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MUSCLE ACTIVATION PATTERNS OF LOWER-BODY MUSCULATURE AMONG 3 TRADITIONAL LOWER-BODY EXERCISES IN TRAINED WOMEN

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ABSTRACT

Korak, JA, Paquette, MR, Fuller, DK, Caputo, JL, and Coons, JM. Muscle activation patterns of lower-body musculature among 3 traditional lower-body exercises in trained women. *J Strength Cond Res* 32(10): 2770–2775, 2018—The deadlift and back and front squats are common multijoint, lower-body resistance exercises that target similar musculature. To our knowledge, muscle activity measured using surface electromyography has never been analyzed among these 3 exercises. Furthermore, most literature examining this topic has included male participants creating a void in the literature for the female population. Knowledge of lower-body muscle activation among these 3 exercises can aid coaches, trainers, and therapists for training and rehabilitative purposes. Trained women ($n = 13$) completed 2 days of testing including a 1-repetition maximum (1RM) estimation, an actual 1RM, and 3 repetitions at 75% 1RM load for the deadlift and back and front squats. Muscle activity of the 3 repetitions of each muscle was averaged and normalized as a percentage to the 1RM lifts for the deadlift and front and back squats. Five separate repeated-measure analysis of variances were performed indicating muscle activity of the gluteus maximus (GM) differed among the 3 exercises ($p = 0.01$, $\eta_p^2 = 0.39$). Specifically, post hoc analysis indicated greater muscle activity during the front squat (M = 94%, $SD = 15\%$) compared with the deadlift (M = 72%, $SD = 16\%$; $p \leq 0.05$) in the GM. No significant differences were observed among the lifts in the vastus medialis, vastus lateralis, biceps femoris, and rectus femoris. Strength and conditioning specialist and trainers can use these findings by prescribing the front squat to recruit greater motor units of the GM.

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INTRODUCTION

Strength and conditioning coaches routinely recommend squat variations and deadlift exercises to target lower-body musculature because of large muscle recruitment, use of multiple joints, and similarities to activities of daily living (9). Squat variations and deadlift exercises are used interchangeably in training because of a belief that they have similar lifting characteristics and produce comparable training results (12). However, Hales et al. (12) states that the technique of the lifts is different.

The 2 common forms of the squat exercise are the front and the back squat. Gullett et al. (11) stated that greater muscle activation can be found in the distal quadriceps during the front-squat exercise compared with the back-squat exercise, and the front squat requires lower muscular force in the lower back. However, empirical evidence of muscle activity using surface electromyography (EMG) is lacking to support this conclusion. Previous research has indicated that loads placed on the front of the body produce significantly higher lumbar paraspinal muscle activity in comparison with loads placed on the back of the body (8). To our knowledge, only 3 studies have included an examination of muscle activation patterns of the lower body for the front- and back-squat exercises. Gullett et al. (11) found no significant differences in muscle activity of the rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), biceps femoris (BF), semitendinosus (ST), and erector spinae (ES) between the front- and back-squat exercises during 2 sets of 3 repetitions of a 70% of 1-repetition maximum (1RM) load. Some authors have rationalized that the lack of muscle activity differences was due to the relatively low submaximal load that was used in this study (5). Contreras et al. (7) found no statistical differences in muscle activity among a front squat, parallel, and full squat when examining the BF, VL, and upper and lower gluteus maximus (GM) with a 10RM load in healthy women. Finally, Yavuz et al. (24) found higher muscle activity in the VM in the front squat compared with back squat but greater muscle activity in the ES during the back squat with a 1RM in trained men.

