Effect of Three Different Muscle Action Training Protocols on Knee Strength Ratios and Performance

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Abstract
Ruas, CV, Brown, LE, Lima, CD, Costa, PB, and Pinto, RS. Effect of three different muscle action training protocols on knee strength ratios and performance. J Strength Cond Res 32 (B): 2154–2165, 2018—Hamstring to quadriceps (H:Q) ratios are often used to assess strength imbalances. The aims of this study were to compare 3 different muscle action training protocols on H:Q strength balance and functional performance. Forty untrained men (age: 22.87 ± 2.28 years, mass: 70.66 ± 11.049 kg, ht: 174.29 ± 6.90 cm) performed 6 weeks of training on an isokinetic dynamometer. They were randomly assigned to one of 4 groups; concentric quadriceps and concentric hamstring (CON/CON), eccentric quadriceps and eccentric hamstring (ECC/ECC), concentric quadriceps and eccentric hamstring (CON/ECC), or no training. Mixed Factor analyses of variance were used to compare interactions for variables pretest and posttest between groups (p ≤ 0.05). The ECC/ECC group showed significant increases in H:Q functional ratio (pre = 0.73 ± 0.092, post = 0.87 ± 0.098), ECC peak torque (PT) (pre = 226.44 ± 67.80 N·m, post = 331.74 ± 54.44 N·m), isometric PT (IPT) (pre = 173.69 ± 41.41 N·m, post = 203.091 ± 30.82 N·m), countermovement jump (CMJ) (pre = 52.73 ± 6.95 cm, post = 58.16 ± 6.10 cm), and drop jump (DJ) (pre = 52.91 ± 6.080 cm, post = 58.20 ± 7.72 cm), whereas the CON/CON group increased the rate of torque development (pre = 152.19 ± 65.0074 N·m·s⁻¹, post = 225.26 ± 88.80 N·m·s⁻¹). There were no differences between groups for CON PT, squat jump, conventional ratio or 40 m sprint. Our findings suggest that ECC/ECC training may be the most effective at increasing functional H:Q strength ratios, as well as ECC PT, IPT, CMJ, and DJ performance. Eccentric training increases ECC PT, thereby increasing the functional H:Q ratio. Eccentric training also improves vertical jumping involving ECC actions. CON/CON training may be more effective at increasing explosive muscle strength.

Key Words: unilateral, antagonist/agonist, exercise

Introduction
Hamstring to quadriceps (H:Q) strength ratios are often used to describe muscle strength properties and imbalances to screen for potential risks of lower-extremity muscle and ligament injuries during sports. Risk is most often associated with the failure of hamstring to produce enough strength to decelerate knee rotation or anterior tibial shear (1,2,14,15,39). Ratios can be classified as either conventional or functional. The conventional ratio calculates balance between hamstring and quadriceps concentric (CON) strength, where values of at least 0.6 may indicate appropriate balance and reduced injury risk (1,2,39). However, the functional ratio considers hamstring eccentric (ECC) to quadriceps CON strength reflecting deceleration of the leg, where values of approximately 1.00 may indicate greater joint stability during sports activities (1,39). Nevertheless, these values may vary according to functional sports activities, because different sports, skills, and tasks may alter the H:Q relationship in a specific manner and, thereby, performance (39).

Several studies have demonstrated that specific muscle action training can be effective at increasing hamstring and quadriceps CON or ECC peak torque (PT) (3,4,8,10,11,19,33), which may increase H:Q strength ratios (14,18,19). Gioftsidou et al. (18) found that a 2 mo/3 times a week specific CON muscle action training program resulted in restoration of muscular H:Q balance and strength of professional soccer players. Croisier et al. (14) found that CON and ECC knee flexors training increased conventional and functional ratios of soccer players with muscle imbalances, and reduced injury or reinjury, lower-limb pain, and discomfort. They concluded that training programs focused on ECC training are effective at increasing H:Q balance and...
reducing strength deficits on return to play. Besides specific improvements in dynamic CON and ECC PT, different muscle action training protocols can increase isometric PT (IPT) \( (4,10) \), rate of torque development (RTD) \( (12,33) \), and functional performance \( (15,21,41) \).

