Hylonome

Sex comparisons of strength and coactivation following ten weeks of deadlift training

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Abstract

Objectives: To examine the effects of a ten week deadlift training program on peak torque and agonist-antagonist coactivation. **Methods:** Fifty-four untrained subjects (mean age=23 years) participated in this investigation, and were randomly assigned to a training (males, n=17; females, n=17) or control (males, n=9; females, n=11) group. The subjects in the training group performed deadlifts twice per week. Isometric peak torque for the leg extensors and flexors and surface electromyographic (EMG) amplitude for the superficial quadriceps and biceps femoris muscles were assessed. **Results:** Deadlift training increased leg extension peak torque for the males (P=.008, Cohen's d=0.43) and females (P=.003, d=0.48). Leg flexion peak torque improved for the females (P=.001, d=0.45). Increased EMG amplitude for the superficial quadriceps femoris muscles when they served as agonists was demonstrated for the females (P=.010, d=0.40), but not the males (P=.059, d=0.20). For both sexes, the effect sizes for the decline in biceps femoris coactivation were large. **Conclusion:** Deadlift training elicited improvements in strength and agonist-antagonist coactivation in untrained subjects, and particularly, novice females.

Keywords: Motor Unit, Torque, Barbell, Hamstrings, Quadriceps

Introduction

The barbell deadlift is a multiple joint exercise that involves the recruitment of dozens of large muscles[1-3]. The ability to perform the barbell deadlift requires a unique combination of strength, balance, and coordination from the legs, hips, and lower back. The exercise begins with the lifter standing directly in front of the barbell with it nearly touching his/her shins. The lifter then reaches down by bending at the knee and hip joints, and the barbell is grasped with either a pronated or an alternated grip. The barbell is then pulled from the floor in a vertical fashion while the lifter attempts to maintain an extended, rigid spine. The barbell is lowered to the floor, and this process can be repeated for as many repetitions as desired. Physical therapists and other exercise practitioners often in-

corporate the barbell deadlift into training programs in an attempt to improve leg, hip, and back strength, as well as bone mineral density and muscle mass[1]. Few researchers have performed training studies involving the barbell deadlift, and these investigations have either combined it with a variety of other movements[4,5] or used variations of the exercise[6,7]. Other investigators have focused on biomechanical aspects of the exercise using electromyography (EMG) and motion analyses[2,3].

Studies have shown that females have a higher rate of anterior cruciate ligament (ACL) injury, and the majority of these events occur during noncontact situations that involve landing and/or cutting[8]. Previous authors have speculated that leg flexion strength is an important predictor of ACL injury[8-11], and strength training is often incorporated into programs designed to prevent such injuries from occurring[7,10,12]. While cross-sectional studies have examined hamstrings and quadriceps strength in both healthy and injured subjects[8,9,11], very few have assessed changes with training. Most notably, Holcomb et al.[7] examined the effects of six weeks of strength training on hamstrings-to-quadriceps strength ratios in twelve Division IA collegiate soccer players. The subjects trained under the supervision of the university's strength and conditioning coach, and the exercises included stiff-legged deadlifts, leg curls, good mornings, and glute-ham raises. The primary finding was that the mean±SD "functional" hamstrings-to-

quadriceps strength ratio increased from 0.96±0.09 to 1.08±0.11. It was concluded that six weeks of hamstring-emphasized strength training was sufficient for reducing the potential for ACL injury in collegiate soccer players. One topic that has yet to be examined in the literature is the influence of barbell deadlift training on the prevalence of lower-body injuries, particularly in females. The fact that the barbell deadlift relies on significant recruitment of the hamstring musculature suggests that its incorporation into an exercise program may be protective in nature.

A joint's net torque is defined as the difference between the torques produced by the agonist versus antagonist muscles[13]. Thus, changes in the activation patterns for agonists and/or antagonists represent a neuromuscular adaptation that occurs independent of alterations in the morphological characteristics of a muscle. Reductions in coactivation are thought to be an important adaptation to training[14], and individuals that display a high level of skill or efficiency for a given task typically exhibit minimal antagonist activity[13]. Several previous investigations have examined the effects of strength training on agonist-antagonist coactivation[15-19]. Studies by Carolan and Cafarelli[15] and Häkkinen et al.[16] both demonstrated reduced biceps femoris coactivation following a strength training program that primarily involved extension at the knee joint. Not all authors have reported reductions in coactivation following strength training, however, and methodological differences among studies (e.g., muscle[s] tested, joint angle assessed, the age of the subjects studied, specificity of testing versus training, etc.) complicate their comparison. de Boer et al.[17] studied neuromuscular adaptations for the plantarflexor and dorsiflexor muscles following one year of strength training in elderly females, and reported increased EMG amplitude values for both the gastrocnemius and tibialis anterior during plantarflexion maximum voluntary contractions (MVCs). Beck et al.[18] reported no changes in coactivation following two days of isokinetic strength training, and this was consistent with results reported previously by Holtermann et al.[19]. What remains to be determined is whether a sex difference exists in agonist-antagonist coactivation for the hamstrings and/or quadriceps following strength training.

This study had two purposes: [1] to examine the effects of a ten week barbell deadlift training program on unilateral, isometric MVC leg extension and flexion strength in previously untrained males and females, and [2] to examine changes in EMG amplitude for the superficial quadriceps femoris and biceps femoris muscles during MVCs of the leg extensors and flexors. We theorized that the females would show lower leg flexion peak torque values during pretesting, but that barbell deadlift training would lessen the difference between the sexes. We further hypothesized that these adaptations would result in increased EMG amplitude for each of the muscles when they served as agonists (i.e., superficial quadriceps femoris muscles during extension, biceps femoris during flexion), but decreased values would be observed when they functioned as antagonists (i.e., biceps femoris during extension, superficial quadriceps femoris muscles during flexion).

