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A Comparison of Gluteus Maximus, Biceps Femoris, and Vastus Lateralis Electromyography Amplitude in the Parallel, Full, and Front Squat Variations in Resistance-Trained Females

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Front, full, and parallel squats are some of the most popular squat variations. The purpose of this investigation was to compare mean and peak electromyography (EMG) amplitude of the upper gluteus maximus, lower gluteus maximus, biceps femoris, and vastus lateralis of front, full, and parallel squats. Thirteen healthy women (age = 28.9 ± 5.1 y; height = 164 ± 6.3 cm; body mass = 58.2 ± 6.4 kg) performed 10 repetitions of their estimated 10-repetition maximum of each respective variation. There were no statistical ($P \le .05$) differences between full, front, and parallel squats in any of the tested muscles. Given these findings, it can be concluded that the front, full, or parallel squat can be performed for similar EMG amplitudes. However, given the results of previous research, it is recommended that individuals use a full range of motion when squatting, assuming full range can be safely achieved, to promote more favorable training adaptations. Furthermore, despite requiring lighter loads, the front squat may provide a similar training stimulus to the back squat.

Keywords: relative loading, electromyography, lower extremity, resistance training, exercise

The squat is not only a core movement in Olympic weightlifting and powerlifting, but it is also a staple exercise for athletes and bodybuilders. Due to its applicability to functional exercise and sport, numerous variations have been developed and employed in the fields of strength and conditioning and physical therapy. Many of these squat variations have been investigated and/or compared in terms of kinetics,[1–4] kinematics,[1,3,5,6] muscle activation,[1,2,7,8] hormonal response,[9–11] postactivation potentiation,[12–15] correlations to performance,[16–19] and transfer of training.[20–23] In addition, several reviews[24–27] and one meta-analysis[28] have been conducted on the squat exercise.

Like most exercise and sports medicine research, a disproportionate amount of previous research on the squat was completed on male subjects.[29] To the authors' knowledge, only 2 studies have investigated squat electromyography (EMG) amplitude in female subjects,[30,31] one of which noted greater biceps femoris EMG in females than their male counterparts.[31] Furthermore, anthropometric and kinematic differences exist between males and females during the squat, which means that squat data cannot be extrapolated between sexes.[32] Therefore, there is a need to fill this gender gap in the literature.

With regards to gluteus maximus EMG amplitude in the squat exercise, several important studies have been conducted. Caterisano and colleagues[33] investigated the effects of squat depth on gluteus maximus EMG. The investigators found that gluteus maximus EMG amplitude statistically increased with depth (35.5% vs 28.0%). However, as noted by Clark and colleagues,[34] Caterisano and colleagues[33] did not use the same relative load at each squat depth tested, which may have affected the outcome. Paoli and colleagues[35] and McCaw and Melrose[36] both found statistical increases (.0288 mV vs .0205 mV and 9.4 μV.s vs 8.3 μV.s, respectively) in gluteus maximus EMG amplitude and integrated EMG values, respectively, with increases in squat stance width. Aspe and Swinton[37] analyzed the back squat and the overhead squat and found that, at 90% 3-repetition maximum (RM), the back squat elicited statistically greater gluteus maximus EMG amplitude than the overhead squat (92.7% vs 60.9%), in addition to statistically greater biceps femoris (71.1% vs 54.0%) and vastus lateralis (99.2% vs 82.3%) EMG amplitude.

A number of studies have compared front and back squat variations.[1,8,23,38–43] Gullett and colleagues[1] examined kinetic and EMG differences between the front and back squats and found that the back squat exhibited statistically greater knee moments (1.0 N·m/kg vs 0.7 N·m/kg), but no statistical differences between biceps femoris, rectus femoris, semitendinosus, vastus lateralis, vastus medialis, or erector spinae EMG amplitude were found. Intuitively, the back squat utilizes greater energy from the hips while the front squat utilizes greater energy from the knees.[41] Russell and Phillips[39] found similar knee extensor moments, trunk extensor moments, trunk angles, and lumbar compressive and shear forces between front and back squats. Stuart and colleagues[38] described similar anteroposterior shear and compressive forces at the knee, knee fl xion/extension moments, and quadriceps EMG amplitude in front and back squats. In this study, hamstring EMG amplitude

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was found to differ significantly between the front and back squat at 90° and 60° in the ascent phase, but the authors failed to specify which exercise variation elicited greater hamstring EMG amplitude. Lastly, Yavuz and colleagues[43] investigated the EMG amplitude of the vastus lateralis, vastus medialis, rectus femoris, semitendinosus, biceps femoris, gluteus maximus, and erector spinae in front and back squats performed to 90° knee flexion. The only differences the investigators observed were greater vastus medialis EMG amplitudes in the front squat, and greater semitendinosus EMG amplitude during the ascending phase of the back squat.