Neuromuscular adaptations are generally specific to the muscle actions trained \( (4,22) \). The most common are CON quadriceps and CON hamstring (CON/CON), ECC quadriceps and ECC hamstring (ECC/ECC), and CON quadriceps and ECC hamstring (CON/ECC) \( (8,18,19,33) \). However, the most advantageous muscle action training protocol to elicit the greatest increases in H:Q balance is unknown. Therefore, the aims of this study were to compare 3 different muscle action training protocols on H:Q strength balance, as well as on PT, IPT, RTD, and functional performance of squat jump (SJ), countermovement jump (CMJ), drop jump (DJ), and 40-m sprint. Our hypothesis was that ECC/ECC training would be the most advantageous for ECC PT, IPT, RTD, functional ratio, and vertical jumps involving eccentric strength (CMJ and DJ); CON/CON training would be the most advantageous for CON PT, SJ, and conventional ratio; and CON/ECC training would be the most advantageous for 40-m sprint.

**METHODS**

**Experimental Approach to the Problem**

Subjects were randomly assigned to one of 4 groups; CON quadriceps and CON hamstring (CON/CON), ECC quadriceps and ECC hamstring (ECC/ECC), CON quadriceps and ECC hamstring (CON/ECC), or no training (CNTRL). The training groups performed 6 weeks of dominant and non-dominant knee exercise on a Biodex System 2 isokinetic dynamometer (Biodex Medical Systems, Shirley, NY, USA). Dominant leg CON and ECC quadriceps and hamstring PT, IPT, RTD, conventional and functional ratios, and functional performance were measured before and after training (Figure 1).

**Subjects**

Forty men (mean \( \pm SD \) age: 22.87 \( \pm 2.28 \) years, mass: 70.66 \( \pm 11.049 \) kg, ht: 174.29 \( \pm 6.90 \) cm) volunteered to participate. However, subjects were not completely sedentary, but participated in recreational and sport activities. Before participation, all subjects read and signed a University Institutional Review Board–approved informed consent form based on the Declaration of Helsinki of ethical principles for medical research involving human subjects (California State University Institutional Review Board Committee, Fullerton, CA, USA, approved this study). The form contained a description of the study and sections where subjects described their medical history for safety conditions to be satisfied.

**Procedures**

**Pretraining Tests.** All tests were performed on 2 separate days, separated by 48 hours. On day one, subjects were measured for mass on a digital scale (Model # ES200L; Ohaus, Pine Brook, NJ, USA), and height on a wall-mounted stadiometer (Seca Stadiometer, ON, Canada). After this, IPT, RTD (dominant leg), and functional performance were measured. On day 2, subjects were measured for isokinetic CON and ECC quadriceps and hamstring PT. Each test was separated by 10 minutes of rest, and every test had 2 minutes of rest between test and warm-up sets.

**Isokinetic Peak Torque.** Maximal quadriceps and hamstring CON and ECC PT for the dominant leg were measured on the Biodex isokinetic dynamometer. Subjects sat comfortably on the machine and had straps applied across their thighs and chest to avoid superfluous movement \( (7) \). The dynamometer’s axis of rotation was aligned with the lateral condyle of their test knee \( (7–9) \). The lower leg was attached to the machine’s lever arm ankle cuff \( 2 \) cm above the medial malleolus. Before testing, subjects performed a specific isokinetic warm-up of 10 CON extension-flexion repetitions at \( 180^\circ \) per second and 3 repetitions at \( 60^\circ \) per second. On completing the warm-up, testing started with CON, followed by ECC. Testing was performed at \( 60^\circ \) per second through a \( 90^\circ \) range of motion \( (0^\circ \) at full extension).

The CON test consisted of 5 extension-flexion repetitions, and subjects were asked to push the lever arm as hard and fast as possible. Eccentric tests also consisted of 5 repetitions at \( 60^\circ \) per second, and subjects were asked to resist the movement of the machine, pushing and pulling the lever arm as hard and fast as possible \( (42) \). Tests were separated by 2 minutes of rest. Verbal encouragement was given during all tests, but no visual feedback was provided.

