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Hamstring Activation During Lower Body Resistance Training Exercises

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Purpose: The purpose of this study was to evaluate differences in hamstring activation during lower body resistance training exercises. This study also sought to assess differences in hamstring-to-quadriceps muscle activation ratios and gender differences therein. ***Methods:*** A randomized repeated measures design was used to compare six resistance training exercises that are commonly believed to train the hamstrings, including the squat, seated leg curl, stiff leg dead lift, single leg stiff leg dead lift, good morning, and Russian curl. Subjects included 34 college athletes. Outcome measures included the biceps femoris (H) and rectus femoris (Q) electromyography (EMG) and the H-to-Q EMG ratio, for each exercise. ***Results:*** Main effects were found for the H ($P < 0.001$) and Q ($P < 0.001$). Post hoc analysis identified the specific differences between exercises. In addition, main effects were found for the H-to-Q ratio when analyzed for all subjects ($P < 0.001$). Further analysis revealed that women achieved between 53.9 to 89.5% of the H-to-Q activation ratios of men, for the exercises assessed. In a separate analysis of strength matched women and men, women achieved between 35.9 to 76.0% of the H-to-Q ratios of men, for these exercises. ***Conclusions*:** Hamstring resistance training exercises offer differing degrees of H and Q activation and ratios. Women compared with men, are less able to activate the hamstrings and/or more able to activate the quadriceps. Women may require disproportionately greater training for the hamstrings compared with the quadriceps.

Keywords: injury prevention, muscle balance, co-contraction, knee, strength training

The hamstring muscle group is the most frequently injured, representing approximately 12 to 24% of all athletic injuries.[1,2] These injuries may be due to disproportionate training performed for the quadriceps,[3] with hamstring strains occurring more frequently in those who demonstrated hamstring weakness, and lower hamstring-to-quadriceps strength ratios.[2] Thus, hamstring strength is important for athletic performance and injury prevention in a variety of sports.[4]

In addition to hamstring strains, anterior cruciate ligament (ACL) injuries are common. For female athletes, ACL injuries account for 69.0% of all serious knee

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injuries,[5] and represent approximately 4.8% of all athletic injuries.[6,7] The hamstrings relationship to the ACL has been demonstrated in a variety of studies. According to More et al,[8] in-vitro assessment of a cadaveric model revealed that the hamstring acts as an ACL synergist decreasing the anterior translation of the tibia as well as reducing internal tibial rotation during a simulated squat. Others have reported that hamstring activation stabilizes the ACL deficient knee, aids ligaments in maintaining joint stability, equalizes articular surface pressure distribution,[8] and regulates the joints' mechanical impedance.[3,9]

Training the quadriceps disproportionately to the hamstrings may inhibit hamstring coactivation, reduce joint stability, and increase anterior tibial translation in response to strong quadriceps forces.[10,11] Fortunately, hamstring training reduces hamstring inhibition, hamstring-to-quadriceps imbalance, bilateral hamstring deficits, and the risk of reinjury for those who had previous hamstring strains.[3,12] Hamstring resistance training reduces magnitude of the hamstring-to-quadriceps muscle imbalance, which may prevent muscle strains[13,14] and ACL injuries.[3,12] Resistance training exercises offering higher hamstring activation are believed to be optimal for hamstring strength development and rehabilitation of those with ACL problems and should include closed–kinetic chain (CKC) exercises.[15,16] Unfortunately, evidence is limited with respect to optimal resistance training exercises for activating the hamstrings.

In an attempt to quantify the role of the hamstring during resistance training, researchers have used electromyography (EMG) to examine muscle activation during variations of the dead lift,[17] squat and leg press,[18] squat with varying loads, and variations in squat technique.[19–22,24] In the most comprehensive assessment of hamstring activation to date, Wright et al[23] demonstrated that the leg curl and stiff leg dead lift were superior to the back squat.

At present, information is limited regarding which resistance training exercises maximally activate the hamstrings, the resultant hamstring-to-quadriceps activation ratios, and if gender differences exist despite the fact that training the hamstring muscle group is critical for performance and may play an important role in hamstring and ACL injury prevention. Therefore, the primary purpose of this study was to assess a variety of resistance training exercises to quantify hamstring activation. This study also sought to assess the activation of the rectus femoris to determine biarticular quadriceps muscle function and to determine a measure of activation ratios between the muscles assessed during these exercises, as well as to determine if there are gender differences in these variables. Quantification of these resistance training exercises is necessary to provide clinicians with information about the optimal exercises for hamstring strengthening and rehabilitation programs for hamstring and ACL injuries.