Materials and methods

Subjects

Twenty-six males (mean±SD age= 24±3 years; body mass= 83.0±17.4 kg) and twenty-eight females (age= 22±2 years; body mass= 67.8±8.8 kg) volunteered to participate in this investigation. All subjects were healthy and not affected by any neuromuscular and/or musculoskeletal disorders. Each subject had refrained from lower-body strength training during at least the previous six months. The study and its procedures were approved by the Texas Tech University Institutional Review Board for Human Subjects, and all subjects signed an informed consent form and completed a health history questionnaire prior to enrollment. This study was conducted during the summer of 2013.

Following enrollment, each subject was randomly assigned to either a deadlift training group (males, n=17; females, n=17) or a control group (males, n=9; females, n=11). All of the subjects were asked to avoid lower-body strength training outside of the investigation. None of the subjects were involved in competitive sports or endurance training.

Familiarization and data collection

The first visit to the laboratory served as a familiarization of testing session. Upon arrival, the subjects were seated on an isokinetic dynamometer (Biodex System 3, Biodex Medical Systems, Shirley, NY) in accordance with the manufacturer's instructions for testing of the knee joint. Straps were secured around the subjects' hips and chest, and they were instructed to hold onto the handles throughout testing. The left knee joint was visually aligned with the input axis of the dynamometer. Once the subjects were comfortably seated, the dynamometer's settings were recorded to ensure consistency throughout the study. All isometric testing was performed at knee joint angles of 60º and 30º below the horizontal plane for the leg extensors and flexors, respectively. The familiarization session began with a warm-up of three submaximal isometric muscle actions of the left leg extensors and flexors. The subjects were instructed to provide an effort corresponding to roughly 50% of their maximum for ten seconds during the warm-up muscle actions. Following the warm-up period, the subjects performed two isometric MVCs for the leg extensors and flexors. Each MVC was six seconds in duration, and two minutes of rest were allowed between attempts. The order of testing was randomized. During each MVC, the subjects were verbally encouraged to "push" and "pull" as hard as possible during each extension and flexion, respectively. No data were collected during the familiarization session.

Forty-eight hours following the familiarization session, the subjects returned to the laboratory. Upon arrival, they were seated and strapped to the dynamometer as described previously. Before each data collection session, a correction of the dynamometer was performed to ensure that the peak torque values were not artificially inflated due to gravity. Following the warm-up, the subjects performed two, six-second isometric MVCs of the left leg extensors and flexors. The order was again randomized, and two minutes of rest separated each MVC. The

	Males		
	Leg Extension Peak Torque (Nm)	Leg Flexion Peak Torque (Nm)	Isometric Hamstrings-to-Quadriceps Ratio (%)
P	0.851	0.344	0.376
95% Confidence Interval for Mean Difference	-8.6 to 6.9	-6.1 to 2.2	-3.0 to 1.2
Cohen's d	0.02	0.11	0.12
ICC 3,1	0.867	0.840	0.780
SEM	12.7	6.9	3.5
SEM (%)	7.2	7.7	6.8
MD	35.2	19.2	9.6
	Females		
	Leg Extension Peak Torque (Nm)	Leg Flexion Peak Torque (Nm)	Isometric Hamstrings-to-Quadriceps Ratio (%)
P	0.399	0.679	0.761
95% Confidence Interval for Mean Difference	-8.7 to 3.6	-3.0 to 2.0	-2.5 to 3.4
Cohen's d	0.10	0.04	0.06
ICC 3,1	0.848	0.901	0.614
SEM	10.6	4.3	5.0
SEM (%)	9.3	7.7	10.2
MD	29.3	11.8	14.0

Table 1. Test-retest reliability statistics for the peak torque data in this study. ICC= intraclass correlation coefficient, SEM= standard error of measurement, MD= minimal difference needed to be considered real.

peak torque value (Nm) for each isometric MVC was determined based on the greatest value in the torque curve. For both muscle groups, the MVC with the highest peak torque value was used for data analysis. Once the peak torque values for the leg extensors and flexors were determined, they were expressed as an isometric hamstrings-to-quadriceps strength ratio ([leg flexion peak torque/leg extension peak torque]×100). The subjects were asked to follow these instructions prior to testing: [1] refrain from lower-body exercise, [2] drink plenty of water, [3] do not make changes to your normal dietary habits (including the consumption of caffeine/coffee), and [4] try to get 7-8 hours of sleep the evening prior to testing. These exact data collection procedures were repeated ten weeks later. Pretesting and posttesting occurred at the same time of day (±1 hour). For the subjects in the training group, the posttest was scheduled a minimum of 72 hours following the final training session. The test-retest reliability statistics for the present study's isometric peak torque dependent variables are shown in Table 1. All of the data was collected by the same investigator.

EMG measurements

Bipolar surface EMG signals were detected during each isometric MVC from the vastus lateralis, vastus medialis, rectus femoris, and biceps femoris. The signals were detected with four separate Trigno™ wireless EMG sensors (interelectrode distance = 10 mm [Delsys Inc., Boston, MA]) with a bandwidth of 20-450 Hz. The sensors were placed over the muscles in accordance with the Surface EMG for the Non-Invasive Assessment of Muscles project[20]. For the superficial quadriceps femoris muscles, the detection surface of each sensor was oriented perpendicularly to the length of the muscle fibers. For the biceps femoris, the sensor was oriented in the direction of the line between the ischial tuberosity and the lateral epicondyle of the tibia. The sensors were fixed to the skin with double-sided tape. To ensure consistency of the sensor placements, photographs of each subject's leg were taken during the pretest, and were referenced during data collection for the posttest. Prior to testing, the skin over each of the four muscles was shaved and cleansed with rubbing alcohol. The EMG signals were digitized at a sampling rate of 2,000 samples/second and stored in a personal computer (Dell Optiplex 755, Round Rock, TX) for subsequent analyses.