The highest PT values across all repetitions and tests were used for further analysis. The conventional ratio was calculated by dividing hamstring CON PT by quadriceps CON PT, whereas the functional ratio was calculated by dividing hamstring CON PT by quadriceps CON PT \( (1,2,39) \). High reliability has previously been found for quadriceps and hamstring CON PT \( ( intraclass correlation coefficient [ICC] > 0.92) (9) \) and ECC PT \( ( ICC > 0.80) (42) \) tests.

**Isometric Peak Torque and Rate of Torque Development.** Maximal quadriceps and hamstring IPT for the dominant leg were tested on the same Biodex isokinetic dynamometer. Subjects sat on the machine using the same procedures as the isokinetic PT tests. Before testing, subjects performed an isokinetic CON extension-flexion warm-up of 10 repetitions at \( 180^\circ \) per second through the same \( 90^\circ \) range of motion and performed submaximal preliminary repetitions for familiarization. Their legs were then positioned at \( 60^\circ \) of knee extension, and testing began with isometric quadriceps followed by hamstring. Both tests consisted of 3 reps for 5 seconds, and were separated by...
5 minutes of rest. They were asked to push for the quadriceps test and to pull for the hamstring test, as hard as possible. Others have demonstrated the effectiveness of this instruction during isometric testing (40). Instructions and verbal encouragement were given during the test, but no visual feedback was provided. The average of 3 repetitions was used for further analyses. Rate of torque development was calculated as IPT/time to reach IPT (20). Procedures of IPT and RTD were based on guidelines of accurate assessment of muscle strength and power (7), and have shown high reliability (ICC >0.84) in previous studies using similar procedures (17,24).

**Functional Performance Tests.** Vertical jumps were CMJ, SJ, and DJ, which were performed on an Advanced Mechanical Technology, Inc., force plate (Advanced Mechanical Technology, Inc., Watertown, MA, USA) with an EPIC device positioned next to the force plate for subjects to reach and touch visual vanes as a target. For CMJ, subjects started in a standing position, dropped to a self-selected squatting position, then jumped up as high and fast as possible with arm swing, with no pause at the bottom (7). For DJ, subjects stepped off a 40-cm box and on landing, jumped up as high and fast as possible with arm swing (30,32). For SJ, subjects hands were placed akimbo, then they lowered to a squat position, remained still for 2 seconds, then jumped up as high and fast as possible (7). Three attempts were allowed for familiarization of each test, and 5 minutes of rest was given between tests. The average of 3 reps of each vertical jump test was considered for further analyses. Jump height was measured by custom LabVIEW (version 2014; National Instruments...
Corporation, Austin, TX, USA) software on a desktop computer connected to the force plate. Procedures of SJ, CMJ, and DJ were based on guidelines of accurate assessment of muscle strength and power (7), and have previously been found to be highly reliable tests (ICC > 0.90) (31,32).

Forty-meter sprint was performed on a grass field. An electronic timing system (Speedtrap II; Brower, Salt Lake City, UT, USA) using infrared beams recorded all times (5). In addition, 10-meter split times (0–10, 10–20, 20–30, 30–40) were recorded by separate timing lights. Before testing, subjects warmed up by jogging 40 m, then performed 3 maximal sprints, separated by 5 minutes of rest. The start position was immediately behind the starting line using a staggered stance with the nondominant foot in front and the dominant foot in back (26). The average of 3 maximum sprints was used for analyses. Previous investigators have reported the reliability of these 40-m sprint procedures (ICC > 0.90) (25,27).