Likewise, there are limited data on muscle activity differences between squat and deadlift exercises. Lumbar-sacral ES and upper lumbar ES muscle activity are greater during 80% 1RM-squat and deadlift exercises in comparison with superman and side-bridge exercises, with no difference between the squat and the deadlift (13). Furthermore, Barnes et al. (2) found no significant differences in quadriceps muscle activity between a back squat and deadlift while performing 8 sets of 2 repetitions at 95% 1RM load in trained men. Understanding lower-body muscle activation patterns between squat variations and the deadlift exercise is important for strength and conditioning professionals, trainers, and therapists who want to isolate or create greater activation of selected lower-body muscles for training adaptions, performance increases, injury prevention, or rehabilitation techniques. Furthermore, most studies examining muscle activity during lower-body resistance training have included predominantly male participants leading a potential void in the literature for the female population (7). Finally, anthropometric and kinematic differences between sexes exist, so future research is needed to fill in this gap (18).

Therefore, the purpose of this study was to compare peak muscle activity of the VL, VM, RF, BF, and GM among the back squat, front squat, and deadlift in trained women at a 75% 1RM load. It was hypothesized because of unpublished data and previous literature that the front-squat and deadlift exercises would elicit higher muscle activity of the VL, VM, and RF in comparison with the back squat. Furthermore, it was hypothesized that the back squat would produce greater muscle activity of the GM.

Methods

Experimental Approach to the Problem

A repeated-measures, within-subject design was used to determine how the VM, VL, BF, RF, and GM muscles activate using EMG among a back-squat, front-squat, and deadlift exercise. To examine our hypothesis, muscle activity was measured on trained women while completing both a 1RM and 3 repetitions at 75% 1RM load for the back-squat, front-squat, and deadlift exercises. All EMG data were obtained in the same testing session eliminating the possibility of day-to-day fluctuations and improper reapplication of EMG electrodes.

Subjects

Trained women ($n = 13$) participated in the study ($\pm$ *SD* 22.8 $\pm$ 3.1 years, range 21-28; 166.4 $\pm$ 4.2 cm; 73.4 $\pm$ 14.0 kg). All participants had a minimum of 1-year lifting experience and had been actively participating in resistance training for 6 months before beginning the study (11). Furthermore, participants were asked to refrain from alcohol consumption and lower-body resistance training 48 hours before testing. This study was approved by the Middle Tennessee State University Institutional Review Board (#17-2023). Participants were informed of the benefits and risks of the investigation before signing an institutionally approved informed consent document to participate in the study.

Procedures

Participants were required to attend 2 sessions, which included a familiarization session and a training session. Session 1 included completion of all required paper work and anthropometric measurements. Height was assessed using a stadiometer (Model 222; SECA Corporation, Hamburg, Germany) to the nearest 0.1 cm, whereas body mass was measured to the nearest 0.1 kg using a digital scale (Model 770; SECA Corporation). Anthropometric measurements were taken with participants wearing gym shorts and a t-shirt, without shoes. Furthermore, participants completed practice repetitions for the deadlift, front-squat, and back-squat exercises with a standard size Olympic lifting bar with bumper plates. The session 1 repetitions were completed using relatively heavy loads (≤5 repetitions) to gather

Table 1. Electromyography electrode placement.

Muscle	Electrode placement
Vastus medialis	80% between anterior spina iliaca superior and joint space in front of the anterior border of medial ligament.
Vastus lateralis	Two-thirds from anterior spina iliaca superior to lateral patella.
Biceps femoris	50% between ischial tuberosity and lateral epicondyle of tibia.
Gluteus maximus	50% on the line between sacral vertebrae and greater trochanter.
Rectus femoris	50% from anterior spina iliaca superior to superior part of the patella.