EMG signal processing

All signal processing was performed using custom programs written with LabView software (version 8.2, National Instruments, Austin, TX). The EMG signals from the isometric MVCs were selected from the one-second portion of the torque curve that encompassed the peak value. The root-mean-square (μV RMS) value of each selected signal was calculated as a measure of EMG amplitude[13]. When the muscles served as agonists, absolute EMG amplitude values (μV RMS) were examined. Antagonist muscle activity was reported as a percentage of the muscle's EMG amplitude value when it served as an agonist[15].

Figure 1. An example of the barbell deadlift technique used in this study. The image on the left shows the subject just prior to the pull from the floor. The image on the right shows the subject after completing the concentric portion of the exercise.
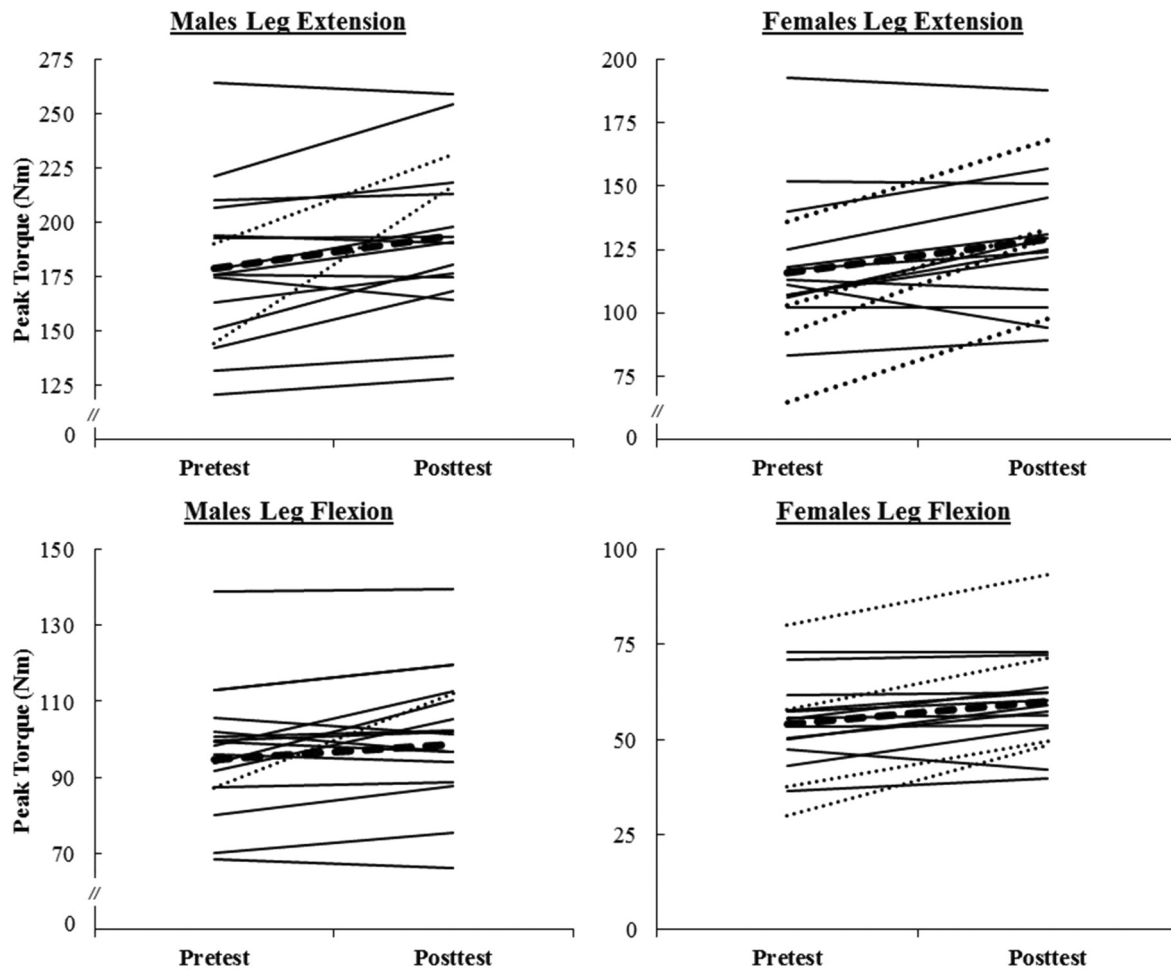
Barbell deadlift training

The subjects assigned to the training group visited the laboratory twice per week for ten weeks (i.e., 20 total training sessions). A minimum of 48 hours of rest was allowed between training sessions, and most subjects visited the laboratory on Mondays and Thursdays or Tuesdays and Fridays. If a subject missed two consecutive training sessions, he/she was removed from the study. As the subjects in this study were not familiar with the barbell deadlift, they all received individual instruction and verbal feedback regarding their exercise technique throughout the entire study. The subjects were taught to deadlift with their feet shoulder width apart, and their toes were pointed forward. The barbell barely touched the anterior portion of the leg, and the tibias were in a vertical position (i.e., the knees were not over the barbell). The subjects were instructed to keep their cervical spine in a neutral position throughout the range of motion. The arms were kept just outside of the thighs, and subjects were allowed to use either a pronated or an alternated grip. Special attention was paid to each subject's lower back, and the subjects were taught to perform the barbell deadlift with their lumbar spine in an extended position (Figure 1). Use of the Valsalva maneuver was encouraged. Weight belts and wrist straps were not permitted, but chalk was available and its use was recommended. Over the

course of the more than 700 training sessions that took place during this study, three injuries were reported.

