Original Research

A Comparison of Muscle Activation Among the Front Squat, Overhead Squat, Back Extension and Plank

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ABSTRACT

International Journal of Exercise Science 13(1): 714-722, 2020. The purpose of this study was to compare the muscle activation of the scapula, leg, and trunk among the front squat (FS), overhead squat (OHS), back extension (BE) and plank (PL). Seven recreationally trained men (age: 28 ± 3.6 years, body mass: 92 ± 26.1 kg, height: 175 ± 5.3 cm, 3-RM front squat test: 125 ± 49.8 kg, 3-RM overhead squat test: 91 ± 15.5 kg) participated in this within-subject crossover design. Two isometric exercises (plank and Biering-Sorenson back extension) were also included for trunk musculature comparisons. Neuromuscular activation of the vastus lateralis (VL), biceps femoris (BF), thoracic region of erector spinae (ES), middle trapezius (MT), rectus abdominis (RA), external oblique (EO), serratus anterior (SA), and anterior deltoid (AD). The neuromuscular activity of the FS and OHS were analyzed using a 2 X 3 (squat variation X intensity) repeated measures analysis of variance (ANOVA). Effects were further analyzed by Bonferroni corrected paired t-tests. Results showed that AD activity was significantly greater ($p < .05$) during the FS compared to OHS at 65 and 95% of the 3-RM, while MT activity was significantly greater ($p < .05$) during the OHS than the FS at 80 and 95% of the 3-RM. ES activity was significantly greater ($p < .05$) during both the FS and OHS compared to the BE, but PL elicited significantly greater EO and RA activity than both the FS and OHS. These findings reveal that the FS and OHS can help facilitate the activation of muscles supporting the shoulder complex, scapula and lower back.

KEY WORDS: Strength, Resistance Training, Muscle Activation, Squat

INTRODUCTION

Externally loaded squats are a common part of resistance training programs designed for improving sports performance due to their ability to progressively overload the lower extremity and posterior trunk musculature (1, 3, 4, 10, 22, 29, 31). Common barbell squat variations include the back squat, in which the barbell is positioned on the posterior trunk above the acromion (31), the front squat (FS), in which the barbell is position anteriorly on the clavicle and above anterior deltoid (14), and the overhead squat (OHS), in which the barbell is in an overhead position by gripping the barbell with palms, elbows fully extended and radial-ulnar joint pronated (27, 31).

Olympic weightlifters commonly perform the front squat and overhead squat because of its movement carryover to the power clean and snatch (25).

Success in both the FS and OHS requires significant thoracic extension, upright posture and stabilization of the humerus and scapula, underscoring the importance of the erector spinae and axioscapular muscles like serratus anterior and trapezius (18, 28). The erector spinae significantly contributes to upright posture and extension of the lumbar and thoracic spine through the action of three groups of fibers-illiocostalis, longissimus and spinalis (6, 26). Proper spinal extension allows for optimal positioning in other areas like the neck, shoulder, and hip (17, 30). The scapula, which aligns with the thoracic region of the spine, glides across it with the help of the trapezius and serratus anterior (among other muscles). Consequently, these muscles also act as stabilizers of the scapula when performing flexion or abduction of the glenohumeral joint (18, 28). A balance of scapular stability and mobility is important for overhead athletes like swimmers, baseball pitchers, and tennis players (5). Athletes in these sports overuse the shoulder, which causes anterior shoulder instability (12). The scapula, therefore, must maintain dynamic stability while simultaneously providing controlled mobility (28); ultimately it arranges the glenohumeral joint in an optimal position for muscular function. Thoracic extension allows for all the aforementioned movements to occur so that the scapula may rotate upward to change the orientation of the glenoid fossa, allowing overhead position (13, 17, 18, 28, 30).

Though squat variations have been extensively studied, the vast majority of attention has been given to leg musculature such as vastus medialis, vastus lateralis, gastrocnemius, soleus, and bicep femoris, as well as trunk musculature such as the rectus abdominis, external oblique and erector spinae. Comparison studies have previously examined these muscles in the free weight barbell squat and smith machine squat (24), FS and back squat (31), back squat on various unstable surfaces (23), high bar and low bar back squat (9), back squat and weighted sled (16), partial and full back squat (8), different stance widths during back squat (21), and back squat vs OHS (2). Still, to date, a dearth of knowledge exists concerning how the FS and OHS differentially impact muscle activity of the scapula and trunk. Therefore, the purpose of this study is to compare muscle activation of the scapula, trunk and leg between the FS and OHS. We hypothesize that the demand of scapular stabilization in the overhead squat would result in greater muscle activation in the shoulder complex muscles.