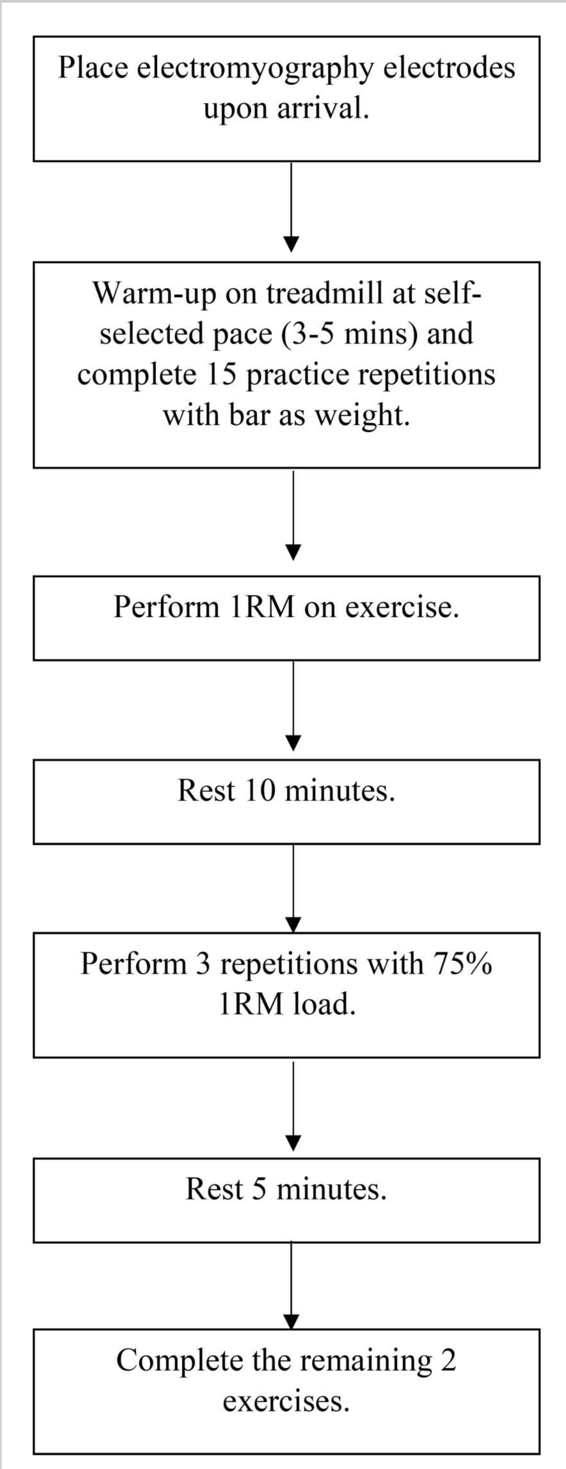

Figure 1. Participant flow chart for the testing protocol in a counterbalanced order performing the back-squat, front-squat, and deadlift exercises.

estimates of participants' 1RM for the 3 exercises using a training load estimation table (20).

Participants returned for the second session 3 to 4 days later to assess muscle activity during the 3 exercises. On arrival, EMG electrodes were secured to the skin using double-side adhesive tape over the VL, VM, RF, BF, and GM muscles on each participants' dominant leg (i.e., leg used to kick a soccer ball). Electrode placement locations are outlined in Table 1 (14). Hair was shaved from the electrode sites, when necessary, and the skin was exfoliated with redux paste before placement of the electrodes to reduce signal impedance. Adhesive stretch covering was placed over top of each electrode to further secure the electrodes to the skin. Participants were then asked to warm-up by walking on a treadmill at a self-selected pace for 3–5 minutes. Participants then performed 15 repetitions for each exercise with a standard Olympic weight bar. The electrode signals were checked while participants completed the warm-up. In a randomized order, participants completed a 1RM of either the deadlift, front-squat, or back-squat exercise followed by the measurement trials at 75% 1RM. Each 1RM was obtained in 3 or fewer attempts. The first 1RM attempt was with the starting load obtained from the National Strength and Conditioning Association (NSCA) 1RM estimation table gathered during session 1 (20). If an attempt was completed with ease successfully, 5-minute rest was given and weight was increased until a valid 1RM was obtained (20). However, if the participants' 1RM attempt was unsuccessful, the weight was reduced and the attempted was tried again until successful (20). Once the 1RMs were determined, participants were given 10 minutes of rest before performing the set of 3 repetitions at 75% 1RM for the first exercise (23). Repetitions were performed at a pace of 2 seconds for the eccentric action and 1 second for the concentric action with a 2-second pause between repetitions set by a metronome (13). Once the 1RM and 3 repetitions were completed for one exercise, participants were given 5-minute rest before moving to the next exercise (Figure 1).