Since repetition maximum testing for the barbell deadlift is not recommended for untrained individuals[21] and the majority of the subjects could not perform the exercise correctly upon enrollment, the training loads were not based on the results from strength assessments (e.g., percentage of a one-repetition maximum). Instead, we sought to determine the heaviest external load that could be used that allowed each subject to perform five sets of five repetitions with correct technique. To accomplish this, the males and females began their first training session with an external load of 61.4 and 29.5 kg, respectively, and weight was added based on the subject's ability to perform a set. Each training session began with two warm-up sets of five repetitions. Three minutes of rest were allotted between each set. As a means of progressive overload, 0.45-2.2 kg was added to the barbell for each training session. In the event that five repetitions within a set could not be completed, or if the exercise technique became compromised because of fatigue, 0.45-2.2 kg was removed from the barbell. If the subjects were unable to complete five repetitions for each of the five sets, a sixth set was allowed so that 25 repetitions could be performed. All of the subjects in the training group performed a total of 25 repetitions for each of the 20 training sessions.

Figure 2. Individual subject peak torque pretest-posttest change scores following ten weeks of barbell deadlift training. The thick dotted lines correspond to the mean values. The thin dotted lines show the data for the subjects that exceeded the minimal difference needed to be considered real statistic. Data for the control subjects have not been displayed.

Statistical analyses

Three separate two-way mixed factorial (group [males training, males control, females training, females control] x time [pre, post]) analyses of variance (ANOVAs) were used to examine the isometric peak torque data for the leg extension and flexion MVCs, as well as the isometric hamstrings-to-quadriceps strength ratio. Two separate three-way mixed factorial (group [males training, males control, females training, females control] x muscle [vastus lateralis, vastus medialis, rectus femoris] × time [pretest, posttest]) ANOVAs were used to examine the EMG amplitude values for the superficial quadriceps muscles during the leg extension (i.e., agonists) and flexion (i.e., antagonists) MVCs. Two separate two-way mixed factorial (group [males training, males control, females training, females control] × time [pre, post]) ANOVAs were used to examine the EMG amplitude values for the biceps femoris when it served as an agonist (i.e., leg flexion) and an antagonist (i.e., leg extension). When appropriate, follow-up analyses in-cluded two-way repeated measures ANOVAs, one-way ANOVAs, Bonferroni post-hoc comparisons, and paired samples t-tests. In addition, 95% confidence intervals (CIs) for mean differences, partial eta squared ($\acute{\eta}^2$), and Cohen's d statistics were examined. According to Stevens[22], partial eta squared values of 0.01, 0.06, and 0.14 correspond to small, medium, and large effect sizes, respectively. Cohen[23] described d values of 0.20, 0.50, and 0.80 as corresponding to small, medium, and large effect sizes, respectively. The reliability statistics reported in Table 1 are in accordance with the recommendations discussed by Vincent and Weir[24]. Notably, the minimal difference needed to be considered real was calculated as follows: standard error of measurement × 1.96 × 1.41. The primary advantage of the minimal difference needed to be considered real statistic is that it can be used for individual subject analyses in making determinations about whether a given change is meaningful. Individual subject peak torque responses have been displayed in Figure 2. An alpha level of .05 was used to determine statistical significance for all analyses.
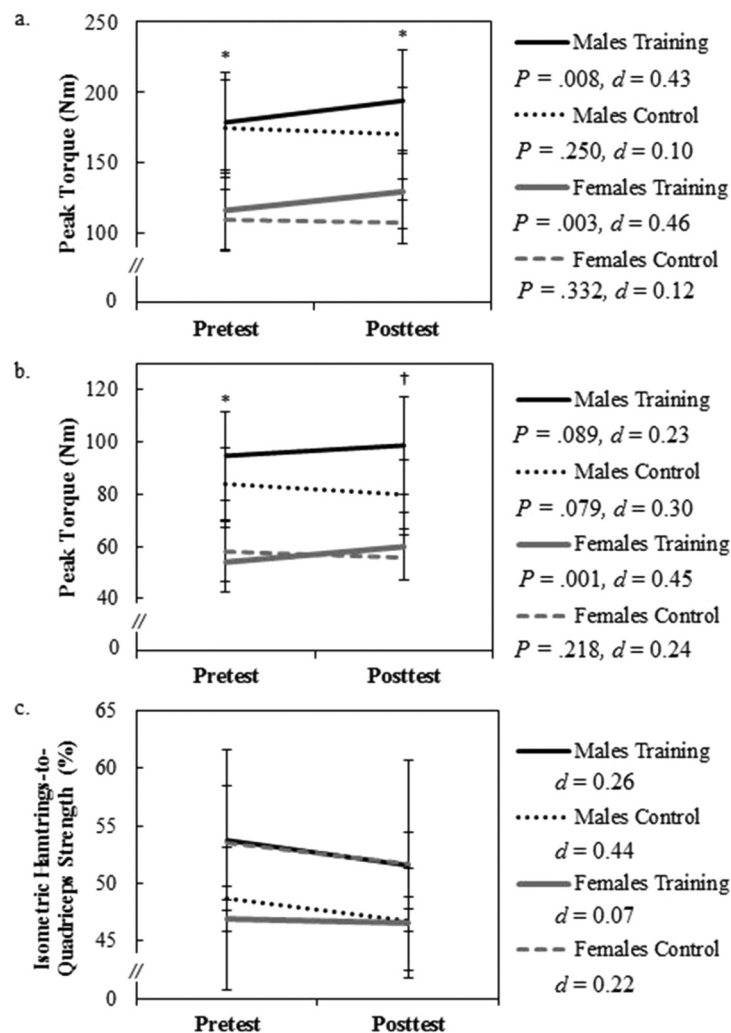
Figure 3. Mean±SD peak torque values for the (a.) leg extensors and (b.) flexors during isometric maximum voluntary contractions for the four groups before and after the barbell deadlift training intervention. The bottom graph (c.) displays the mean±SD leg isometric hamstrings-to-quadriceps strength ratios for each of the four groups. The significance level and/or Cohen's d effect size for each pretest-posttest analysis has been included with the legend. For the isometric hamstrings-to-quadriceps strength ratio, there was a main effect for group (males training >females training). *= males training and control >females training and control; †= males training >all other groups.