Numerous studies have compared differences in squat depths.[5,6,30,33,44–47] Gorsuch and colleagues[30] found that parallel squats elicited statistically greater rectus femoris (0.18 mV vs 0.14 mV) and erector spinae (0.16 mV vs 0.13 mV) EMG amplitude than partial squats but reported that hamstring EMG amplitude was not statistically different. Bryanton and colleagues[5] described an increase in knee extensor and hip extensor relative muscular effort with increases in squat depth. Both patellofemoral joint reaction forces and external knee fl xion moments increase with increases in squat depth.[46,47] Drinkwater and colleagues[44] found that partial squats produced greater peak power and peak forces, but full squats produced greater peak velocities and work. Esformes and Bampouras[45] found that, in a study examining the effects of postactivation potentiation, parallel squats led to significantly greater improvements than quarter squats in countermovement jump height, peak power, impulse, and flight time (22.2%–28.0%). Wretenberg and colleagues[6] described greater knee moments and greater biceps femoris EMG amplitude during deep squats in comparison with parallel squats, but the two squat styles exhibited similar hip moments, rectus femoris EMG amplitude, and vastus lateralis EMG amplitude.

The front, full, and parallel squat are 3 common variations of the squat. The purpose of this investigation was to compare upper gluteus maximus, lower gluteus maximus, biceps femoris, and vastus lateralis EMG amplitude during 10 repetitions utilizing estimated 10RM front, full, and parallel squat loads in resistance trained women. Previous researchers have indicated that hamstrings EMG amplitude is likely to be unaffected by depth, quadriceps EMG amplitude is likely to be increased by increasing depth, and that the effect of depth on gluteus maximus EMG amplitude is unclear. Therefore, it is hypothesized that there would be no difference in upper gluteus maximus, lower gluteus maximus, or biceps femoris EMG amplitude between the front, full, and parallel squat, but the front and full squat would elicit greater vastus lateralis EMG amplitude than the parallel squat.

Methods

Thirteen experienced, resistance trained women (age = 28.9 ± 5.1 y; height = 164 ± 6.3 cm; body mass = 58.2 ± 6.4 kg) participated in this study. Subjects had 7.00 ± 5.8 years of resistance training experience and a 10RM of 39.2 kg, 46.7 kg, and 53.1 kg in the front, full, and parallel squat, respectively. Inclusion criteria required subjects to be between 20–40 years of age, have at least 3 years of consistent resistance training experience, and be familiar with performance of the front, full, and parallel squat. All subjects were healthy and free of any musculoskeletal or neuromuscular injuries, pain, or illnesses. Subjects filled out an informed consent form and Physical Activity Readiness Questionnaire (PAR-Q). Any subject that answered "Yes" to any of the questions on the PAR-Q or refused to sign the informed consent form would have been excluded. Subjects were advised to refrain from training their lower body for 72 hours before testing. To ensure acceptable performance in the 3 squat variations, subjects performed each movement using only a barbell while the lead researcher evaluated technique. If a subject reported pain, discomfort, or failed to perform the movement correctly, she would have been excluded from participation. If, for any reason, a subject could not complete a trial, her data would have been discarded. All recruited subjects fulfilled the inclusion criteria, and no subjects were excluded. The study was approved by the Auckland University of Technology Ethics Committee.

Subjects first performed a 10-minute general warm-up consisting of various dynamic stretches for the lower body musculature. Afterward, 3 progressively heavier specific warm-up sets were performed for the front, full, and parallel squat. Next, subjects' 10RM in each squat variation were calculated using the methods described by Baechle and Earle[48] and Vigotsky and colleagues[49] by performing as many repetitions with what each subject perceived to be a moderately heavy load. Order of the testing was randomized.

Subjects were asked to wear appropriate clothing for access to the EMG electrode placement sites. Before placing the electrodes on the skin, excess hair was removed with a razor, and skin was cleaned and abraded using an alcohol swab. After preparation, self-adhesive disposable silver/silver chloride pregelled dual-snap surface bipolar electrodes (Noraxon Product #272, Noraxon USA Inc., Scottsdale, AZ) with a diameter of 1 cm and an interelectrode distance of 2 cm were attached in parallel to the fibers of the right upper gluteus maximus, lower gluteus maximus, biceps femoris, and vastus lateralis in concordance with the recommendations of Hermens and colleagues[50] and Fujisawa and colleauges.[51] More specificall , "[upper gluteus maximus] electrodes were placed two finger s width above the line just under the spina iliaca posterior superior and the trochanter major; [lower gluteus maximus] electrodes were set below the same line,"[51] biceps femoris electrodes were "placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia,"[50] and vastus lateralis electrodes were "placed at 2/3 on the line from the anterior spina iliaca superior to the lateral side of the patella."[50] After the electrodes were secured, a quality check was performed to ensure EMG signal validity.

