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Abstract

Mehls, K, Grubbs, B, Jin, Y, and Coons, J. Electromyography comparison of sex differences during the back squat. *J Strength Cond Res* XX(X): 000–000, 2020—Currently, there is limited information regarding the muscle activity differences between men and women during the traditional back squat. The back squat is a widely used exercise which stimulates lower-body musculature; thus, information regarding the muscle activity patterns during this exercise is pertinent when prescribing resistance training. This study evaluated muscle activity differences (using surface electromyography) in men and women during the traditional back squat with a load prescribed to elicit strength gains. Resistance-trained men ($n = 14$) and women ($n = 14$) performed 3 sets of 4 repetitions in the traditional back squat using 85% of their pretest 1 repetition maximum. Muscle activity data were collected for 6 muscles including the vastus lateralis, vastus medialis, rectus femoris, gluteus maximus, semitendinosus, and biceps femoris (BF). Independent sample t tests revealed a significantly higher normalized muscle activity men in the BF muscle during the descending phase of the back squat. No other muscle activity differences were present between men and women. These results indicate that men activate the BF muscle during the traditional back squat to a greater extent than women. For women, it may be necessary to consider other exercises to optimally stimulate and strengthen the BF muscle during resistance training.

Key Words: muscle activity, sex comparison, resistance training

Introduction

The National Academy of Sports Medicine describes a muscle imbalance as an irregular length of muscles around a joint causing dysfunction at the joint (3). The alterations in muscle length cause some muscles to be overactive and others to be underactive, resulting in movement pattern compensations that increase the risk of knee injury (3). Quadriceps dominance is a neuromuscular imbalance where the quadriceps musculature is recruited to stabilize the knee joint as opposed to recruiting the posterior chain (7). This imbalance seems to occur more often in female athletes than male athletes and is believed to contribute to the high rate of anterior crucible ligament (ACL) injuries in women (2,7–9).

Two studies compared the muscle activation of the anterior and posterior chains between men and women during a single leg squat. Electromyography (EMG) analysis indicated that recreational and collegiate female athletes use significantly greater muscle activation in the quadriceps for knee joint stabilization than their male counterparts (18,21). It has been suggested that the increased use of the quadriceps for knee stabilization during a single leg stance position may place a greater amount of shear force on the ACL and result in a higher knee injury rate (18). Hewett et al. suggest that to correct quadriceps dominance in women and reduce the rate of ACL injury, training programs must be designed to optimize the activation and strengthening of the posterior chain.

The traditional back squat is frequently used in training programs to activate and strengthen both the anterior and posterior chain (6). It has been shown that men and women do adopt different movement patterns during the traditional back squat, which could initiate the activation of different musculature during squat execution and have exercise prescription implications (12,19). Currently, the physiological explanation for this disparity is unknown because analysis from the aforementioned study was limited to the kinematic variables of the back squat and reports of the muscle activation patterns of women during the traditional back squat are sparse (4). Lynn and Noffal (11) compared muscle activity between recreationally trained men and women (23 years) and reported greater muscle activation in the posterior chain of women compared with men during both a regular and counterbalanced squat. However, squats were limited to loads which could be held at 90° of flexion with the shoulders, thereby limiting the overload capacity of the squat movement pattern. Because these results contradict those of Youdas et al. (2007) and Zeller et al. (21), further investigation into muscle activity differences between men and women is required.

Muscle activity data allow practitioners to prescribe exercise based on muscles isolated during a movement. Despite its wide use in training programs, little data exist about the muscle activity differences of men and women in the back squat. Therefore, the purpose of this study was to compare the muscle activation differences in the vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), gluteus maximus (GM), semitendinosus (ST), and biceps femoris (BF) muscles between recreationally active men and women during a traditional back squat using EMG. It was hypothesized that women would display a relatively greater amount of muscle activation in the anterior chain to complete the traditional back squat when compared with men.

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Methods

Experimental Approach to the Problem

To compare the muscle activity differences between sexes during the back squat, resistance-trained men and women completed 3 sets of the back squat using 85% of their 1 repetition maximum (1RM). Electromyography data were collected on the VL, VM, RF, GM, ST, and BF for comparison. Dependent variables included the average peak muscle activity of each muscle during the 3 sets of the back squat.