Training Sessions. Training sessions began 72 hours after day 2 testing. They consisted of 2 sessions a week for 6 weeks lasting about 20 minutes each, separated by at least 48 hours. Subjects comfortably sat on the same Biodex isokinetic dynamometer using the same procedures, and performed the same specific isokinetic warm-up of 10 CON extension-flexion repetitions as PT and IPT tests. The CON/CON group began by performing 10 maximal repetitions at 210° per second for quadriceps and hamstrings. The ECC/ECC group began by performing 10 maximal repetitions at 60° per second for quadriceps and hamstrings. The CON/ECC group began by performing 10 maximal repetitions at 60° per second for quadriceps and hamstring. The intensity of training was increased every week by decreasing the angular velocity for CON and increasing it for ECC in 30° per second increments (18,19,21). Also, the volume of training was increased by one set every week (4,10) (Table 1). The CON/ECC group did not perform training sets at the same consistent flow (i.e., the performance of both movements within one set) as CON/CON and ECC/ECC because of limitations of the isokinetic dynamometer in having a specific mode for this muscle action training. They first performed only CON knee extension (10 repetitions), followed by ECC knee flexion (10 repetitions), with no rest time between muscle actions. Therefore, all training groups performed the same 20 repetitions in total for quadriceps and hamstrings. The CNTRL group did not train, but returned to the laboratory to be tested after 6 weeks.

Posttraining Tests. Posttests were performed 72 hours after the last training session. Subjects performed the same tests as

<table>
<thead>
<tr>
<th>Table 1. Training program design.</th>
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<tr>
<td>Weeks</td>
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<tr>
<td>CON/CON</td>
</tr>
<tr>
<td>speed</td>
</tr>
<tr>
<td>1</td>
</tr>
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<td>6</td>
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Figure 2. Mean and SD of conventional and functional ratios between pretest and posttest for concentric/concentric (CON/CON), eccentric/eccentric (ECC/ECC), concentric/eccentric (CON/ECC), and control (CNTRL) groups. *Significantly greater than pretest (p ≤ 0.05).
pretraining in the same order on 2 different days separated by 48 hours. In addition, the same exact instructions for the pretest were given to subjects at the posttest, and they were again asked to refrain from physical activity 48 hours before testing.

**Statistical Analyses**
Normality of all values was verified by the Shapiro-Wilk test. A $2 \times 2 \times 4$ (ratio $\times$ time $\times$ group) mixed factor analyses of variance (ANOVA) was used to compare ratios. A $2 \times 2 \times 4$ (muscle $\times$ action $\times$ time $\times$ group) mixed factor ANOVA was used to compare PT. Two $2 \times 2 \times 4$ (muscle $\times$ time $\times$ group) mixed factor ANOVAs were used to compare IPT and RTD. Four $2 \times 4$ (time $\times$ group) mixed factor ANOVAs were used to compare CMJ, DJ, SJ, and total 40-m sprint time. A $2 \times 4 \times 4$ (time $\times$ split $\times$ group) mixed factor ANOVA was used to compare 40-m sprint split times. Follow-up tests for interactions and main effects included paired $t$ tests and post hoc analysis (Fisher’s least significant difference [LSD]), respectively. All data are shown as mean and SD, and all analyses were performed with SPSS 21.0 (Statistical Package for Social Sciences, Chicago, IL, USA). Effect sizes for each significant difference between pretests and posttests between groups were calculated by Cohen’s $d$, in which values $<0.50$ were considered trivial, 0.50–1.25 small, 1.25–1.90 moderate, and $>2.0$ large for untrained subjects (37). An a priori alpha level of 0.05 was used to determine statistical significance.

**RESULTS**
For ratios, there was an interaction of ratio $\times$ time $\times$ group ($p \leq 0.05$). This was followed up with four $2 \times 2$ (ratio $\times$ time) ANOVAs, one for each group. The CON/CON group demonstrated a main effect for ratio, where functional ratio ($1.60 \pm 0.15$) was greater than conventional ratio ($1.36 \pm 0.17$) ($p \leq 0.05$). The ECC/ECC group demonstrated an interaction ($p \leq 0.05$), which was followed up with 2 paired $t$ tests, where functional ratio post was greater than pre ($p \leq 0.05$), but conventional ratio post was not different than pre ($p > 0.05$). The CON/ECC group demonstrated a main effect for ratio, where functional ratio ($1.54 \pm 0.24$) was greater than conventional ratio ($1.30 \pm 0.12$) ($p \leq 0.05$). The CNTRL group demonstrated no interactions or main effects ($p > 0.05$) (Figure 2). Effect sizes for pretest and posttest comparisons between groups were $d = -0.091$ (CON/CON), $d = 0.16$ (ECC/ECC), $d = -0.74$ (CON/ECC), and $d = 0.66$ (CNTRL) for conventional ratio, and $d = 0.43$ (CON/CON), $d = 1.56$ (ECC/ECC), $d = -0.27$ (CON/ECC) and $d = -0.0086$ (CNTRL) for functional ratio.
### Table 2. Mean and SD of hamstring and quadriceps isometric peak torque (IPT) between pretest and posttests for concentric/concentric (CON/CON), eccentric/eccentric (ECC/ECC), concentric/eccentric (CON/ECC), and control (CNTRL) groups.*