Results

### Leg extension peak torque

There was a significant group x time interaction (P=.003, $\acute{\eta}^2$=.238 [Figure 3a]). The follow-up one-way ANOVAs across the pretest and posttest data were statistically significant (P<.001), and for both analyses, the Bonferroni post-hoc comparisons indicated that the groups for the males (training and control) showed higher leg extension peak torque values than those for the females. The results from the four paired samples t-tests indicated that the mean leg extension peak torque values significantly increased for the males (P=.008, 95% CI for the mean difference=-26.1 to -4.6 Nm, d=0.43) and females (P=.003, 95% CI for the mean difference=-21.2 to -5.3 Nm, d=0.46) in the training group, but no changes were demon-

strated for the control subjects. For the training group, two males and four females demonstrated change scores that exceeded the minimal difference needed to be considered real (Figure 2).

Leg flexion peak torque

There was a significant group x time interaction (P=.002, $\acute{\eta}^2$=.248 [Figure 3b]). The follow-up one-way ANOVA across the pretest leg flexion peak torque data was significant (P<.001), and the Bonferroni post-hoc comparisons indicated that the groups for the males (training and control) showed higher leg flexion peak torque values than those for the females. The one-way ANOVA across the posttest data was also significant (P<.001), but the males in the training group demonstrated higher mean leg flexion peak torque values than
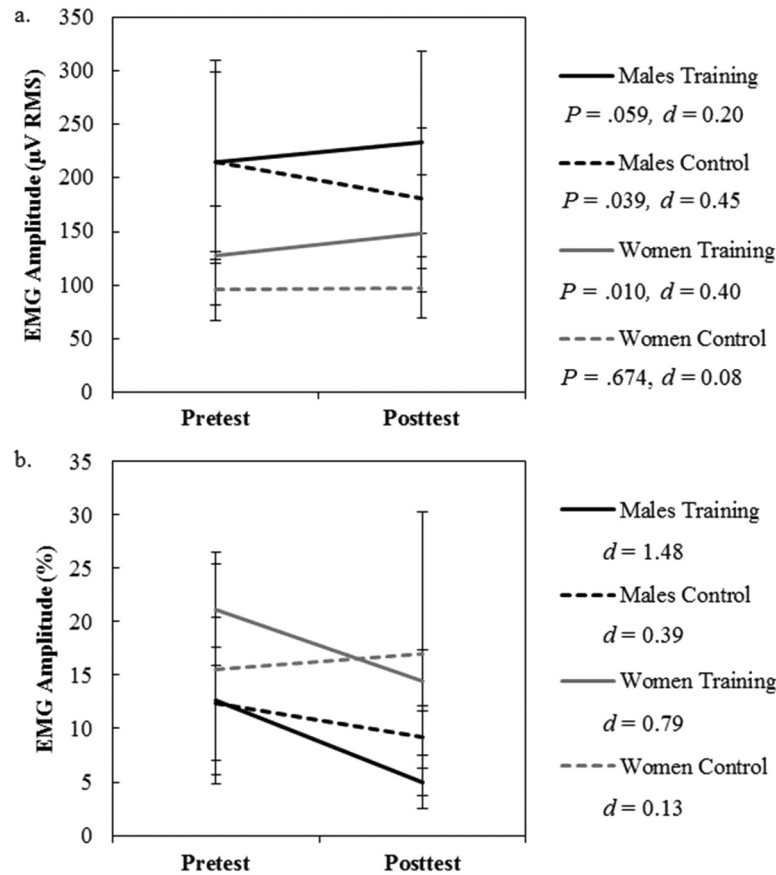
Figure 4. The top graph (a.) displays the mean ± SD pretest and posttest EMG amplitude values for the superficial quadriceps femoris muscles (collapsed across the vastus lateralis, vastus medialis, and rectus femoris) during unilateral, isometric leg extension MVCs. The data shown are reflective of absolute values (µV RMS). Data from the three muscles have been collapsed for this figure because their individual analyses provided no unique information. The bottom graph (b.) displays the mean±SD pretest and posttest EMG amplitude values for the biceps femoris when it served as an antagonist during the leg extension MVCs. The values are expressed as a percentage of EMG amplitude when the muscle served as an agonist. The significance level and/or Cohen's d effect size for each pretest-posttest analysis has been included with the legend.

the other three groups. The follow-up paired samples t-test for the males in the training group was not statistically significant (P=.089, 95% CI for the mean difference=-8.7 to 0.7 Nm), and the effect size was small/moderate (d=0.23). In contrast, the females in the training group demonstrated significant improvements in leg flexion peak torque (P=.001, 95% CI for the mean difference=-9.1 to -2.6 Nm, d=0.45). No changes in leg flexion peak torque were demonstrated for the control subjects. For the training group, one male and four females demonstrated change scores that exceeded the minimal difference needed to be considered real (Figure 2).