Subjects

Resistance-trained men (mean ± *SD*: $n = 14$; age: 23.71 ± 3.02 years; height: 179.94 ± 6.61 cm; body mass: 86.03 ± 9.10; 1RM: 138.79 ± 25.77) and women ($n = 14$; age: 20.64 ± 1.45 years; height: 169.06 ± 8.74 cm; body mass: 77.85 ± 17.51; 1RM: 82.86 ± 22.40) participated in the study. Subjects were required to have 1 year of resistance training experience and be actively performing the traditional back squat in training for the past 3 months. Subjects were recruited from the student population at the university via word of mouth. Subjects who were currently suffering or recovering from an orthopedic injury that prevented them from completing the movement were excluded from the study. All subjects were informed of the benefits and risks of the training protocol and signed an informed consent document before participation in the study. This study was approved by the Middle Tennessee State University Institutional Review Board before data collection (#18-2182).

Procedures

Subjects were required to attend 2 training sessions. The sessions were spaced a minimum of 48 hours apart, and subjects were asked to refrain from lower-body resistance training and alcohol consumption for 48 hours before each session. During the first session, anthropometric measures were taken with subjects wearing t-shirts, socks, and gym shorts. Height was assessed to the nearest 0.1 cm using a stadiometer (SECA Corporation, Model 222, Hamburg, Germany), and body mass was determined using a digital scale (Tanita Worldwide, Model BF 522; Arlington Heights, IL) to the nearest 0.1 kg. After measurements were taken, subjects prepared for a 1RM test by completing a warm-up that consisted of a 3-minute row on an ergometer (Concept II) followed by 2 sets of 15 meters of each of the following: high knees, butt kicks, lunges, and high leg kicks. After the warm-up, subjects squatted a weight that could be achieved 15 times. One repetition maximum was then determined using guidelines from the National Strength and Conditioning Association (6).

Upon arrival for the second session, the subjects' skin was prepared by exfoliation with redux paste and hair was removed, when necessary, to reduce signal impedance. Electromyography electrodes were attached to the skin using double-sided adhesive tape and secured to the skin using adhesive stretch covering. Electrodes were placed on the VL, VM, RF, GM, ST, and BF of the subjects' right leg using locations provided by SENIAM. Electromyography data were obtained using a wireless surface EMG system (Tringo; Delsys, Natick, MA). In addition, an electrogoniometer (Biometrics LTD, Newport, United Kingdom) was placed on the right hip and knee joint of the subject to monitor the joint angle of the subjects and differentiate between the descending and ascending phases of the lift. Subjects then completed the same warm-up used in session 1.

After a 2-minute rest period, 2 maximal voluntary isometric contractions (MVICs) were performed with 1 minute of rest between contractions for each muscle. For the VL, RF, and VM, subjects were seated plyometric box high enough so their foot did not contact the ground and asked to push against manual pressure applied just above the ankle in the direction of knee flexion. The GM was tested with the subject laying prone on a mat and lifting the entire leg upward while manual resistance was applied just above the knee. Finally, the BF and ST were tested with the subject lying prone on a mat with the knee bended at approximately 45° while manual pressure was applied at the ankle in the direction of knee extension (15).

Subjects warmed-up using progressively heavier loads on a standard Olympic barbell and were instructed to squat with the bar placed across the posterior deltoids and descend until the tops of their thighs were parallel with the ground (6). A bungee cord was placed at this parallel squat depth, and subjects were required to touch the bungee with their buttocks on each rep before ascending. When the subject was ready, 85% of their 1RM was placed on the barbell, and the subjects completed 3 sets of 4 repetitions. Speed of the movement was controlled using a metronome so that the descending portion was 2 seconds and the ascending portion was 1 second, and a 2-minute rest period was provided between each set. Electromyography data were collected for all sets.

Data Processing. All EMG data were normalized to the MVIC data collected for each subject to represent muscle activation of each muscle as a % of MVIC. A band-pass filter was applied to the EMG signal with cutoff frequencies of 20 and 450 Hz (10), and data signals were full-wave rectified and smoothed using a root-mean-square filter with a moving window of 250 ms (1,10). Goniometer data were analyzed using a time-shift calculation script set to 0 seconds. The peak amplitude for each repetition was used to calculate the average peak amplitude for each set to be used in the statistical analysis. Using goniometer data, each repetition was visually inspected for the point which the subject reached 90° of flexion so that a peak amplitude could be calculated for both the ascending and descending phase of the back squat. All data processing was performed using EMG-worksanaylsis software (Model SC-S08-4.5.3; Delsys) and Microsoft excel (2016).

