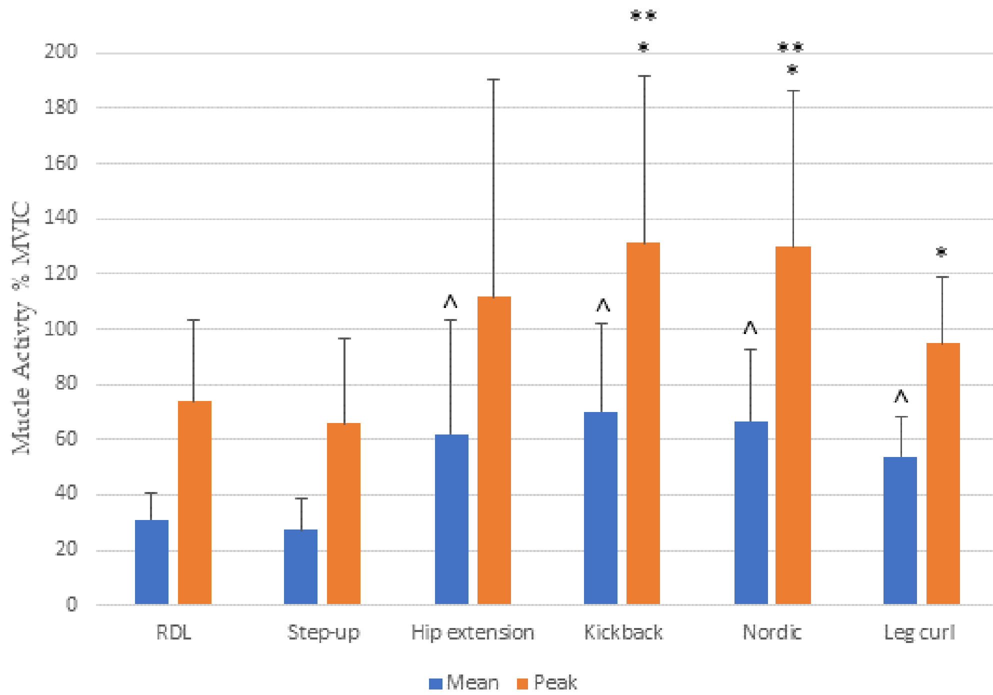

Figure 2. BFmed peak and mean muscle activity among the six exercises as a percentage to the MVIC. Note: * greater vs. Step-up ($p < .01$), ** greater vs. RDL ($p < .05$), ∧ greater vs. RDL and Step up ($p < .05$).