Ten minutes after estimated 10RM testing, maximum voluntary isometric contraction (MVIC) testing was performed. For the gluteus maximus, 2 MVIC positions were tested. The first involved a prone bent-leg hip extension against manual resistance applied to the distal thigh, as used by Boren and colleagues,[52] and the second involved a standing glute squeeze. Pilot data from our laboratory revealed that some subjects achieve higher levels of gluteus maximus EMG amplitude with the standing glute squeeze than during the prone bent-leg hip extension against manual resistance; thus, both conditions were recorded and EMG was normalized to whichever contraction elicited greater EMG amplitude. Biceps femoris MVIC was determined by having the subject lay prone and produce maximum knee fl xion torque at 45° knee fl xion against manual resistance applied to the distal leg just above the ankle, as reported by Mohamed and colleagues.[53] Two vastus lateralis MVIC positions were used. The first had the subject sit and produce maximum knee extension torque against manual resistance applied to the distal leg just above the ankle at 90° hip fl xion and 90° knee fl xion, as detailed by Kong and Van Haselen[54] (except without the use of an isokinetic dynamometer), while the second used a 90° hip fl xion and 180° knee position. Whichever contraction elicited greater EMG amplitude was used for normalization. In all MVIC positions, subjects were instructed to contract the tested muscle "as hard as possible."

After 10 minutes of rest following MVIC testing, subjects performed 10 repetitions utilizing their estimated 10RM of front, full, and parallel squats in a randomized order and counterbalanced fashion. During all squat variations, subjects' feet were slightly wider than shoulder-width apart, with toes pointed forward or slightly outward. For the front squat, the barbell was placed across the anterior deltoids and clavicles. Subjects fully fl xed their elbows to position the upper arms parallel to the floor (Figure 1).[1] During both back squat variations (full and parallel), the barbell was placed in the high bar position across the shoulders on the trapezius, slightly above the posterior aspect of the deltoids (Figure 2, Figure 3).[1] In both the front and full squat, subjects descended until the knees were maximally fl xed (Figure 1, Figure 2).[55] Descent during the parallel squat was limited to the point at which the tops of the thighs were parallel with the floor (Figure 3).[56] Subjects were given 5 minutes of rest between sets. No predetermined tempo was set as to better mimic typical training conditions.

Raw EMG signals were collected at 2000 Hz, with a gain of 500, by a Myotrace 400 EMG unit (Noraxon USA Inc., Scottsdale, AZ). Data were sent in real time to a computer via Bluetooth and recorded and analyzed by MyoResearch 3.6 Clinical Applications software (Noraxon USA, Inc., Scottsdale, AZ). A 10–500 Hz bandpass filter was applied to EMG data. Signals of all 10 repetitions were rectified and smoothed with a root mean square (RMS) algorithm with a 100-millisecond window. Mean and peak data were normalized to a mean peak of a 1000-millisecond window from the MVIC trials. While peak allows for all near-instantaneous increases in muscle activation to be seen, mean is robust to both movement artifact and time, thus providing a reliable average of EMG amplitude over the entire movement.[57]

Repeated measures analyses of variance (ANOVA) were performed using Stata 13 (StataCorp LP, College Town, TX), wherein mean and peak EMG between exercises, within subjects, and within muscle effects were calculated. Bonferroni post hoc tests were performed on any measure that achieved a main effect. Alpha was set to .05. Partial η^2 effect sizes were calculated and reported, as were their 95% confidence intervals (95% CI). Partial η^2 effect sizes were interpreted based upon the guidelines of Cohen;[58] that is, a partial η^2 of .02 is small, .13 is medium, and .26 is large.

Results

No differences were found between any measured outcomes, except for vastus lateralis peak EMG, which revealed no pairwise differences.