Isometric hamstrings-to-quadriceps strength ratio

There was no group x time interaction (P=.840, $\acute{\eta}^2$=.016) and no main effect for time (P=.089, $\acute{\eta}^2$=.057 [Figure 3c]). There was, however, a main effect for group (P=.016, $\acute{\eta}^2$=.185). When collapsed across time, the marginal mean for the males in the training group (52.7%) was significantly greater than the females in the training group (46.7%), but no

other differences were noted. For the males in the training group, one of the subjects exceeded the minimal difference needed to be considered real. None of the females demonstrated changes for this variable that exceeded the minimal difference needed to be considered real.

EMG amplitude for the superficial quadriceps femoris muscles during leg extension MVCs

There was no group × muscle × time interaction (P=.701, $\acute{\eta}^2$=.037 [Figure 4a]). There was, however, a group × time interaction (P=.001, $\acute{\eta}^2$=.283), as well as a main effect for muscle (P=.010, $\acute{\eta}^2$=.087). For muscle, when collapsed across both group and time, EMG amplitude for the vastus lateralis (174.7 µV RMS) was greater than that for the rectus femoris (148.4 µV RMS). The one-way ANOVA across the pretest scores was significant (P<.001), and the bonferroni post-hoc comparisons indicated that the mean EMG amplitude values for both groups for the males were significantly greater than those for the females. The one-way ANOVA across the posttest scores was
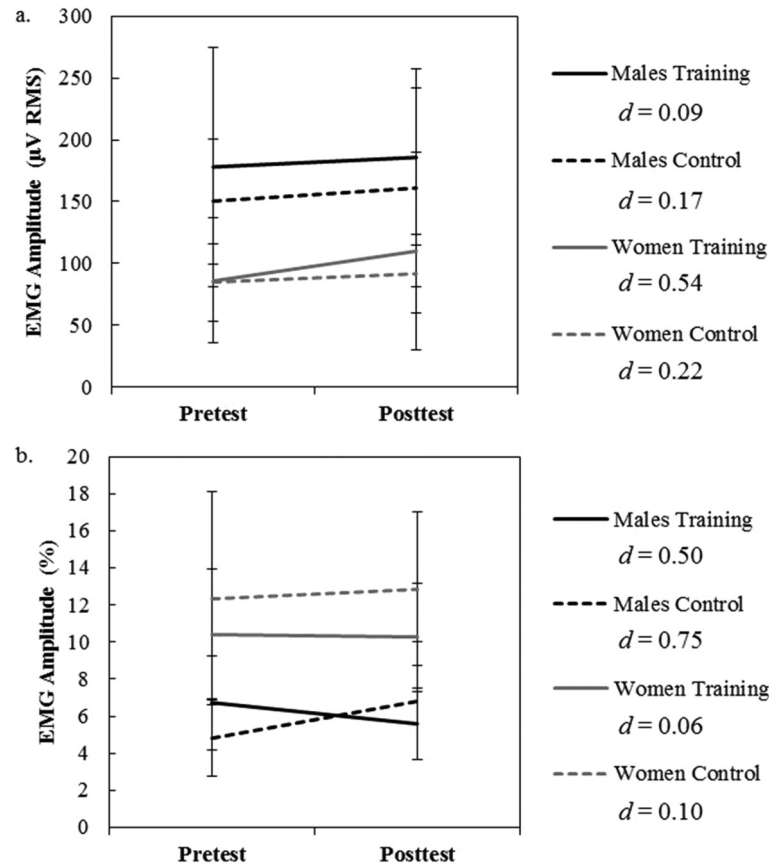
Figure 5. The top graph (a.) displays the mean ± SD pretest and posttest EMG amplitude values for the biceps femoris during unilateral, isomteric leg flexion MVCs. The data shown are reflective of absolute values (μV RMS). The bottom graph (b.) displays the mean±SD pretest and posttest EMG amplitude values for the superficial quadriceps femoris muscles (collapsed across the vastus lateralis, vastus medialis, and rectus femoris) when they served as an antagonists during the leg flexion MVCs. Data from the three muscles have been collapsed for this figure because their individual analyses provided no unique information. The values are expressed as a percentage of EMG amplitude when the muscles served as agonists. The Cohen's *d* effect sizes are displayed with the legends.

also significant ($P<.001$), and the bonferroni post-hoc comparisons were the same as those for the pretest (i.e., males training and males control > females training and females control). Follow-up paired samples *t*-tests indicated that the barbell deadlift training program significantly increased the EMG amplitude values for the superficial quadriceps femoris muscles for the females ($P=.010$, 95% CI for the mean difference= -34.7 to -5.6 μV RMS, $d=0.40$), but not the males ($P=.059$, 95% CI for the mean difference= -38.0 to 0.7 μV RMS, $d=0.20$). In addition, the control group for the males displayed significantly lower EMG amplitude values for the superficial quadriceps femoris muscles at posttesting ($P=.039$, 95% CI for the mean difference= 2.2 to 65.8 μV RMS, $d=0.45$).

EMG amplitude for the biceps femoris during leg extension MVCs

There was no group x time interaction ($P=.066$, $\acute{\eta}^2=.133$ [Figure 4b]). There were, however, main effects for both group ($P=.001$, $\acute{\eta}^2=.280$) and time ($P=.004$, $\acute{\eta}^2=.157$). For group, when

collapsed across time, the males in the training and control groups showed lower biceps femoris coactivation than both groups for the females. For time, when collapsed across group, biceps femoris coactivation decreased from the pretest to the posttest (15.4% for pretest, 11.4% for posttest). On the basis of the large $\acute{\eta}^2$ value for the interaction term, 95% CIs for the mean differences and Cohen's *d* values for the pretest-posttest changes were examined. The results were as follows: males training, 95% CI for the mean difference= 3.6 to 11.8%, $d=1.48$; females training, 95% CI for the mean difference= 2.1 to 11.3%, $d=0.79$; males control, 95% CI for the mean difference= -1.8 to 8.1%, $d=0.39$; females control (increased coactivation), 95% CI for the mean difference= -10.3 to 7.3%, $d=0.13$.