Methods

Subjects

Thirty-four subjects including 21 men and 13 women NCAA Division-I or Division-III athletes (20.38 ± 1.77 years) volunteered for this study. Subject

Table 1 Subject Characteristics

Variable	All Subjects	Women (N = 13)	Men (N = 21)
Age (y)	20.38 ± 1.78	20 ± 0.70	20.61 ± 0.71
Age range (y)	18–26	19–21	18–26
Weight (kg)	77.94 ± 18.30	63.64 ± 18.30	86.80 ± 17.90
Weight range (kg)	54.55–133.64	54.55–72.73	65.90–133.64
Training (days/week)	4.15 ± 1.79	4.00 ± 1.77	4.24 ± 1.84
Squat 6 RM (kg)	101.47 ± 34.08	68.18 ± 12.31	122.07 ± 25.65
Squat 6RM range (kg)	52.27–184.09	52.27–88.64	84.09–184.09

Values are mean ± SD.

characteristics are presented in Table 1. All subjects provided written informed consent for this study, which was approved by the university's internal review board.

Research Design

This study used a randomized repeated measures research design to compare EMG activation of the hamstring muscle group (H) and the rectus femoris (Q) during six resistance training exercises. The research hypothesis was that there were differences in H and Q activation between the exercises studied and that men and women would manifest different H-to-Q activation ratios characterized by Q dominance for women. Independent variables included the resistance training exercise assessed and gender. Dependent variables included the root mean square (RMS) EMG of the H and Q as well as for the H-to-Q ratio, all expressed as a percentage of the RMS EMG of the MVIC, for each of the exercises evaluated, as well as gender differences in these variables. Data were also analyzed for squat strength matched men and women.

Methodology

Before a pretest orientation and the primary testing session, subjects participated in a general and dynamic warm-up, consistent with the methods previously used.[19] All subjects were familiarized with the test procedures during the pretest orientation, including performing an MVIC at 60° of knee flexion for the H and Q, with selectorized seated leg curl (Hammer Strength, Schiller Park, IL, USA) and leg extension (Magnum Fitness Systems, South Milwaukee, WI, USA) machines respectively, loaded with an immovable mass. In addition, each subject's 6-repetition maximum (RM) was assessed for the randomly ordered test exercises, including the squat, seated leg curl, stiff leg dead lift, single leg stiff leg dead lift, good morning, and the Russian curl. The exercises selected are frequently used and are commonly believed to be effective at training the hamstrings. The squat was included because it is was previously compared with two hamstring exercises,[23] and serves as a useful reference for hamstring-to-quadriceps activation ratio under conditions where the quadriceps are typically dominant. Six RMs were chosen because assessment of muscular strength, as opposed to endurance, was desired. After approximately 72 hours, during which no resistance training was performed, subjects returned for the primary testing session. Each subject performed a MVIC for the H and Q for 5 seconds. Subjects then performed 2 full range-of-motion repetitions, at maximal volitional velocity, using their 6-RM loads, for each of the randomly ordered test exercises. Limiting the test to two repetitions per exercise, randomization of the exercise order, and 5 minutes of recovery were provided between the MVICs as well as all exercises, to reduce order and fatigue effects. The technique for each exercise is described as follows.

Squat Methods

Subjects performed the squat using a closed pronated grip, slightly wider than shoulder width apart, with the barbell positioned at the base of the neck, the scapula retracted and the cervical spine slightly hyperextended. The feet were slightly abducted and positioned flat on the floor in a bilateral stance slightly wider than shoulder width. Subjects descended by flexing the hips and knees until the bottom of the thighs were parallel to the floor, while keeping a constant floor-to-torso angle, normal lordotic arch, scapula retracted, and knees aligned over the feet. Subjects ascended using similar form.

Seated Leg Curl Methods

Subjects performed the seated leg curl while seated leg in a leg curl machine with their legs positioned parallel to each other and with their back firmly against the seat back and secured to the seat using the machines belt. The subjects' knees were aligned with the axis of the machine, and ankles were placed on top of the roller pad, with the exercise beginning is a position of knee extension. Subjects flexed the knees moving the machine through its full range of motion, while gripping on the machine's handgrips and keeping the buttocks and back in contact with the machine's seat and seat back. Subjects then allowed their knees to extend to return to the starting position. The subjects' ankles were maintained in a neutral position throughout the range of motion of the exercise.