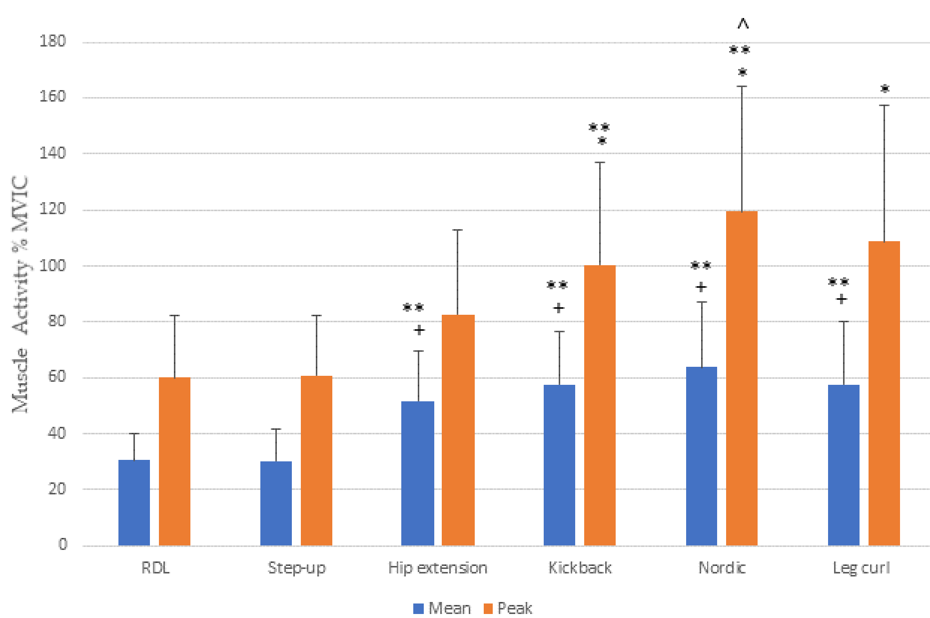

Figure 3. BFdist peak and mean muscle activity among the six exercises as a percentage to the MVIC. Note: * greater vs. RDL ($p < .05$), ** greater vs. Step-up ($p < .01$), ∧ greater vs. Hip extension ($p < .05$), + greater vs. RDL ($p < .01$).

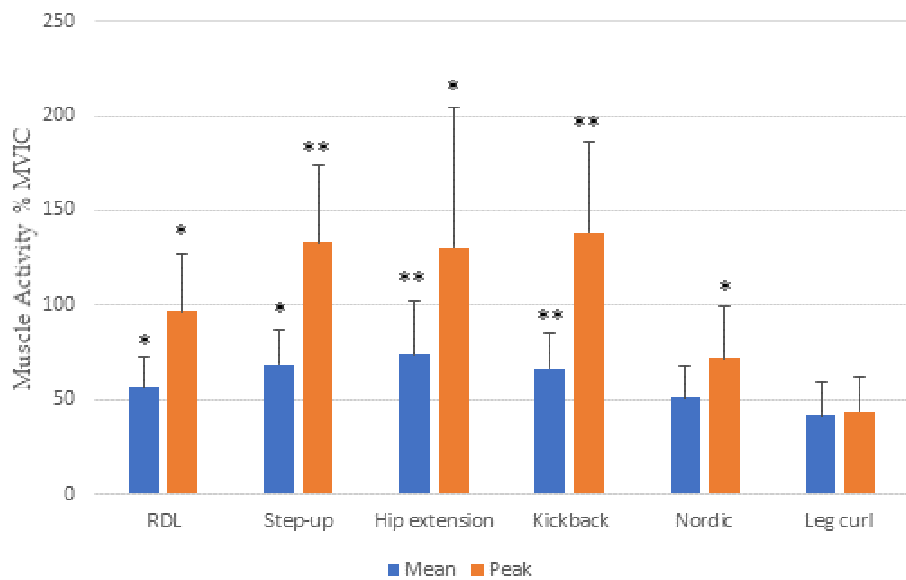

Figure 4. GMax peak and mean muscle activity among the six exercises as a percentage to the MVIC. Note: * greater vs. Leg curl ($p < .05$), ** greater vs. Nordic and Leg curl ($p < .05$).

DISCUSSION

The purpose of this study was to assess muscle activation of the BFprox, BFmed, BFdist and GMax amongst a RDL, Step-up, hip extension, cable kickbacks, Nordic hamstring exercise, and machine leg curl in resistance trained women. It was hypothesized that hip hinging exercises would elicit greater activation of the GMax and BFprox while knee flexion exercises would cause greater muscle activation of the BFmed and BFprox. While specifics are addressed below, our hypothesis was partially supported with the exception of the kickback exercise. Our findings suggest proximal medial and distal BF muscle activation patterns are exercise-dependent, supporting the findings by Hegyi et. al (10).

Figure 1. indicates BFprox peak and mean muscle activation amongst the six exercises. Results show the Kickback and Nordic exercises elicited greater peak muscle activation vs. the Step-up, while mean muscle activation was greater in the Kickback, Nordic, and Leg curl exercises compared to the Step up. Lastly the Nordic exercise indicated greater mean muscle activation compared to the RDL. This contradicts the initial hypothesis which stated that hip-dominant exercises such as Step-up would elicit significantly higher proximal activation than the knee-dominant exercises like Nordic curls and Leg curl exercises. Furthermore, Hegyi et al. (11) found similar findings with the BFprox eliciting higher muscle activation during a Nordic curl compared to a stiff-leg deadlift. Considering the significantly elevated mean data for GMax with Nordic curls activating the muscle as much as RDL and the Step-up, the Nordic curl could be a good exercise for rehabilitation and prevention of upper hamstring tears as it targets the affected area while also strengthening the antagonists to the primary mechanism of injury (6).