Surface EMG was obtained during both the 1RM and 3 repetitions at 75% 1RM for all 3 exercises using a wireless EMG system (Trigno; Delsys, Natick, MA, USA). Participants were required to complete each repetition during the front- and back-squat exercise with feet shoulder width, toes facing forward, and to descend until thighs were parallel with the floor. A bungee cord was placed at parallel height for each participant who descended until the buttocks touched the cord for the repetition to count. A high bar placement across the posterior deltoids at the middle of the trapezius was used with the back squat while either a parallel- or crossed-arm position, according to participants' preference, was used with the front squat (20). The deadlift exercise was performed according to NSCA guidelines (20). A Certified Strength and Conditioning Specialist collected all data and ensured proper technique throughout all repetitions.

Table 2. Participants' 1RM and training loads (n = 13).*

Characteristic	M	±*SD*
Back-squat 1RM (kgs)	78.0	13.4
Back-squat TL (kgs)	56.2	10.2
Front-squat 1RM (kgs)	60.7	13.8
Front-squat TL (kgs)	45.5	10.3
Deadlift 1RM (kgs)	84.5	13.5
Deadlift TL (kgs)	63.7	10.2

*1RM = 1-repetition maximum; TL = training load of 3 repetitions at 75% 1RM.

Data Processing. Surface EMG data were band-pass filtered with high-pass and low-pass cut-off frequencies of 20 and 450 Hz, respectively, with a sampling rate of 2,000 samples per second (24). The data were then full-wave rectified and smoothed using a root mean square (RMS) filter with a moving window of 250 ms (24). The peak RMS signals of the 3 repetitions of each muscle during the total exercise period were averaged and normalized as a percentage of the peak RMS signals obtained during the 1RM lifts for the deadlift, front squat, and back squat, respectively (16). A repetition included the eccentric and concentric portions of each exercise.

Statistical Analyses

Five separate one-way repeated-measures analysis of variance (ANOVA) using Hyunh-Feldt adjustment with exercise type as the within-subject factor (back squat, front squat, and deadlift) were conducted for each of the 5 muscles (VL, VM, RF, BF, and GM) to compare muscle activity among the exercises. Post hoc analysis included the Sidak procedure. An alpha level was set at 0.05 for all statistical procedures. Effect sizes were calculated for all analysis performed using partial eta squared (η^2). Outlier muscle activity data were removed for statistical analysis if recordings were greater or less than ±2 *SD* from the mean (1). Removed outlier data still met required power analysis.

Results

Descriptive statistics for 1RM and the 3 repetition training loads are shown in Table 2. A total of 3 participants' muscle activity were removed from the statistical analysis for the RF muscle, 2 were removed from the VL muscle, and 2 were removed from the GM muscle. Five separate one-way repeated-measures ANOVAs indicated no significant differences were found in muscle activity for the VM, $F(2,18) = 0.49$, mean square of