Statistical Analyses

All statistical analyses were performed using IBM SPSS Statistics 24 (Armonk, NY). For each set of the 6 muscle groups (VL, RF, VM, GM, BF, and ST), 2 independent-sample t tests were used to compare the averages between men and women: one for descending peak and one for ascending peak. For all t tests, an alpha level was set to 0.05. Effect sizes were calculated for all t tests using Cohen's d with pooled standard deviations (5).

Results

Descriptive statistics for normalized muscle activity are presented in Table 1. Men displayed a significantly higher amount of muscle activity in the BF during the descending phase of the squat in all 3 sets: set 1 $t(26) = 2.33$, $p = 0.028$, $d = 0.89$ (95% confidence interval [CI] 0.01–1.59), set 2 $t(26) = 3.85$, $p = 0.001$, $d = 1.46$

Table 1
Normalized muscle activity in men vs. women.*

	Set 1				Set 2				Set 3			
	Men		Women		Men		Women		Men		Women	
Muscle	M	*SD*	M	*SD*	M	*SD*	M	*SD*	M	*SD*	M	*SD*
VL												
DSC	0.65	0.38	0.85	0.64	0.71	0.50	0.80	0.58	0.71	0.42	0.79	0.55
ASC	0.83	0.51	0.96	0.59	0.93	0.62	0.95	0.69	0.87	0.56	0.92	0.57
RF												
DSC	2.18	2.80	2.06	1.21	1.97	1.90	1.76	0.78	2.22	2.04	1.80	0.73
ASC	2.60	3.73	2.34	1.68	2.08	1.96	1.87	0.92	2.20	1.82	1.82	0.71
VM												
DSC	2.91	1.87	2.70	2.04	2.92	1.96	2.65	1.96	2.80	1.99	2.60	1.78
ASC	3.72	2.40	3.22	2.12	3.59	2.35	3.13	2.40	3.52	2.38	3.17	2.05
GM												
DSC	0.41	0.28	0.64	0.62	0.41	0.28	0.53	0.34	0.41	0.31	0.51	0.30
ASC	0.96	0.62	1.21	0.96	0.91	0.61	1.12	0.87	0.95	0.71	1.10	0.78
BF												
DSC	1.42	1.00	0.57	0.91†	1.44	1.08	0.31	0.18†	1.30	0.97	0.44	0.42†
ASC	1.82	1.35	1.15	2.02	1.70	1.22	1.31	2.79	1.65	1.27	1.51	3.29
ST												
DSC	0.23	0.10	0.22	0.13	0.21	0.11	0.22	0.14	0.22	0.09	0.24	0.16
ASC	0.35	0.15	0.49	0.31	0.34	0.15	0.44	0.25	0.36	0.13	0.49	0.37

*VL = vastus lateralis; RF = rectus femoris; VM = vastus medalis; GM = gluteus maximus; BF = biceps femoris; ST = semitendinosus; DSC = descending phase; ASC = ascending phase.
†Significant group difference between men and women during that set; $p < 0.05$.

(95% CI 0.52–1.72), and set 3 $t(26) = 3.05$, $p = 0.005$, $d = 1.15$ (95% CI 0.28–1.44). There were no significant differences between groups for muscle activity in the VL, RF, VM, GM, or ST during any sets (Table 2).

Discussion

To date, there has been little work conducted evaluating the muscle activation patterns of women during the traditional back squat (4). This study evaluated the differences in muscle activity in the VL, RF, VM, GM, BF, and ST between men and women during the traditional back squat. It was hypothesized that women would generate higher anterior chain muscle activity when compared with men. The results showed no significant findings in the VL, RF, VM, GM, or ST. Conversely, during the descending phase of the lift, men displayed a significantly greater amount of muscle activity in the BF, a primary muscle of the posterior chain.

A plausible explanation may be the relative training load (training load in kg/body mass in kg) discrepancy between sexes. The male subjects used a mean relative training load of $M = 1.37$, whereas the women used $M = 0.922$, a statistically significant difference $t(26) = 4.745$, $p = 0.000$, $d = 1.77$. It has been noted that EMG activity increases as load increases (13). A higher relative load may require a greater coactivation of several muscle groups, thus necessitating greater recruitment of the BF to decelerate the load during the descending phase of the lift. With a higher relative load, the BF is recruited "in addition to" not "instead of" the anterior chain, further explaining why anterior chain muscle activity was not decreased in men.