Stiff Leg Dead Lift Methods

Subjects performed the stiff leg dead lift by holding the barbell with an approximately shoulder-width grip, with extended elbows and arms in an anatomically correct position with the exception of using a closed pronated grip. The feet were placed flat on the floor in a hip-width stance with the knees slightly flexed to approximately 15° and toes pointed straight ahead. Subjects then flexed the hips allowing the torso and barbell to lower to a point where the weight plates lightly touched the floor. Subjects then extended their hips and torso returning to an upright position. Through the entire range of motion of the exercise, the subjects maintained approximately 15° of knee flexion, their normal lordotic arch, retracted scapula, and a slightly extended cervical spine.

Single Leg Stiff Leg Dead Lift Methods

Subjects performed the single leg stiff leg dead lift by standing erect holding two dumbbells at their side using a semisupinated grip with extended elbow. Subjects stood on their right leg only with the knee slightly flexed to approximately 15° and toes pointed straight ahead. The subjects left knee was flexed to approximately 45° and at no time made contact with the floor. Subjects then flexed the hips of the right leg allowing the torso and dumbbells to lower to a point where the dumbbells lightly touch the floor. Subjects then extended their hip and torso returning to an upright position. Subjects were instructed to avoid abduction and adduction of the right hip during the performance of the exercise. Through the entire range of motion of the exercise, the subjects maintained slight knee flexion, their normal lordotic arch, retracted scapula, and a slightly extended cervical spine.

Good Morning Methods

During the performance of the good morning, subjects gripped the barbell with a closed pronated grip slightly wider than shoulder width and positioned the barbell at the base of the neck, the scapula retracted, and the cervical spine slightly hyperextended. The feet were positioned flat on the floor in a bilateral stance of shoulder width with the toes pointed forward. Subjects then flexed the hips, while maintaining constant knee flexion of approximately 15°, allowing the torso and barbell to lower to point where the torso was parallel to the floor. Subjects then extended their hips and torso returning to an upright position. Through the entire range of motion of the exercise, the subjects maintained limited knee flexion, their normal lordotic arch, retracted scapula, and a slightly extended cervical spine.

Russian Curl Methods

Subjects began the Russian curl exercise in a kneeling position on a "glute-ham" machine, with the knees positioned 4 cm posterior of the apex of the machine's pad. The ankles were secured between the machine's foot pads. At the beginning of the exercise the subjects' knees were flexed at approximately 90° while the hips were extended in the anatomically correct position. This hip position was maintained throughout the exercise. Subjects held their exercise load, in the form of a weight plate, in their hands, which were placed in a crossed-arm position touching their chest. Subjects extended their knees lowering their torso until they were nearly parallel to the ground, while maintaining an anatomically correct hip position, normal lordotic arch, and a neutral cervical spine. Subjects then flexed the knee, thus moving back to the starting position.

Electromyography

Electromyography was used to quantify muscle activity using a two-channel, fixed shielded cabled, Delsys Bagnoli-2 EMG system (Delsys Inc. Boston, MA, USA). The input impedance was 10^{15} Ω and the common mode rejection ratio was >80 dB. Electroymyographic data from the H and Q were recorded at 1024 Hz using rectangular shaped (19.8 mm wide and 35 mm long) bipolar surface electrodes with 1 × 10 mm 99.9% Ag conductors, and an interelectrode distance of 10 mm. Electrodes were placed on the longitudinal axis of the muscles with the H electrode located halfway between the gluteal fold and the popliteal fossa. The Q electrode was placed halfway between the greater trochanter and medial epicondyle of the femur. A common reference electrode was placed 10 mm anterior and halfway between the medial condyle and medial malleolus of the tibia. Electrode placement was chosen to assess biarticular knee flexor and extensor muscles similar to methods previously used in studies that compared variations of closed and open–kinetic chain exercises.[19,25] Furthermore, quantification of hamstring activation has frequently been studied using one electrode on either the belly or biceps femoris.[3,15,22,25,26] Skin preparation included shaving hair, abrading, and cleaning the surface with alcohol. Elastic tape was applied to ensure electrode and cable placement, and provide cable strain relief. Surface electrodes were connected to an amplifier and streamed continuously through an analog-to-digital converter (Delsys Inc.) to an IBM-compatible notebook computer. All data were filtered with a bandpass filter allowing 10 Hz high pass and 450 Hz low pass, saved, and analyzed with the use of computer software (EMGworks 3.1, Delsys Inc.). Root mean square EMG signal processing was calculated over a 125-ms moving window and used on all EMG data for the duration of the exercise and normalized to the RMS EMG signal of the MVIC to determine H and Q activation, H-to-Q activation ratios, performance between genders, and to evaluate results with respect to previous research. Data were analyzed for the second repetition of each exercise and compared with the MVIC of each muscle group. Data for the MVIC were analyzed for the 3rd to 4th second of the 5-second muscle action.