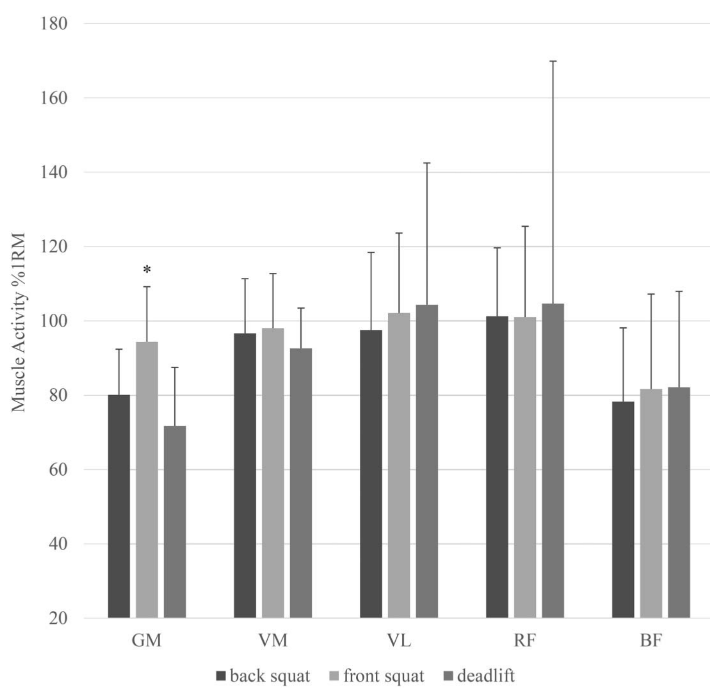

Figure 2. Muscle activity among the deadlift, front squat, and back squat as a percentage of the 1RM. *Front squat > deadlift ($p \leq 0.05$); 1RM = 1 repetition maximum; GM = gluteus maximus; VM = vastus medialis; VL = vastus lateralis; RF = rectus femoris; BF = biceps femoris.

the error = 0.02, $p = 0.62$, $\eta_p^2 = 0.05$, the VL, $F(1.6, 16.1) = 0.16$, MSE = 0.11, $p = 0.81$, $\eta_p^2 = 0.02$, the BF, $F(2,24) = 0.08$, MSE = 0.07, $p = 0.92$, $\eta_p^2 = 0.01$, or the RF, $F(1.1, 13.3) = 0.03$, MSE = 0.33, $p = 0.89$, $\eta_p^2 < 0.01$. However, muscle activity of the GM differed among exercises, $F(1.7, 17.3) = 6.46$, MSE = 0.03, $p = 0.01$, $\eta_p^2 = 0.39$. Post hoc analysis indicated that muscle activity was greater for the GM during the front-squat exercise compared with the deadlift exercise ($p = 0.04$).

Discussion

In this study, we compared muscle activity of the VL, VM, RF, BF, and GM while completing the back-squat, front-squat, and deadlift exercises in trained women. Contrary to our hypothesis, the primary finding is that GM muscle activity was greater during the front-squat exercise in comparison with the deadlift exercise (Figure 2).

Although both the squat and deadlift are lower-body multijoint exercises, Hales et al. (12) state that the technique of the lifts are different. The NSCA describes the lowest depth of the deadlift as the thighs being above parallel to the floor, whereas the lowest depth of the front squat is described as the thighs being parallel to the floor (20). Caterisano et al. (4) reported that as squat depth increased because of greater hip flexion from a partial squat to a full squat, muscle activity of the GM also increased. Furthermore, Kang et al. (15) indicated VM and VL muscle activity increased as hip-flexion angle increased. A possible explanation for the greater GM muscle activity during the front squat is related to the larger hip flexion leading to a greater external lever arm of the external load in comparison with the deadlift. Interestingly, though, there was no statistical difference in the GM between the back and front squat. However, the frontal bar placement of the bar during the front squat will shift the center of mass forward on the participant (3). A larger sagittal plane lever arm of the external load to the hip joint would effectively increase the hip extensor torque required to counteract the external flexor torque, thus increasing muscular tension at different muscle lengths during the movement. Muscle spindles respond to changes in muscle tension and length of stretch and, when stimulated, initiate muscle contraction (21). It is possible that the front squat caused greater muscle spindle activation in the GM than the deadlift because of increased hip flexion of the lift and subsequent increased muscle fiber length and tension.

Synergistic dominance is defined as a neuromuscular phenomenon when synergist muscles dominate a weak or inhibited prime mover. This dominance can lead to arthrokinetic dysfunction and injury (6). A common example of synergistic dominance is thought to occur between the GM and the hamstring complex (19). If the GM is weak, the hamstrings will dominate the primary mover role, thereby placing disproportionate stress on the hamstrings and increasing the risk of injury. In a scenario of synergistic dominance, strength and conditioning specialists use resistance training exercises that optimally activate musculature to address muscular weakness and therefore, since the front squat elicited greater muscle activity of the GM compared with the deadlift, the front squat may be a more favorable exercise to target GM involvement. However, the current study used healthy trained participants, so future investigations should investigate this postulation with individuals with known weak GM muscles.