It has been demonstrated that women display lower levels of posterior chain muscle activation than men in functional movement tasks other than the back squat. Youdas et al. (2007) reported that during a single-leg squat, women displayed 14% more EMG activity in the quadriceps ($p = 0.04$) and 18% ($p = 0.04$) less hamstring activity than men. It has also been shown that during the initial phases of landing, women display significantly lower ($p < 0.05$) amount of hamstring activity that men (17). This evidence of quadriceps dominance has been linked to the higher rate of ACL tears in female athletic populations, where women tear their ACL 2 to 8 times more often than men (7–9,18).

Anterior crucible ligament injuries often occur during descending phases of functional activities such as landing or cutting, when foot strike happens and the body is required to resist knee flexion (17). Resisting knee flexion requires the neuromuscular activation of both the anterior and posterior chain, where the posterior chain acts as an agonist to the ACL, making it primarily responsible for resisting anterior translation (16). For this reason, it has been proposed that when training, particularly in women, focus on the activation and strengthening of the posterior chain is paramount in training the body to properly decelerate, thus preventing injury (7,16).

The back squat is a common resistance training exercise that is prescribed to increase strength and muscular activity in the anterior and posterior chain (6). The descending phase of the lift mimics functional movements where the body must decelerate, resist knee flexion using the anterior and posterior chain, and then accelerate during the ascending phase to complete the lift. Our results indicate that during the descending phase of this lift, men activated a greater amount of the posterior chain than women; therefore, the traditional back squat alone may not be the optimal training modality for women training to strengthen and activate the posterior chain. Other resistance training exercises that better isolate BF in the posterior chain such as the Nordic hamstring curl, kettle bell swing, supine leg curl, or seated leg curl (14,20) should be considered when designing training programs for female recreational athletes. Future studies should evaluate exercises that are believed to isolate the BF in women and implement a training intervention to alter the neuromuscular recruitment of posterior chain. Furthermore, tracking this group of recreational athletes throughout a season to monitor injury would determine the effectiveness of such a program.

Table 2
Results of all independent-sample *t*-tests.*

Muscle	Set 1			Set 2			Set 3		
	F	*p*	*Cohens d*	*F*	*p*	*Cohens d*	*F*	*p*	*Cohens d*
VL									
DSC	1.54	0.31	0.38	0.00	0.95	0.17	0.14	0.66	0.16
ASC	0.06	0.54	0.23	0.00	0.94	0.03	0.01	0.82	0.08
RF									
DSC	1.98	0.89	0.05	4.99	0.71	0.14	9.32	0.47	0.27
ASC	1.47	0.81	0.09	3.65	0.71	0.13	8.53	0.48	0.27
VM									
DSC	0.39	0.87	0.10	0.74	0.71	0.14	1.01	0.77	0.10
ASC	1.56	0.56	0.22	0.66	0.61	0.19	0.19	0.68	0.16
GM									
DSC	2.52	0.21	0.48	0.51	0.29	0.38	0.04	0.39	0.32
ASC	0.36	0.43	0.37	0.19	0.47	0.28	0.00	0.61	0.20
BF									
DSC†	2.71	0.02	0.89	25.30	0.001	1.46	12.59	0.01	1.15
ASC	0.04	0.32	0.39	0.34	0.63	0.18	0.59	0.89	0.05
ST									
DSC	0.61	0.92	0.08	0.60	0.74	0.07	0.72	0.70	0.15
ASC	7.94	0.16	0.57	4.40	0.19	0.92	3.55	0.23	0.46

*VL = vastus lateralis; RF = rectus femoris; VM = vastus medalis; GM = gluteus maximus; BF = biceps femoris; ST = semitendinosus; DSC = descending phase; ASC = ascending phase.
†Significant group difference between men and women for the muscle group across all sets $p < 0.05$.

A possible limitation to the current study is the noted difference in the relative training load between men and women. If this study were conducted with a group of recreational athletes where relative training loads were similar, it is possible that the differences in posterior chain muscle activity would diminish. In addition, body fat content at the EMG sensor locations may have varied between males and females, potentially magnifying the differences seen in muscle activity. Finally, data regarding the number of years, training was not recorded for this study, and it is feasible that this could play a role in the muscle activity level differences seen in the populations.

Practical Applications

Our findings indicated that recreationally active women have significantly less activation of the BF muscle during the descending phase of the traditional back squat compared with recreationally active men. Coaches and trainers should consider this information when selecting strengthening exercises to target the posterior chain muscles. Selecting assistive exercises for female athletes who isolate the BF may be a better approach to posterior chain strengthening in women than the traditional back squat.

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