METHODS

Participants
Seven recreationally trained men (age: 28 ± 3.6 years, body mass: 92 ± 26.1 kg, height: 175 ± 5.3 cm, 3-RM FS: 125 ± 49.8 kg, 3-RM OHS: 91 ± 15.5 kg) with more than one year of resistance training (>3X week) and at least six months of performing FS and OHS (1X week) participated in this study. All subjects expressed written consent prior to participating and the research investigation was approved by the California State University Long Beach institutional review board. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (19).

Protocol
Session one consisted of participants performing 3-RM of the FS and OHS. Once informed consent was filled out, a five-minute stationary bike warm-up was administered followed by dynamic warm-up. Each exercise in the dynamic warm-up was performed for 30 seconds and consisted of arm circles, straight legged kicks, lateral lunges, knee hugs, resistance banded horizontal shoulder abduction and body weight squats. Participants then performed a 3-RM of the FS or OHS; the squat condition that was performed first was randomized. A previously used 3-RM protocol (2) was adopted wherein participants were asked to estimate their 3-RM load, and from that, 50%, 70%, and 90% were used as warm up loads. This was followed by four maximum attempts to achieve the 3-RM. The load was increased after each 3-RM attempt in accordance with what the participant deemed appropriate. Participants were given two to five minutes of rest between all sets (warm-ups and 3-RM attempts). The 3-RM score was accepted upon successful completion of three consecutive repetitions of the squat to the depth of at least top of the thigh reaching parallel to floor by visual observation of researcher (2). After completion of either 3-RM squat, FS or OHS (randomized) participants rested ten minutes before attempting 3-RM protocol of the other squat condition. Squat depth was practiced prior to testing and was monitored through visual inspection at all times by the principal investigator (PI). Depth was considered acceptable once the PI observed a 90° angle from the knee to the hip to the floor (parallel squat). Subjects were instructed to practice the concentric/eccentric phases of each squat at a 1:1 second tempo prior to testing.

Session two was performed a week later, and participants were instructed to refrain from any physical activity at least 48 hours before scheduled session. Manually resisted MVIC's of the RA, EO, and ES were conducted in order to perform EMG analysis and to normalize the mean EMG values for the plank and Biering Sorenson back extension. Manual resistance from the researcher was used for most MVIC tests in order to provide adequate static resistance and two trials per muscle were administered (20). MVIC for the RA was obtained by having the participant lay supine with ankles and hips anchored. Participants attempted to perform a sit-up as the researcher applied manual downward resistance on the chest and shoulders. For the EO, participants laid on their side with ankles and hips anchored. Participants would attempt lateral spinal flexion as manual downward resistance was applied on the shoulder. MVIC for the ES was obtained by having participants lay in the prone position with ankles anchored; manual downward resistance was place on the posterior deltoids to resist spinal extension. After MVIC testing, participants performed a dynamic warm-up similar to that of session one and started the squat trials. The first squat variation and consequent relative intensities were chosen in random, with the intensities being 65%, 80%, and 95% of their 3-RM. Participants performed three repetitions at each intensity with two to five minutes of rest in between sets. Although movement speed was not controlled, participants were asked to perform each repetition with control and were suggested to perform a one second eccentric and one second concentric. Lastly, participants performed, in random order, the front plank and Biering-Sorensen back extension for 30 seconds. These isometric exercises were used to compare core and trunk musculature.

Electromyography: Surface EMG dual circular pre-gelled electrodes with 20mm of spacing (Noraxon AZ, USA) were placed on the following eight muscles: vastus lateralis (VL), biceps femoris (BF), thoracic region of erector spinae (ES), middle trapezius (MT), rectus abdominis (RA), external oblique (EO), serratus anterior (SA), and anterior deltoid (AD). Placement of each electrode followed the suggestion of Konrad (20), and the skin around the suggested area was shaved (if needed), cleaned with alcohol, and abraded before electrode placement (20). MVIC's were performed for two trials per muscle, held isometrically for five seconds and with one minute of rest in between trials. The highest MVIC amplitude was accepted for analysis. A point was marked in the EMG software at the start of each repetition while recording in real time. Raw EMG signal values were sampled at 2000hz filtered (6-pole Butterworth and band pass filtered 10-500hz) and full wave rectified, smoothed with a moving a 75ms root mean square window for the duration of the three squat trials per squat variation (65%, 80%, and 95% 3-RM). The values were then analyzed for the second repetition by calculating the area under the curve. Only the RA, EO, and ES MVIC's were conducted to normalize against the isometric exercises. The isometric exercises were analyzed for a five second window (10-15 seconds) (Noraxon AZ USA).

Statistical Analysis
Differences in neuromuscular activity during the FS and OHS were analyzed using a 2 X 3 (squat variation X intensity) repeated measures analysis of variance (ANOVA). Only the second repetition of each 3-RM attempt was used for analysis. Differences in EMG values during the highest intensity squat and isometric trunk exercise was analyzed using an independent T test. Significant main effects were further analyzed with paired t-test. Statistical significance was set a priori $p \leq 0.05$. All statistical analysis was performed on SPSS IBM SPSS version 25.