<table>
<thead>
<tr>
<th></th>
<th>CON/CON</th>
<th>ECC/ECC</th>
<th>CON/ECC</th>
<th>CNTRL</th>
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<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Quadriceps</td>
<td>248.37±66.14</td>
<td>257.36±62.99</td>
<td>225.62±56.88</td>
<td>261.39±45.56</td>
</tr>
<tr>
<td>Hamstring</td>
<td>143.74±34.71</td>
<td>145.38±30.73</td>
<td>121.77±28.87</td>
<td>144.79±25.92</td>
</tr>
<tr>
<td>Collapsed</td>
<td>196.00±48.72</td>
<td>201.37±45.70</td>
<td>173.70±41.41</td>
<td>203.09±30.83</td>
</tr>
</tbody>
</table>

*Data collapsed across muscle.
†Significantly greater than pretest (p ≤ 0.05).

### Table 3. Mean and SD of hamstring and quadriceps total rate of torque development (RTD) between pretest and posttest for concentric/concentric (CON/CON), eccentric/eccentric (ECC/ECC), concentric/eccentric (CON/ECC), and control (CNTRL) groups.*

<table>
<thead>
<tr>
<th></th>
<th>CON/CON</th>
<th>ECC/ECC</th>
<th>CON/ECC</th>
<th>CNTRL</th>
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<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
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<tr>
<td>Quadriceps</td>
<td>155.45±84.27</td>
<td>258.68±121.57</td>
<td>248.35±175.50</td>
<td>220.14±89.023</td>
</tr>
<tr>
<td>Hamstring</td>
<td>148.93±74.070</td>
<td>191.85±103.92</td>
<td>168.31±135.83</td>
<td>169.16±108.66</td>
</tr>
<tr>
<td>Collapsed</td>
<td>152.19±65.007</td>
<td>225.27±88.80†</td>
<td>208.33±141.21</td>
<td>194.65±67.43</td>
</tr>
</tbody>
</table>

*Data collapsed across muscle.
†Significantly greater than pretest (p ≤ 0.05).
‡Significantly greater than posttest (p ≤ 0.05).
For isokinetic PT, there was a 4-way interaction \((p \leq 0.05)\). This was followed up with four 2 \times 2 (muscle \times action \times time) ANOVAs, one for each group. The CON/CON group demonstrated a main effect for muscle, where quadriceps \((1,056.33 \pm 182.070 \text{ N} \cdot \text{m})\) was greater than hamstring \((694.55 \pm 114.57 \text{ N} \cdot \text{m})\), and a main effect for action, where ECC \((955.63 \pm 162.80 \text{ N} \cdot \text{m})\) was greater than CON \((795.25 \pm 142.70 \text{ N} \cdot \text{m})\) \((p \leq 0.05)\). The ECC/ECC group demonstrated an interaction of muscle \times action \times time \((p \leq 0.05)\) that was followed up with 2 paired \(t\) tests, which demonstrated that quadriceps ECC post was greater than quadriceps CON post \((p \leq 0.05)\), and hamstring ECC \((175.61 \pm 34.46 \text{ N} \cdot \text{m})\) was greater than hamstring CON \((146.13 \pm 42.13 \text{ N} \cdot \text{m})\) \((p > 0.05)\) (Figure 3). Effect sizes for pretest and posttest comparisons between groups were \(d = 0.34\) (CON/CON), \(d = 0.24\) (ECC/ECC), \(d = 1.29\) (CON/ECC), and \(d = 0.093\) (CNTRL) for quadriceps CON PT, and \(d = 0.63\) (CON/CON), \(d = 0.57\) (CON/ECC), and \(d = 0.21\) (CNTRL) for hamstring ECC PT. Effect sizes for pretest and posttest comparisons between groups were \(d = 0.24\) (CON/CON), \(d = 0.31\) (ECC/ECC), \(d = 0.37\) (CON/ECC), and \(d = 0.47\) (CNTRL) for hamstring CON PT, and \(d = 0.63\) (CON/CON), \(d = 1.51\) (ECC/ECC), \(d = 0.57\) (CON/ECC), and \(d = 0.21\) (CNTRL) for hamstring ECC PT.