Statistical Analyses

Data were analyzed with SPSS 16.0 for Windows (Microsoft Corporation, Redmond, WA, USA) using a repeated-measures ANOVA with Bonferroni adjusted pairwise comparisons of significant findings. Independent samples *t* tests were conducted to determine differences in strength, age, training frequency, and hamstring-to-quadriceps ratios between genders as well as strength-matched men and women. Assumptions for linearity of statistics were tested and met. Statistical effect size (d) and power (η^2) are reported, and all data are expressed as means ± SD. The a priori alpha level was set at $P < .05$.

Results

Results reveal no significant interaction between gender and exercise type, $F(5, 33) = 0.355$, $p = 0.88$, $d = 0.14$, $\eta^2 = 0.01$. Thus, the muscle activation in response to these exercises is not different between men and women. Significant main effects for exercise type were found for the H, $F(5, 33) = 65.04$, $p = 0.00$, $d = 1.00$, $\eta^2 = 0.66$, as well as for the Q, $F(5, 33) = 69.94$, $p = 0.00$, $d = 1.00$, $\eta^2 = 0.697$, RMS EMG normalized as a percentage of the RMS EMG of the MVIC, demonstrating that a number of these exercises result in different degrees of activation of the H and Q. Specific difference between exercises are described in Tables 2 and 3.

In addition, significant main effects were found for the H-to-Q activation ratio when analyzed for all subjects, $F(5, 33) = 21.26$, $p = 0.00$, $d = 1.00$, $\eta^2 = 0.39$,

Table 2 Percentage of H RMS EMG of the MVIC for Each of the Resistance Training Exercises Evaluated (Analysis of All Subjects; N = 34)

	Russian Curl (RC)	Seated Leg Curl (SLC)	Stiff Leg Dead Lift (SLDL)	Single Leg Stiff Leg Dead Lift (SGLDL)	Good Morning (GM)	Squat (S)
RMS normalized as % RMS MVIC	98.0 ± 39.0[a]	81.0 ± 28.0[a]	49.0 ± 27.0[b]	48.0 ± 39.0[c]	43.0 ± 16.0[d]	27.0 ± 20.0[a]

Values are mean ± SD.

[a]Significantly different than all other exercises ($P < .001$)

[b]Significantly different than RC, SLC, and S ($P < .05$)

[c]Significantly different than RC, SLC, GM, and S ($P < .05$)

[d]Significantly different than RC, SLC, SGLDL, S ($P < .05$)

Table 3 Percentage of Q RMS EMG of the MVIC for Each of the Resistance Training Exercises Evaluated (Analysis of All Subjects; N = 34)

	Squat (S)	Single Leg Stiff Leg Dead Lift (SGLDL)	Good Morning (GM)	Stiff Leg Dead Lift (SLDL)	Seated Leg Curl (SLC)	Russian Curl (RC)
RMS normalized as % RMS MVIC	74.0 ± 40.0[a]	20.0 ± 10.0[b]	12.0 ± 8.0[b]	12.0 ± 20.0[c]	7.0 ± 5.0[d]	5.0 ± 4.0[d]

Values are mean ± SD.