No main effects were found for mean EMG amplitude of the upper gluteus maximus (P = .98; $F_{2,24}$ = 0.02; partial η^2 = .00; 95% CI = 0.0–1.0), lower gluteus maximus (P = .474; $F_{2,24}$ = 0.77; partial η^2 = .06; 95% CI = 0.0–0.24), biceps femoris (P = .31; $F_{2,24}$ = 1.23; partial η^2 = .09; 95% CI = 0.0–0.29), and vastus lateralis (P = .21; $F_{2,24}$ = 1.69; partial η^2 = .12; 95% CI = 0.0–0.33) (Table 1). The partial η^2 values suggest small effects were observed for the upper gluteus maximus, lower gluteus maximus, and biceps femoris, and a medium effect for the vastus lateralis; however, it cannot be said that these effects were not due to chance alone.

No main effects were found for peak EMG amplitude for the upper gluteus maximus (P = .90; $F_{2,24}$ = 0.10; partial η^2 = .01; 95% CI = 0.0–0.10), lower gluteus maximus (P = .60; $F_{2,24}$ = 0.52; partial η^2 = .04; 95% CI = 0.0–0.21), or biceps femoris (P = .96; $F_{2,24}$ = 0.04; partial η^2 = .00; 95% CI = 0.0–0.04). Although a main effect was found for peak vastus lateralis EMG activity (P = .03; $F_{2,24}$ = 4.27; partial η^2 = .26; 95% CI = 0.0–0.47), Bonferroni post hoc testing revealed no pairwise differences (Table 1). The partial η^2 values suggest small effects were observed for the lower gluteus maximus and biceps femoris, and a large effect for the vastus lateralis; however, for the lower gluteus maximus and biceps femoris, it cannot be said that these effects were not due to chance alone.

Discussion

Our hypothesis was partially confirm d in that there were no observable differences between full, front, and parallel squats in the upper gluteus maximus, lower gluteus maximus, and biceps femoris; however, the front and full squat failed to elicit statistically greater vastus lateralis EMG amplitude than the parallel squat. Unsurprisingly, subjects used the greatest amount of load in the parallel squat (53.1 ± 17.0 kg), followed by full (46.7 ± 17.1 kg) and front (39.2 ± 15.6 kg) squats, respectively. These findings are in line with Gullett

Figure 1 — Front squat form.

Figure 2 — Full squat form.

Figure 3 — Parallel squat form.

Table 1 Mean ± *SD* of EMG (%MVIC) values in the parallel, full, and front squat

	Parallel	Full	Front
Mean			
Upper gluteus maximus	29.35 ± 16.45	29.58 ± 16.26	29.15 ± 14.35
Lower gluteus maximus	45.29 ± 23.54	42.24 ± 21.51	43.89 ± 20.75
Biceps femoris	14.92 ± 6.64	14.39 ± 6.41	13.11 ± 4.70
Vastus lateralis	110.35 ± 47.24	123.82 ± 67.42	124.22 ± 72.96
Peak			
Upper gluteus maximus	84.85 ± 42.91	88.13 ± 47.83	84.62 ± 50.48
Lower gluteus maximus	129.60 ± 60.45	124.76 ± 55.44	134.62 ± 55.71
Biceps femoris	37.50 ± 18.39	38.59 ± 16.82	39.35 ± 22.79
Vastus lateralis	243.92 ± 121.63	280.54 ± 166.16	302.61 ± 191.80

Abbreviations: EMG = electromyography; MVIC = maximum voluntary isometric contraction.

et al,[1] Gorsuch et al,[30] and Yavuz et al,[43] where investigators found no statistical differences between mean EMG amplitude of the muscles measured in this study. Specificall , Gullet et al[1] found no differences in vastus lateralis or biceps femoris EMG during front and parallel squats, Gorsuch et al[30] did not find statistical differences in biceps femoris EMG during partial and parallel squats, and Yavuz et al[43] did not find differences in gluteus maximus, biceps femoris, or vastus lateralis EMG during front and back squats. However, Gullett et al[1] also investigated the rectus femoris, vastus medialis, semitendinosus, and erector spinae, Gorsuch et al[30] also investigated the rectus femoris, erector spinae, and gastrocnemius, and Yavuz et al[43] also investigated the vastus medialis, rectus femoris, semitendinosus, and erector spinae; thus, it is possible that had this study investigated these muscles, too, differences may have been observed. It should be noted that our results differ from Caterisano et al,[33] who found that gluteus maximus EMG amplitude statistically increased with depth. However, as noted by Clark et al,[34] Caterisano et al[33] did not use relative loading, which seems to have affected the outcome, as in this study subjects used 12.8% greater 10RM loads during the parallel squat compared with the full squat.