Figure 2. indicates BFmed peak and mean muscle activation amongst the six exercises. Mean muscle activation of the Hip extension, Kickback, Nordic curl, and leg curl were greater compared to the RDL and Step-up exercises, while peak activation of the kickback and Nordic curl was greater compared to the RDL. Lastly, peak activation of the leg curl was greater compared to the Step-up. This partially agrees with our hypothesis that leg flexion exercises promote greater activation of the BFmed compared to more hip hinging/extending exercises like the RDL, Step-up and Hip extension exercises. Findings suggest trainers, coaches etc. should prescribe the kickback, Nordic, and leg curl exercises to recruit the greatest muscle activation.

Similarly, to other regions of the BF, the Nordic curl elicited the highest mean and peak activation (Figure 3). Mean muscle activation of the Hip extension, Kickback, Nordic curl, and leg curl was greater compared to the RDL and Step-up exercises. Peak muscle action amongst the Kickback, Nordic curl, and leg curl exercises were greater compared to the Step-up, Hip extension, and RDL exercises. Our hypothesis was partially supported with the leg flexion exercises (Nordic curl and leg curl) having greater activation compared to the hip hinging movements (RDL and step-up). Hegyi et al. (11) findings agree BFdist produced higher muscle activation during a Nordic curl compared to a stiff-leg deadlift. Similarly, to the BFmed, trainers, coaches etc. should prescribe the kickback, Nordic, and leg curl exercises to recruit the greatest muscle activation when compared to the RDL, Step-up and hip extension exercises.

Figure 4. indicates the four exercises that involve a large degree of hip extension (RDL, Step-up, hip extension, and kickbacks) elicited greater peak and mean muscle activation compared to the two-knee flexion focused exercises (Nordic and leg curl) for GMax muscle activation. One challenge for strength coaches and trainers are prescribing movements that conduct both hip extension with knee flexion. For example, a traditional squat exercise performs primarily knee and hip extension, while sprinting performs both knee flexion with hip extension.

Regarding the BF muscle, our conclusions are very similar to the findings of Hegyi et al. (10), who measured muscle activation of the BF and semitendinosus amongst nine hamstring exercises in 19 amateur male athletes. The current study used four of the same exercises compared to Hegyi et al. (11), and our findings are similar in that proximal, medial, and distal BF EMG voltage varied significantly among exercises. Future studies should duplicate similar methodologies with higher lifting intensities e.g. a three repetition max vs. 75% of 1RM load for three repetitions, as higher lifting intensities will increase muscle activation recruitment. Furthermore, due to body fat distribution, and fat being an inhibitor for surface EMG, future studies should investigate differences between biological women vs. men on hamstring muscle activation between knee flexion vs. hip hinging exercises.

Limitations in the current study was a lack of data from the GMax sensor in one of the participants due to an equipment error during the MVIC as well as the lack of data from all sensors during the Step-up exercise from the same participant due to signal interference. This interference was isolated to a single participant and did not affect the quality of the remaining data. Next, surface EMG is only valid when proper skin preparation procedures are followed. The same investigator prepared all EMG sensor applications to reduce error. Next, hydration status can affect EMG voltage. Participants were instructed to arrive rested and hydrated to combat this. Lastly, few participants had completed MVICs on the targeted muscles, possibly causing alterations of baseline normalization voltage.

In conclusion, strength coaches, trainers, and therapist should prescribe kickbacks and Nordic hamstring curls to target the BFprox and prescribe more knee flexion moments such as the Nordic hamstring exercise and leg curls to target the BFdist. Of all six movements analyzed, the Nordic hamstring exercise consistently elicited the highest voltage among the proximal, medial, and distal BF. Lastly, strength coaches, trainers, and therapist should use RDLs, Step-up, Hip extension and kickback exercises to recruit the GMax compared to the Nordic hamstring exercise and leg curl exercise. Future studies should be conducted replicating the current methodology comparing the findings to resistance trained males. Furthermore, future studies should analyze peak and mean activity during both the eccentric and concentric phases.

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