RESULTS

A within-subjects crossover design was used to compare muscle activation of the AD, BF, EO, ES, RA, MT, SA, and VL of participants performing the front squat and overhead squat. Subject descriptive data are shown in Table 1.

Table 1. Subjects' descriptive data (n=7, mean ± SD).

Age (yrs)	28±3.6
Height (cm)	175±5.3
Body Mass (kg)	92±26.1
3-RM FS (kg)	125±49.8
3-RM OHS (kg)	91±15.5

SD = Standard Deviation

Relative Front Squat and Overhead Squat Comparison: Activity of the AD was significantly greater (p< .05) during the FS than OHS at both 65% and 95% of the 3-RM, while MT muscle activity was significantly greater (p< .05) during the OHS at 80% and 95% of the 3-RM (Table 2.).

Table 2. Overall EMG Activity of All 8 Muscles During the Front Squat and Overhead Squat at 65%, 80%, and 95% Intensity

Muscles	FS65%	FS80%	FS95%	OS65%	OS80%	OS95%
AD	1937.4 ±1525.5*	1817.9 ±1276.2	2783.9 ±1622.8*	548.9 ±276.3	1205.3 ±1121.5	1940.8 ±1896.9
EO	67.2 ± 57.7	85.6 ±48.4	309.2 ±392.8	84.8 ±23.5	125.9 ±38.1	219.5 ±121.4
RA	75.6 ± 24.6	97.7 ±31.4	153.5 ±55.8	87.9 ±30.4	165.9 ±57.1	204.4 ±136.8
VL	472..4 ± 193.0	651.8 ±289.1	832.9 ±499.5	472.3 ±192.9	651.7 ±270.8	905.9 ±423.2
BF	123.1 ±86.3	255.7 ±297.0	271.7 ±226.1	127.6 ±116.6	157.6 ±98.4	227.2 ±132.9
SA	947.5 ± 544.9	1346.3 ±922.1	2098.2 ±1269.2	425.3 ±373.9	832.9 ±683.4	1235.3 ±872.5
MT	309.3 ±166.8	495.4 ±290.4	843.5 ±408.7	570.0 ±391.3	1038.4 ±576.4*	1399.1 ±735.8*
ES	352.4 ±229.1	458.1 ±293.6	661.9 ±463.9	229.7 ±235.8	550.4 ±372.2	569.1 ±524.2

Values expressed as mean ± Standard Deviation
Note: * Significantly greater than corresponding muscle of the other squat ($p < 0.05$)

Isometric Core/Trunk Comparison: RA, EO and ES activity was also compared between isometric exercises and the heaviest FS and OHS (Tables 3 and 4). The heaviest load instead of the average neuromuscular activity was compared since the heaviest load stimulated greatest activity. RA (t=3.327, p< .05) and EO (t=4.268, p < .05) muscle activity was significantly greater during the plank compared to the FS. ES activity was significantly greater during both FS (t= 3.045, p < .05) and OHS (t=3.469, p < .05) compared to the BE.

Table 3. Mean EMG activities as a percentage of maximal voluntary isometric contraction (% MVIC) for the posterior core ES during FS95, OS95, and Biering-Sorenson back extension

	Front Squat	Overhead Squat	Back Extension
Muscle			
ES	53.8 ± 16.7*	63.4 ± 23.3*	33.7 ± 10.2

Values expressed as mean ± Standard Deviation, FS95= Front Squat at 95% relative intensity, OS95= Overhead Squat at 95% relative intensity, *Note*: * Significantly greater than back extension (p < 0.05)

Table 4. Mean EMG activities as a percentage of maximal voluntary isometric contraction (% MVIC) for the anterior core (RA & EO) during FS95, OS95, and plank exercise

	Front Squat	Overhead Squat	Plank
Muscle			
RA	12.6 ± 5.9	14.4 ± 6.4	27.5 ± 11.9*
EO	15.1 ± 1.2	16.9 ± 3.1	23.7 ± 3.7*

Values expressed as mean ± Standard Deviation, FS95= Front Squat at 95% relative intensity (concentric phase) OS95= Overhead Squat at 95% relative intensity (concentric phase), *Note*: * Significantly greater than front squat (p < 0.05)