For IPT, there was an interaction of time \times group \((p \leq 0.05)\) that was followed up with 4 paired \(t\) tests, one for each group. For the ECC/ECC group, post was greater than pre.
(\(p \leq 0.05\)). For the CON/CNTRL, CON/ECC, and CNTRL groups, post was not different than pre (\(p > 0.05\)) (Table 2). Effect sizes for pretest and posttest comparisons between groups were \(d = 0.14\) (CON/CNTRL), \(d = 0.63\) (ECC/ECC), \(d = 0.41\) (CON/ECC), and \(d = -0.0052\) (CNTRL) for quadriceps IPT, and \(d = 0.047\) (CON/CNTRL), \(d = 0.80\) (ECC/ECC), \(d = -0.025\) (CON/ECC), and \(d = -0.054\) (CNTRL) for hamstring IPT.

For RTD, there was an interaction of time \(\times\) group (\(p \leq 0.05\)) that was followed up with 4 paired \(t\) tests, one for each group. For the CON/CNTRL group, post was greater than pre (\(p \leq 0.05\)). For the ECC/ECC and CON/ECC groups, post was not different than pre (\(p > 0.05\)). For the CNTRL group, pre was greater than post (\(p \leq 0.05\)) (Table 3). Effect sizes for pretest and posttest comparisons between groups were \(d = 1.23\) (CON/CNTRL), \(d = -0.10\) (ECC/ECC), \(d = 0.24\) (CON/ECC), and \(d = -0.41\) (CNTRL) for quadriceps RTD, and \(d = 0.58\) (CON/CNTRL), \(d = 0.0063\) (ECC/ECC), \(d = -0.21\) (CON/ECC), and \(d = -0.30\) (CNTRL) for hamstring RTD.

For CMJ, there was an interaction of time \(\times\) group (\(p \leq 0.05\)) that was followed up with 4 paired \(t\) tests, one for each group. For the ECC/ECC group, post was greater than pre (\(p \leq 0.05\)). For the CON/CNTRL, CON/ECC and CNTRL groups, post was not different than pre (\(p > 0.05\)) (Figure 4). Effect sizes for pretest and posttest comparisons between groups were \(d = 0.23\) (CON/CNTRL), \(d = 0.78\) (ECC/ECC), \(d = 0.58\) (CON/ECC), and \(d = -0.093\) (CNTRL). For DJ, there was an interaction of time \(\times\) group (\(p \leq 0.05\)) that was followed up with 4 paired \(t\) tests, one for each group. For the ECC/ECC group, post was greater than pre (\(p \leq 0.05\)). For the CON/CNTRL, CON/ECC, and CNTRL groups, post was not different than pre (\(p > 0.05\)) (Figure 4). Effect sizes for pretest and posttest comparisons between groups were \(d = 0.13\) (CON/CNTRL), \(d = 0.87\) (ECC/ECC), \(d = 0.42\) (CON/ECC), and \(d = -0.18\) (CNTRL). For SJ, there were no interactions or main effects (\(p > 0.05\)) (Figure 4). Effect sizes for pretest and posttest comparisons between groups were \(d = 0.44\) (CON/CNTRL), \(d = 1.27\) (ECC/ECC), \(d = 0.014\) (CON/ECC), and \(d = -0.09\) (CNTRL).