[a]Significantly different than all other exercises ($P < .001$)

[b]Significantly different than all other exercises except for the SLDL ($P < .001$)

[c]Significantly different than the S ($P < .001$)

[d] Significantly different than the S, SGLDL,GM ($P < .01$)

Table 4 H (% RMS EMG MVIC)-to-Q (% RMS EMG MVIC) Ratio for Each of the Resistance Training Exercises Evaluated (Analysis of All Subjects; N = 34)

	Russian Curl (RC)	Seated Leg Curl (SLC)	Stiff Leg Dead Lift (SLDL)	Good Morning (GM)	Single Leg Stiff Leg Dead Lift (SGLDL)	Squat (S)
Hamstring-to-quadriceps ratio	25.09 ± 14.47	14.85 ± 9.77	8.23 ± 5.18	4.87 ± 3.15	2.91 ± 1.56	0.37 ± 0.21

Values are mean ± SD. All exercises are significantly different from each other ($p < 0.05$).

indicating that these exercises produced different activation ratios (Table 4). Separate analysis of the H-to-Q activation ratio was conducted for men, $F(5, 20) = 46.77$, $p = 0.00$, $d = 1.00$, $\eta^2 = 0.70$, and women, $F(5, 12) = 20.42$, $p = 0.00$, $d = 1.00$, $\eta^2 = 0.63$, as well as between and strength-matched men and women. Independent samples t tests of these results revealed that women subjects achieved lower H-to-Q ratios than men for a number of exercises (Table 5). Further analysis of strength-matched men and women revealed that the H-to-Q ratios for women were less than those for the men (Tables 6).

Finally, independent samples t tests demonstrated that there were significant gender differences in squat strength ($P < 0.001$) and in squat strength-to-mass ratio ($P < 0.001$), despite no significant difference in subject's age ($P = 0.33$) or training frequency ($P = .71$).

Discussion

This is the first study to assess measures of hamstring and quadriceps activation and ratios, as well as gender differences, associated with a large variety of hamstring resistance training exercises. Analysis of hamstring activation reveals that for both genders, the Russian curl and leg curl exercises resulted in the greatest hamstring activity. The stiff leg dead lift was superior to the squat and statistically similar to the single leg stiff leg dead lift and the good morning. Similarities between the good morning and stiff leg dead lift may be due to their biomechanical similarities in range of motion at the knee and hip joints. The order of greatest to least mean hamstring activation of each exercise was the same for both men and women. Results of this study are consistent with those of Wright et al,[23] who demonstrated that the leg curl and stiff leg dead lift elicited more EMG activity than the squat. Unlike the findings of Wright et al,[23] the current study yielded significant differences in EMG between the leg curl and stiff leg dead lift and evaluated other exercises as well. Wright et al[23] evaluated both eccentric and concentric phases of the hamstring exercises. Even though an analysis of each these phases of muscle action is instructive, the current study assessed hamstring EMG activity for the entire resistance training movement because the exercises evaluated are not typically performed exclusively in the eccentric or concentric phase.

Previous studies demonstrated no differences in hamstring muscle activation between variations of the dead lift,[17] the knee extension exercise, and leg press,[26] or during compensatory resistance variations of the squat.[19] Escamilla et al[18] demonstrated approximately 58 to 71% greater hamstring activity during the squat than the leg press with variations in activation based on stance width. Specifically, hamstring values during the squat ranging from approximately 31 to 41% of MVIC. In the current study, the H attained 27% of the MVIC during the squat. Thus the squat is not an optimal exercise for training the hamstrings.

Analysis of the Q activation indicated that for both men and women, the squat resulted in predictably more Q activation than the seated leg curl, demonstrating 74% and 7% of the MVIC, respectively. This finding is consistent with previous research that demonstrated Q activation of 6% of MVIC during the leg curl.[9]

Six-RM squat strength and squat strength normalized to body mass of women were approximately 56 and 71% of the values attained by men, respectively

($p < 0.05$). "Previous reports indicate that women are weaker than men, producing approximately 50 and 54% of knee flexion and extension torque. Owing to the large discrepancies, the gender discrepancies may remain even when normalized to body mass.[16,27] In the present study, women were 0.61 year younger than the men and trained an average of 0.24 day less per week (4.00 vs. 4.24 days per week). These measures of the training status of women were statistically similar to those of the men, even though squat strength and squat strength-to-mass ratios were significantly different.

The H-to-Q ratio was found to be considerably higher for open–kinetic chain (OKC) exercises, such as the seated leg curl and Russian curl, than for ground-based CKC exercises, such as the stiff leg dead lift, single leg stiff leg dead lift, good morning, and squat, indicating that there is less quadriceps coactivation during OKC and non-ground-based exercises. However, training with exercises that include Q antagonism may also be useful for injury prevention since the H and Q need to function together during a variety of athletic movement such as jump landings[28] during torsional stress associated with single leg support and cutting.[29] Therefore, exercises such as the stiff leg dead lift, single leg stiff leg dead lift, and good morning may be useful to include in an exercise prescription.