Although no statistical pairwise differences were observed between any measured outcomes, peak vastus lateralis EMG amplitude during front squats was about 21.5% greater than during parallel squats, despite lighter 10RM loads. This large difference in EMG amplitude, combined with the large effect size, occurring without a statistical pairwise difference suggests that our study may have been underpowered. In addition, visual inspection of the results reveals a trend for increasing peak vastus lateralis EMG amplitude from the parallel squat to the full squat to the front squat, and for increasing mean vastus lateralis EMG amplitude from the parallel squat to the full and front squat, in which a medium effect size was observed (Table 1). These findings seem to be coherent with those of Bryanton et al,[5] who reported that the net knee extension moment increased to a greater extent with increasing squat depth than with increasing squat load. The findings may also relate to the more favorable training adaptations observed by Bloomquist et al,[21] where investigators found that squats using a greater range of motion led to greater quadriceps hypertrophy. It is unfortunate that Bloomquist et al[21] did not measure gluteus maximus hypertrophy, nor has it been measured in any other barbell squat study, to the authors' knowledge.

As expected, biceps femoris was not highly activated during any of the squat variations. This is in concordance with other studies,[1,6,37] including Ebben and colleagues,[59] who concluded that squatting was insufficient for hamstring development. On the basis of these findings, it seems logical that other exercises, such as leg curls and stiff-leg deadlifts, should be implemented to ensure maximal hamstring development.

Maximum hip and knee extension requisite moments in the squat occur in considerable hip and knee fl xion.[3,6,46] Because the greatest EMG amplitude is elicited from the gluteus maximus in full hip extension,[60] and from the biceps femoris in full hip extension and 45° knee fl xion,[53] this may explain why the squat does not maximally activate these muscles. Alternatively, the hamstrings might not be highly activated because increasing hamstrings reliance necessitates greater knee extensor moments to counter the hamstrings' knee fl xion moment.[61] However, the MVIC position for the vastus lateralis is obtained with both the hip and knee fl xed to 90°.[54] This is the knee angle at which, in the squat, there is a notable amount of net knee extension moment.[3] This may therefore explain the greater EMG values from the vastus lateralis than the gluteus maximus or biceps femoris. The seemingly high vastus lateralis values in this investigation may also be due to the sample being female subjects, whereas most previous studies used male subjects. Research has shown that women adopt more knee-dominant movement patterns, which would necessarily require more torque from, and therefore more activation of, the quadriceps.[31] Alternatively, it could be due to decreased stability while performing the MVIC trial, as subjects were not strapped into a dynamometer—the subjects sat on a flat bench and the investigator held the leg stable while simultaneously generating manual resistance against the lower limb.

The front squat is performed with the torso more upright, while the back squat is performed with more forward lean.[40] Despite this difference, in males, hip extension torque has been found to be similar,[39] which may explain why there were no statistical differences in gluteus maximus or biceps femoris EMG between front and back squats. However, further research must be completed in females to confirm this theorization. It should be noted that due to individual differences[62] and pathologies such as femoroacetabular impingement,[63] the deep squat may not be a viable option for all individuals. More specificall , Elson and Aspinall[62] described a large variability of hip fl xion mobility between human subjects

(80°–140°), whereby after each subject reached his or her hip fl xion limit, posterior pelvic tilt occurred.

A limitation of investigating the deep squat is the inability to standardize depth among subjects. Interindividual variances in lower body mass, flexibility, and other factors ultimately determine how low a given subject can squat without compromising exercise technique. We did not measure the specific joint angles in the full squat but rather instructed subjects to descend as low as possible while maintaining proper form. Whether such differences have impacts on lower body muscle activation remains to be elucidated.

This was the first study to compare front, parallel, and full squats in women; however, generalizability is specific to young, resistance trained women. Considering that highly trained women have been shown to possess greater hip mobility compared with men,[64] and that many men prefer the low bar squat position as opposed to the high bar squat position we used in this study, it is recommended that more research be performed to gain further insight as to how these squat variations in addition to low bar squat variations affect the EMG amplitude in other populations of women, in addition to populations of men.

The front squat appears to be a viable alternative to the back squat since muscle activation is similar between the two variations. Given that both long-term training and acute biomechanical investigations favor deep squats over parallel or partial squats, it is recommended that an athlete squat as deeply as he or she can, provided he or she can do so safely. However, deep squats are not appropriate for everyone, as it is necessary to have the requisite hip and ankle mobility to safely and properly descend into a deep squat. Individuals with limited hip fl xion ability, whether due to pathologic or morphologic variance, will not be able to squat as deeply while maintaining a lordotic curvature of the spine, which could lead to back injury over time.

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