DISCUSSION

The purpose of this study was to examine the muscle activity around the scapula, leg, and trunk during the FS and OHS, as well as examine isometric exercises like the plank and Biering back extension. To date, little data has directly compared scapular activity between these two squat variations. The present study primarily demonstrated that activity of the AD was greater during the FS than OHS, while MT muscle activity was greater during the OHS. Hence, our hypothesis was partially correct. Overall, activity of core musculature (RA and EO) was greater during OHS

than FS. Lastly, both FS and OHS produced significantly greater ES muscle activity than the Biering-Sorenson back extension. The SA protracts the scapula, which is needed during the front squat to get the barbell into its proper placement between deltoid and coracoid process at clavicle level (28). The AD is also important for the FS because it assists in keeping the humerus in a flexed position, not allowing the barbell to roll off (11). This lends support to the present data showing that AD muscle activity was greater during the FS; though AD still does have an important role in the OHS (2, 14). That the MT exhibited greater activity during the OHS also demonstrates the importance of scapular positioning. MT primarily stabilizes the scapula through retraction and adduction, allowing the humerus to rotate and move about the glenoid cavity in order reach an overhead position (14, 18, 28).

The scapula is attached to the thorax by ligaments stemming from the acromioclavicular joint, while the SA and subscapularis muscle act to suction the scapula close to the thorax to provide ample mobility (28). Mobility and stability of the scapula and shoulder is important for injury prevention and sports performance in overhead athletes (5). Stability of the shoulder is regulated by active and passive muscular mechanisms that serve to maintain sport specific glenohumeral joint mechanics (5). Mobility and function of the scapula would not be possible without assistance from the ES as a thoracic extensor. Although there was no statistical significance in muscle activity of the ES between the FS and OHS, ES muscle activity was greater during both squats when compared to the Biering-Sorenson back extension. These findings fall in line with those of Aspe and Comfort, implying that these types of dynamic loaded exercises (FS and OHS) can strengthen the ES as much or more than isolated and isometric exercises (2, 7).

The concept of squat stabilization has been investigated in terms of stable vs unstable surface (23) and stable vs unstable loads (15). Saeterbakken et al. (23) found that there was greater muscle activity in the abdominal stabilizer muscles during unstable surface (balance disks) when compared to stable surface (smith machine squat). Lawrence et al. (15) found that unstable loading (weight suspended by elastic band placed on barbell) enhanced RA and EO muscle activation when compared to stable loading (normally loaded barbell). The present findings regarding anterior trunk musculature (RA and EO) are consistent with previous studies (2, 14) reporting superior trunk activation during the OHS compared to alternate forms of squats. These findings taken together provide strong evidence that the OHS elicits greater anterior trunk muscle activation when compared to other forms of squat such as back squat and FS because of the requirement to stabilize the barbell overhead (2, 14).

Activation of leg musculature (VL and BF) did not differ between FS and OHS, despite disparities in 3-RM loading between the two lifts, 125±49.8 kg and 91±15.5 kg, respectively. Previous research that compared the back squat and OHS using relative loads revealed greater VL activation in the back squat compared to OHS (2), which the authors attributed to the higher loads used with the back squat. Similarly, Yavus et al. (31) examined the neuromuscular activation of the front squat and back squat with 1-RM loads and found that vastus medialis (VM) activity was greater in the front squat. Greater VM activation was shown in the front squat despite lower mean 1-RM loads 85.00 ± 15.67 kg compared to the back squat, 109.17 ± 25.51 kg. Our results suggest that although achieved 3-RM loads were greater in the FS than in the OHS,

activation patterns of VL and BF may not be significantly different between the two lifts. As observed by the aforementioned studies, back squat appears to significantly alter the activation patterns of quadricep muscles when compared to OHS and FS.

The findings of the present study demonstrate the difference in muscle activation between FS and OHS. The differences in AD and MT activity during these two squats showcase the importance of the scapula and shoulder complex during these lifts. Muscles around the shoulder complex are very active during both lifts, although AD muscle activity appears to be greater during FS, while the MT muscle activity is greater during the OHS. These two squats provided comparable leg musculature activity (VL & BF), so both types of squat can be used to build leg strength while simultaneously build shoulder complex musculature strength. Overhead athletes like swimmers, baseball pitchers and tennis players can benefit from FS and OHS due to the shoulder and scapular stability that is required (5, 12). Though the OHS should not replace traditional abdominal core training, it does provide a way to dynamically utilize abdominal musculature. Since both FS and OHS generated significant ES activity, both forms of squat may be helpful as part of a balanced plan to enhance postural alignment (2, 10, 26).

One possible limitation of the present study is the use of a 3-RM instead of a 1-RM. Utilizing a 1-RM and subsequent relative intensities would better represent loads that are used in populations like Olympic weightlifters. Additionally, EMG output may have been affected by the fact that speed of muscle action was visually monitored but not formally controlled for during testing. Post-hoc power analysis (G*Power) revealed a sample size of 10 to attain power = 0.8, thus the present study is slightly underpowered. Future studies should utilize larger sample sizes, test with true 1-RM's, and control for lifting tempo in order to balance external validity with greater internal control.

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