EMG amplitude for the superficial quadriceps femoris muscles during leg flexion MVCs

There was a significant group × muscle × time interaction ($P=.007$, $\acute{\eta}^2=.103$ [Figure 5a]). A follow-up two-way mixed factorial ANOVA demonstrated a significant group × time in-

teraction ($P<.001$, $\acute{\eta}^2=.274$). There was also a main effect for muscle ($P<.001$, $\acute{\eta}^2=.716$), and when collapsed across both group and time, the EMG amplitude values showed: vastus medialis (14.0%) > vastus lateralis (9.4%) > rectus femoris (7.0%). When collapsed across the three muscles, the one-way ANOVAs were not statistically significant (pretest [$P=.102$], posttest [$P=.062$]) suggesting that there were no mean difference among the four groups. Furthermore, the four separate paired samples t-tests indicated that there were no statistically significant changes from pretest to posttest for EMG amplitude for the superficial quadriceps femoris muscles during the leg flexion MVCs.

EMG amplitude for the biceps femoris during leg flexion MVCs

There was no group × time interaction ($P=.846$, $\acute{\eta}^2=.016$) and no main effect for time ($P=.149$, $\acute{\eta}^2=.041$ [Figure 5b]). There was, however, a main effect for group ($P<.001$, $\acute{\eta}^2=.372$). When collapsed across time, both groups for the males showed higher EMG amplitude values than those for the females.

Discussion

The most important finding of this study was that ten weeks of barbell deadlift training increased the isometric leg extension peak torque values in both sexes, and the effect sizes were moderate. Consistent with our hypothesis, a statistically significant increase in leg flexion peak torque was shown for the females, but not the males. As the peak torque values generally improved for both the leg extensors and flexors, the ratio for these variables did not change with training. Furthermore, the ten week barbell deadlift training program significantly increased the EMG amplitude values for the superficial quadriceps femoris muscles during the leg extension MVCs for the females. Muscle activity for the superficial quadriceps femoris muscles also increased for the males, but the change was trivial. For both training groups, large declines in biceps femoris coactivation were demonstrated following training ($d=1.48$ and 0.79 for males and females, respectively). Barbell deadlift training did not affect muscle activity during the leg flexion MVCs.

This study was the first to examine changes in leg extension or flexion strength following a training program that utilized barbell deadlifts in the absence of other exercises. The most similar study was performed by Holcomb et al.[7], who reported that the six week program resulted in a functional hamstrings-to-quadriceps strength ratio that was greater than 1.0, which is believed to be an important threshold for preventing ACL injuries in athletes[25]. Our peak torque data demonstrated at least three novel findings. First, when collapsed across sex, the barbell deadlift training program improved isometric leg extension peak torque to a greater extent than the results for leg flexion. While this may seem surprising given the fact that the barbell deadlift is often used to improve strength for the posterior thigh[1], we believe that this finding was due to issues related to training versus testing specificity. As displayed in Figure 1, the barbell deadlift is an exercise that involves extension at the knee and hip joints.

Thus, the vastus lateralis, vastus medialis, and vastus intermedius muscles are actively involved in the movement[13]. However, the barbell deadlift does not involve flexion at the knee joint during the concentric portion of the movement. Thus, the biarticular hamstring musculature primarily acts to extend the hip, and also serves as an antagonist to extension at the knee joint. While muscle function of the hip extensors during the barbell deadlift has not been adequately addressed in the literature, important insight can be gained from EMG studies performed by Basmajian[26] and Fujiwara and Basmajian[27]. Basmajian[26] examined needle EMG recordings from the proximal, middle, and distal portions of the rectus femoris, semitendinosus, and semimembranosus during extension or flexion at the knee or hip joints. The results indicated that the middle of each muscle demonstrated greater activity than both the distal and proximal ends, and it was concluded that two-joint muscles pull from end to end. Fujiwara and Basmajian[27] examined bipolar fine-wire EMG signals from the iliopsoas, rectus femoris, medial hamstrings, vastus medialis, and gluteus maximus while each subject lay supine with the leg suspended in a weighted sling. When extension occurred simultaneously at both the knee and hips joints (as is the case with the barbell deadlift), the following results were noted: [1] vastus medialis activity was higher than that for each of the other conditions, including monoarticular extension of the knee joint, [2] the gluteus maximus showed greater activity than the medial hamstrings, and [3] rectus femoris activity was minimal, likely because of antagonist inhibition. Similar findings for the rectus femoris and hamstrings were reported by Doorenbosch et al.[28], who studied muscle function during the act of standing up from a chair. Lastly, thought-provoking findings were reported by Yamashita[29], who examined EMG signals for the vastus medialis, rectus femoris, semimembranosus, and gluteus maximus during individual or combined extension at the hip and knee joints. In one of the experiments, the subjects were required to maintain a constant hip extension force while simultaneously activating their leg extensors. Doing so increased EMG amplitude for the monoarticular vastus medialis, but decreased activity for the hip extensors. Yamashita[29] speculated that his results were related to reciprocal Ia inhibition between antagonist biarticular muscles of the thigh, and that the central nervous system organizes hip extension in a manner that upholds monoarticular function of the knee. Based on the results from these studies[26-29], we concede that adaptations for the hamstrings would have been better studied with a hip extension assessment, rather than our leg flexion MVCs. Our second novel finding was that the increase in leg flexion peak torque was statistically significant for the females ($d=0.45$), but not the males ($d=0.23$). This could be explained by two factors. First, the pretest isometric hamstrings-to-quadriceps strength ratio was 53.7±7.9% and 46.9±6.2% for the males and females in the training group, respectively (Figure 3c). Thus, the leg flexors for the females were relatively weaker than those for the males at the beginning of the investigation. In addition, when sex differences for the barbell deadlift are considered, upper-body strength should not be disregarded. One of our observations was that as additional loads were added to the barbell during the latter weeks of the