When the H-to-Q ratio was analyzed with strength-matched men and women, the gender disparity was more comprehensive. This result suggests that differences in these ratios are not attributable to differences in training status between genders since strength matching of subjects included analysis of the strongest women and weakest men. These findings are preliminary because the number of subjects in this portion of the analysis is small. Gender differences in H-to-Q activation ratios were found in all of the exercises except the stiff leg dead lift and squat, with women attaining approximately 54 to 89% of the male values. During separate analysis of strength-matched women and men, gender difference in H-to-Q ratio were found for all of the exercises, with women demonstrating only 36 to 76% of male values. These results confirm previous reports of gender differences in H-to-Q ratios with women attaining approximately 41 to 61% of ratios typical of men, when assessed with isokinetic testing.[30] The gender differences in H-to-Q ratio associated with the strongest women demonstrate that athletic women are also Q dominant during the performance of resistance training exercises, supporting the general belief that women are Q dominant as demonstrated by isokinetic testing.[31] In the current study, gender differences in H-to-Q ratios were manifested during both OKC and CKC H exercise, during exercises that are not H dominant such as the squat, and with strength matched subjects. Previous research demonstrating gender differences in H-to-Q ratio was limited to isokinetic testing.[31]

Practical Application

Hamstring training should be included in programs designed to increase leg strength, reduce muscle imbalances, prevent H strains, and potentially reduce ACL injuries. Results of this study help determine the H exercises that offer the greatest muscle activation, such as the Russian curl and seated leg curl. Consideration should also be given to including a number of H exercises for program varia-

Table 5 Gender Differences in H-to-Q Quadriceps Ratio Expressed as RMS EMG Normalized as a Percentage of RMS EMG of the MVIC

	Russian Curl (RC)	Seated Leg Curl (SLC)	Stiff Leg Dead Lift (SLDL)	Good Morning (GM)	Single Leg Stiff Leg Dead Lift (SGLDL)	Squat (S)
Men (N = 21)	29.14 ± 16.23	17.45 ± 8.80	8.96 ± 5.96	5.90 ± 3.38	3.36 ± 1.70	0.38 ± .20
Women (N = 13)	18.56 ± 7.90	10.65 ± 10.13	7.06 ± 3.50	3.18 ± 1.80	2.20 ± 0.98	0.34 ± .23
H:Q of women expressed as a percentage of male H:Q	64.7%*	61.0%*	78.8%	53.9%*	65.5%*	89.5%

Values are mean ± SD. H:Q, hamstrings-to-quadriceps ratio.

*Mean H:Q ratios are significantly different between men and women ($P < .05$).

Table 6 Gender Differences in H-to-Q Ratio Expressed as RMS EMG Normalized as a Percentage of RMS EMG of the MVIC for Strength Matched Men and Women

	Russian Curl (RC)	Seated Leg Curl (SLC)	Stiff Leg Dead Lift (SLDL)	Good Morning (GM)	Single Leg Stiff Leg Dead Lift (SGLDL)	Squat (S)
Men (N = 3)	46.96 ± 14.50	27.59 ± 10.90	17.21 ± 1.99	7.76 ± 1.21	5.86 ± 2.37	0.25 ± .0.07
Women (N = 3)	16.84 ± 7.58	17.78 ± 21.04	9.50 ± 3.87	3.12 ± 2.22	2.38 ± 0.10	0.19 ± .02
H:Q of women expressed as a percentage of male H:Q	35.9%*	64.4%*	55.2%*	40.2%*	40.6%*	76.0%*

Values are mean ± SD. H:Q, hamstrings-to-quadriceps ratio.

*Mean hamstrings to quadriceps ratios are significantly different between men and women ($P < .05$)

tion, and to follow the principle of biomechanic specificity. Thus, CKC and ground-based exercises, such as the stiff leg dead lift, single leg stiff leg dead lift, and good mornings, should be included as well, in order to train athletes for sports or activities that require H functioning during simultaneous Q activation. Whereas these CKC exercise options have lower H-to-Q activation ratios compared with the Russian curl and leg curl, these exercises still activate the H to a much greater degree than the Q, and are not likely increase Q dominance in subjects who train with them. Finally, women in this study had lower H-to-Q ratios, which were present regardless of exercise type or subject strength. Thus, H training may be particularly important for women.

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