For 40-m sprint split times, there was an interaction of split \(\times\) time (\(p \leq 0.05\)) that was followed up with 4 paired \(t\) tests, one for each split. The 20–30 m presplit was greater than post (\(p \leq 0.05\)). No other splits were different (\(p > 0.05\)). For full 40-m sprint, there were no interactions or main effects (\(p > 0.05\)) (Table 4). Effect sizes for pretest and posttest comparisons between groups were \(d = -0.16\) (CON/CNTRL), \(d = -0.068\) (ECC/ECC), \(d = 0.17\) (CON/ECC), and \(d = 0.29\) (CNTRL) for 0–10 m; \(d = -0.033\) (CON/CNTRL), \(d = -0.46\) (ECC/ECC), \(d = -0.010\) (CON/ECC), and \(d = 0.16\) (CNTRL) for 10–20 m; \(d = -0.35\) (CON/CNTRL), \(d = -0.59\) (ECC/ECC), \(d = -0.22\) (CON/ECC), and \(d = 0.054\) (CNTRL) for 20–30 m; \(d = -0.32\) (CON/CNTRL), \(d = -0.50\) (ECC/ECC), \(d = -0.19\) (CON/ECC), and \(d = -0.054\) (CNTRL) for hamstring IPT.
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and \( d = 0.054 \) (CNTRL) for 30- to 40-m sprint split times. Effect sizes for pretest and posttest comparisons between groups were \( d = -0.24 \) (CON/CON), \( d = -0.41 \) (ECC/ECC), \( d = -0.13 \) (CON/ECC), and \( d = 0.12 \) (CNTRL) for full 40-m sprint.

**DISCUSSION**

The aims of this study were to compare 3 different muscle action training protocols on H:Q strength balance, as well as on PT, IPT, RTD, and functional performance of SJ, CMJ, DJ, and 40-m sprint. Our results revealed that the ECC/ECC group showed significant increases in the H:Q functional ratio, as well as hamstring and quadriceps ECC PT, IPT, CMJ and DJ, compared with all other groups, whereas the CON/CON group increased RTD. There were no differences between groups for CON PT, conventional ratio or 40-m sprint times or splits. This demonstrates that ECC/ECC training was the most effective overall at increasing functional H:Q strength ratio, as well as ECC PT, IPT, and jump performance. This is partially explained by ECC training increasing ECC PT, which increased the functional H:Q strength ratio, and vertical jumps involving ECC strength (CMJ and DJ). CON hamstring training was only effective at increasing explosive muscle strength. This is partially in accordance with our hypothesis because ECC/ECC training was overall the most advantageous, especially regarding strength, functional tests involving an ECC component and functional ratio. However, RTD was not increased in this group, and CON/CON and CON/ECC training did not increase the variables we were expecting.

Several studies have examined the effectiveness of specific muscle action training on H:Q muscle balance (3,14,18,19,23,34). Improved balance between hamstring and quadriceps is essential because low hamstring strength may be a risk factor for sustaining injuries such as hamstring strains and ACL tears (14,34). Golick-Peric et al. (19) demonstrated that CON/CON training 5 times a week was effective at increasing conventional ratios, resulting in restoration of H:Q muscle balance. Similarly, Gioftsisdou et al. (18) found that a specific CON training program in professional soccer players who had CON unilateral and bilateral knee strength asymmetry resulted in restoration of muscle balance. Croisier et al. (14) demonstrated that CON in addition to ECC knee flexor training increased both conventional and functional ratios. Alternately, Holcomb et al. (23) did not find increases in the conventional ratio after 6 weeks of training with emphasis on hamstring training involving both CON and ECC actions. However, the functional ratio was significantly increased after training. Mjolsnes et al. (34) also found increases in the functional ratio following a protocol focused on hamstring ECC training compared with hamstring CON. They concluded that this resulted from a lack of quadriceps CON strength increases in both groups and a lack of ECC strength increases in the hamstring CON training group. Also, they reported that hamstring ECC training may be the most effective in protecting against muscle strains (34). Although we are not aware of studies directly comparing different quadriceps and hamstring muscle action training on both functional and conventional ratios, our results also demonstrated functional ratio increases only after ECC/ECC training. This ratio is considered as specific to actual game performance and its use is more acceptable for knee imbalance and injury risk assessments, as it considers deceleration performed by hamstring actions during quadriceps CON actions (e.g., running and kicking) (12,39). Since the CON/ECC and CON/CON groups did not demonstrate quadriceps and hamstring CON or hamstring PT increases, the conventional and functional ratios were unchanged. Therefore, because hamstring strains are usually a result of ECC muscle actions, ECC training may be most effective in reducing injury risk (34).