study, many of the females had a difficult time completing the full range of motion. We speculate that many of the males may have had an easier time gradually adding weight to the barbell because of their greater strength for the trapezius, latissimus dorsi, and other muscles involved in retraction of the scapula. Finally, because barbell deadlift training improved peak torque for the leg extensors and flexors, the ratio of these variables was not affected. This is important because the hamstrings-to-quadriceps strength ratio is often cited as an important predictor of ACL injury[8,11,25], and as a result, researchers have studied the most effective means of improving leg flexor strength while disregarding the extensors[7]. However, it is important to note that the majority of studies that have examined this ratio were cross-sectional in nature[11,30], and previous authors have not been interested in changes during the course of a strength training program. We contend that while the hamstrings-to-quadriceps strength ratio is of value, absolute strength and performance during exercises that require multiple joints and muscles to function in a cohesive manner may be of equal or greater importance.

A unique feature of this investigation was the analysis of test-retest reliability statistics for the peak torque data. As discussed by Vincent and Weir[24], while the intraclass correlation coefficient is of value to researchers, it provides limited practical information. In contrast, the standard error of measurement and minimal difference needed to be considered real statistics offer researchers and practitioners with useful data that can be used to assess the effectiveness of an intervention. As shown in Figure 2, a relatively small number of subjects demonstrated changes in leg extension and flexion peak torque that could be considered meaningful. Unfortunately, we are unaware of investigations that have based decisions regarding the outcome of a strength training intervention using the minimal difference needed to be considered real. The fact that the intraclass correlation coefficients were somewhat high, combined with the significant mean pretest-posttest differences for leg extension peak torque for both sexes and leg flexion for the females, complicates the interpretation of these data. We contend that both group mean and individual subject analyses are of value, and encourage more widespread utilization of the minimal difference needed to be considered real statistic when interpreting pretest-posttest changes.

With respect to neuromuscular adaptations, our most noteworthy finding was that agonist muscle activation for the superficial quadriceps femoris increased for the females following barbell deadlift training. Furthermore, the data for the biceps femoris during the leg extension MVCs demonstrated that there was a main effect for time (pre>post), and the pretest-posttest effect sizes for the males and females in the training group were large. In fact, the effect sizes for the declines in EMG amplitude for the biceps femoris when it served as an antagonist were greater than any of the other analyses. Based on the fact that the amplitude of the EMG signal likely reflects the recruitment and firing rates of individual motor units[13], we conclude that ten weeks of barbell deadlift training [1] increased neural drive to the vastus lateralis, vastus medialis, and rectus femoris, particularly for the females, [2] decreased activity for the biceps femoris when it served as an antagonist to leg extension torque,

and [3] had no significant influence on EMG amplitude for each of the four muscles during the leg flexion MVCs. For the superficial quadriceps femoris muscles, our results are in agreement with previous training studies that have demonstrated increased EMG amplitude values for agonists[16,31]. They are also in agreement with investigations that have reported antagonist inhibition following training[15,16]. However, our analysis of a multi-joint barbell exercise was unlike previous studies that utilized comparable training and testing methods, such as the work by Carolan and Cafarelli[15] and Beck et al.[18].

As is the case with all research designs, our investigation had limitations. First, it should be noted that the adaptations that occur as a result of strength training are specific to imposed demands, and changes in any of the acute program variables may have produced different findings. Our results are specific to a barbell deadlift training program that involved two sessions per week, five sets for each training session, three minutes of rest between each set, and loads that corresponded to a rigorous five repetition set. As described previously, the external loads used in this study were not based on the results from repetition maximum testing, and we acknowledge that there may have been a degree of subjectivity in determining the initial training loads. When designing this investigation, we contrasted a variety of approaches, and ultimately decided that repetition maximum strength testing of untrained subjects for an exercise that could result in significant injury should be avoided. A viable alternative approach may have been to spend several weeks introducing the barbell deadlift to each of the subjects, and then perform repetition maximum testing so that precise external loads could be selected. Nonetheless, our approach was effective at eliciting improvements in muscular strength. Lastly, one of the perplexing aspects of our results was the statistically significant decrease in EMG amplitude for the superficial quadriceps femoris muscles for the males in the control group. Upon closer examination of the data, when collapsed across the three muscles, the pretest-posttest change scores for this group showed a very high degree of variability, as the coefficient of variation was greater than 100%. In particular, two of the subjects displayed considerably lower posttest scores for both EMG amplitude and leg extension peak torque. We speculate that these results may have reflected nonmaximal efforts during the posttest by the male subjects in the control group.

In summary, our findings demonstrated that when performed in the absence of other strength training exercises, a ten week barbell deadlift training program significantly improved leg extension peak torque in previously untrained males and females. For the leg flexion MVCs, greater improvements were shown for the females. When examined on an individual subject basis, the majority of the subjects exhibited pretest-posttest change scores that did not exceed the minimal difference needed to be considered real, which presents a bit of a statistical quandary. Our results also demonstrated neuromuscular adaptations to barbell deadlift training, as evidenced by the increased EMG amplitude values for the muscles during the leg extension MVCs that were accompanied by decreased coactivation for the biceps femoris. We conclude

that a simple, ten week barbell deadlift training program was an effective means of eliciting improvements in unilateral, isometric strength and neuromuscular adaptations in previously untrained individuals, and particularly, in novice females.

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