The great majority of previous literature examining lower-body muscle activity during a squat protocol has primarily included the back squat (9,12,13,22,23). Gullett et al. (11) found no difference in muscle activity between the front squat and the back squat with exercise loads of 70% 1RM, similar to the loads in the current study (i.e., 75% 1RM). The lack of difference in muscle activity across squat variations is likely linked to similarities in load placement location and to both variations requiring similar hip flexion. Furthermore, our findings of no differences in muscle activity among squat variations are in agreement with Contreras et al. (7), who also used all female participants, but are in disagreement with Yavuz et al. (24) who found higher muscle activity in the VM in the front squat compared with back squat and higher muscle activity of the ST during the back squat vs. front squat. However, Yavuz et al. (24) used a 1RM load while the current study used a load of 75% 1RM indicating muscle activity will differ between the squat variations as load intensity increases.

The lack of muscle activity significance in the 3 examined quadriceps muscles (VM, VL, and RF) among the 2 squat variations and deadlift was surprising since Yavuz et al. (24) found a difference among these muscles while Gullett et al. (11) did not. Hales et al. (12) concluded that the deadlift and squat exercise differ in 3 specific ways: the squat is a simultaneous movement while the deadlift is a segmented movement; both lifts require different joint movements; and the squat and deadlift pose different trunk configurations, although no muscle activity was measured. However, the findings Hales et al. (12), and Caterisano et al. (4) further support our findings of greater GM muscle activity in the front squat compared with the deadlift likely from increased hip flexion during the squat movement. Furthermore, greater hip flexion during the front squat and back squat causes a greater external lever arm resulting in higher demand for the hip flexors to contract (GM) in comparison with the deadlift exercise. Because the front squat has a frontal load placement vs. the back squat having rear load placement, the front squat would have an even greater external lever arm in comparison with the back squat, which likely lead to the differences observed in GM muscle activity between the front squat and deadlift. Finally, the current findings are in agreement with Barnes et al. (2) who found no differences in muscle activity of the VM and VL between a back squat and deadlift while performing 8 sets of 2 repetitions with 95% 1RM load in trained men. However, Barnes et al. (2) did not measure the RF, BF, and GM muscles.

It is not uncommon when researching muscle activity using EMG to have testing data greater than the maximal voluntary isometric contraction reference point (7,11,17). One interesting finding of the current study is that some muscles during the 3 exercises produced greater muscle activity during the 3 repetitions at a 75% 1RM load than the 1RM trial (Figure 2). It is plausible that there was more activation of stabilizing and accessory musculature during the 1RM than during the 3 repetitions at a 75% 1RM load. This could mean that there was more primary mover activation during the lower load trials (75% 1RM), but higher total motor unit recruitment during the 1RM and recruitment of additional muscle groups synergistic to the GM. However, stabilizing and accessory muscles were not examined, and future studies are needed to corroborate this postulation. Finally, multiple studies have examined muscle activity between a front and back squat during the ascending and descending phase, with the ascending phase eliciting greater EMG data consistently (11,24). However, since this is the first study to the authors' knowledge of its kind, future studies should examine muscle activation patterns during the front squat, back squat, and deadlift during the ascending and descending phase.

Practical Applications

The front-squat exercise elicited greater muscle activation of GM compared with the deadlift exercise likely due to greater hip flexion equating to a greater external lever arm of the external load and subsequent higher muscle spindle activation. If a client or athlete has a weak GM muscle, strength and conditioning specialist and trainers can use these findings by prescribing the front squat to recruit greater motor units of the GM possibly reducing the likelihood of synergistic dominance that can result in arthrokinetic dysfunction and injury.

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The authors have no conflicts of interest to disclose.

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