Investigators have studied the effect of different muscle action training protocols on quadriceps and hamstring CON, ECC, and IPT (3,4,8,10,11,19,22,33). Cadore et al. (10) found that 6 weeks of CON and ECC training performed twice a week, with progression of sets and repetitions each week, resulted in similar increases in knee extensor CON and ECC PT, but IPT was greater only for ECC training. Baroni et al. (4) demonstrated that 4 weeks of ECC training resulted in increases in knee extensor ECC and IPT, which continued to increase throughout 12 weeks of training, when volume of sets and repetitions were increased. They also found that CON strength progressively increased, albeit to a lesser extent, only until the eighth week (4). Although these studies did not train knee flexors, our results partly agree with them, as we also found ECC PT and IPT increases for the ECC/ECC group. However, we did not find significant CON increases for any group, nor increases in ECC PT for the CON/CON or CON/ECC groups. This may be because our training differed from previous studies in progression of volume and intensity, participants’ training status, as well as sets per week and length of training. Higbie et al. (22) compared knee extensor CON and ECC training for 10 weeks, 3 days a week to CNTRL, and demonstrated that only the ECC group increased ECC strength, and only the CON group increased CON strength. Miller et al. (33) also found that 20 weeks of knee extension and flexion ECC/ECC training led to greater ECC gains compared with CON/CON. We also found ECC/ECC training was the most effective at increasing ECC PT. Eccentric strength has been reported to have unique neuromuscular characteristics compared with CON strength, by generating the highest forces with the lowest energy cost (29,38) and neuromuscular activity (10,16,38), therefore demonstrating the ideal characteristics for general strength increases after training (29,38). In ECC muscle actions, torque is greater per cross bridge or passive stretch of series elastic elements (22,29). Also, ECC strength is often less trained than CON strength, which may lead to greater ECC gains in less time.
Eccentric exercise has also been associated with a greater reduction in muscular cocontraction compared with CON after short-term training (36,38). This may explain why the ECC/ECC group showed greater improvements in hamstring ECC PT than the CON/ECC group. However, we did not directly measure muscle cocontraction. Although this study demonstrated no significant changes in CON PT in the concentrically trained groups, it is possible that longer duration training could lead to greater gains; because of neural activation differences between dynamic and static muscle actions (44). This may explain why CON/CON improvements in RTD did not translate to SJ. In addition, the 40-m sprint is a complex movement involving coordinated movements of the arms and legs at high intensities (5,26). This may explain why no difference was found for this functional test.

A potential limitation of this study is that all training was performed on an isokinetic dynamometer. Although this was performed to ensure greater control for specific muscle action training, our results may be difficult to generalize when there is no access to this machine. In addition, although verbal encouragement was provided to participants to give maximal effort across all tests, different effort strategies of some participants in the IPT tests, as well as lack of comprehension to instructions and unfamiliarity with the tests are factors that can not be rejected, which may explain descriptive pretest IPT and RTD mean differences between groups. However, our mixed factor ANOVAs only compared between groups and within groups for time points, and therefore these differences would not affect our results.

Our findings suggest that ECC/ECC training may be the most effective at increasing functional H:Q strength ratios, ECC PT, IPT, CMJ, and DJ performance. Eccentric training increases ECC PT, thereby increasing the functional H:Q strength ratio. Eccentric training also improves vertical jumps involving ECC strength. The CON/CON training may be more effective at increasing explosive muscle strength.

**Practical Applications**

This study demonstrates that training eccentrically for knee flexors and extensors may be the most beneficial way to increase functional H:Q ratio and potentially reduce risk of lower-extremity muscle and ligament injuries. Training eccentrically can also be used to promote general strength and functional performance increases in tasks that rely heavily on ECC muscle actions. However, CON training should be used if the aim is to improve explosive muscle strength. This could help clinicians and coaches in prescribing resistance training programs focused on specific muscle actions for rehabilitation, performance enhancement, and reduction of injury risk.

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**References**

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