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**RESEARCH ARTICLE**

# MUSCLE ACTIVATION DIFFERS BETWEEN PARTIAL AND FULL BACK SQUAT EXERCISE WITH EXTERNAL LOAD EQUATED

**Running title:** EMG of dynamic back squat exercise

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## ABSTRACT

Changes in range of motion affect the magnitude of the load during the squat exercise and, consequently may influence muscle activation. The purpose of this study was to evaluate muscle activation between the partial and full back squat exercise with external load equated on a relative basis between conditions. Fifteen young, healthy, resistance trained men (age: 26±5 years, height: 173±6 cm) performed a back squat at their 10 repetition maximum using two different ranges of motion (partial and full) in a randomized, counterbalanced fashion. Surface electromyography was used to measure muscle activation of the vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), biceps femoris (BF), semitendinosus (ST), erector spinae (ES), soleus (SL), and gluteus maximus (GM). In general, muscle activity was highest during the partial back squat for GM ($P$=0.004), BF ($P$=0.009), and SL ($P$=0.031) when compared to full. There was no significant difference for RPE between partial and full back squat exercise at 10RM (8±1 and 9±1, respectively). In conclusion, the range of motion in the back squat alters muscle activation of the prime mover (gluteus maximus), and stabilizers (soleus and biceps femoris) when performed with the load equated on a relative basis. Thus, the partial back squat maximizes the level of muscle activation of the gluteus maximus and associated stabilizer muscles.

**Keywords**: exercise, strength, performance.

## INTRODUCTION

The squat is an exercise that increases hip and knee extensor muscle strength, which in turn can indirectly improve the performance in athletic and non-athletic populations (34). The squat exercise utilizes muscles with different morphology (monoarticular and biarticular), and the muscle forces also vary depending on joint positions (moment arm, length-tension relationship), whether the muscle acts as a prime mover or stabilizer. Though evidence suggests that architecture, position, and function drive muscle performance during the squat, little is known about the neuromuscular changes that occur from a muscle activation standpoint. Elucidating how muscle activation patterns (monoarticular and biarticular) change during the ankle, knee and hip joint movement during squatting at different knee-joint angles would enhance our understanding of how one could capitalize on maximizing muscle activation, and improve the exercise prescription in the strength and conditioning areas. Considering the squat exercise is a multi-joint task, a large number of muscle groups are simultaneously activated in a complex manner. As a multi-joint exercise, the knee extensors (e.g. rectus femoris, RF; vastus lateralis, VL; and vastus medialis, VM), and hip extensors (e.g. gluteus maximus, GM; biceps femoris, BF; and semitendinosus, ST) are considered to be the prime movers during the squat exercise, with other muscles such as the soleus (SL) and erector spinae (ES) acting in a secondary or stabilizer capacity, respectively (6, 21, 34). Several studies have shown that manipulating features of the squat exercise result in altered muscle activity. These manipulations include changes in foot position (25, 29), barbell position (16), stability of the surface on which the exercise is performed (1, 10, 18, 23, 24), different levels of intensity of load (2), range of motion (2, 6, 20, 32), different equipment (33), and type of contraction (dynamic or isometric) (3, 8, 20).

The rationale for this study is based on the assumption that the changes in range of motion during the back squat affect the magnitude of the external load that can be used, which may thus affect muscle activation. The external load parameters have been referred in previous studies as body weight (BW) or %BW (6, 7, 9, 26), number of repetition maximum (RM) (7, 15), and percentage of repetition maximum (%1RM) (32). There is a paucity of research comparing muscle activation patterns during different knee angles with the external load equated by the range of motion of the back squat exercise. Therefore, the purpose of this study was to evaluate the muscle activation between partial and full back squat exercise when performed with the load equated on a relative basis.

## METHODS

### Experimental Approach to the problem

Our study utilized a randomized and counterbalanced design with repeated measures to evaluate muscle activation between the partial and full back squat exercise with relative external load equated between conditions. All subjects performed a ten repetition maximum (10RM) test equated for each back squat condition (partial and full back squat). The range of motion was determined by an electrogoniometer on the knee joint, and all subjects performed both conditions in a self-selected cadence. Surface electromyography was measured from the vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), biceps femoris (BF), semitendinosus (ST), erector spinae (ES), soleus (SL), and gluteus maximus (GM). All electromyographic data were defined by the electrogoniometer data, characterizing both the concentric and eccentric phase of each repetition. The rating of perceived exertion (RPE) was evaluated after each back squat condition.

## Subjects

To establish the appropriate sample size for this study, a pilot study was conducted to collect data on the peak sEMG amplitude of the root mean square (RMS) from the VL in both conditions. Based on a statistical power analysis derived from these data (RMS VL EMG), it was determined that twelve subjects would be necessary to achieve an alpha level of 0.05, an effect size of 1.22, and a power (1-β) of 0.80 (12). Therefore, we recruited fifteen young, healthy, resistance-trained men (age: 26±5 years, height: 173±6 cm, 10RM test at partial back squat: 92.5±24.9 kg; 10RM test at full back squat: 70.9±23.2 kg and total body mass: 80±8 kg, 5±2 years of experience with the back squat exercise) to participate in the study. Subjects had no previous lower back injury, surgery on the lower extremities, and no history of injury with residual symptoms (pain, "giving-away" sensations) in the lower limbs within the last year. This study was approved by the University research ethics committee and all subjects read and signed an informed consent document (#68/2016).

## Procedures

Prior to data collection, subjects were asked to identify their preferred leg for kicking a ball, which was then considered their dominant leg (22). All subjects were right-leg dominant, and the dominant leg was chosen to be analyzed during the squat exercise conditions. Tests were randomized and counterbalanced for all subjects and experimental conditions. Subjects reported to have refrained from performing any lower body exercise other than activities of daily living for at least 48 hours prior to testing.

Subjects attended two sessions in the laboratory. During the first session, each subject was instructed in the proper back squat technique for both conditions (partial: 0-

90° knee flexion, and full: 0-140° knee flexion). After a subsequent 5-min cycle warm-up at 70 rpm, subjects then performed a ten repetition maximum (10RM) test of the back squat to determine the maximum weight that could be lifted for 10 consecutive repetitions at a self-selected cadence for each condition (partial and full back squat). If a 10RM was not achieved in the first attempt, the load was adjusted by 4–10 kg and a minimum five-min rest was given before the next attempt. Only three trials were allowed per testing session in order to avoid neuromuscular fatigue. Subjects received standard instructions regarding technique, and exercise execution was monitored and corrected when necessary to ensure no stopping between eccentric and concentric phases for each test. Verbal encouragement was provided to facilitate optimal performance. After the 10RM load was determined for a given condition, 30 minutes of rest was allowed before the 10RM determination of the alternative condition.

The second session was conducted 1 week later, and all subjects reported to have refrained from performing any lower body exercise other than activities of daily living for at least 48 hours prior to testing. Subjects warmed-up by cycling for 5-min at 70 rpm and then performed one set of 10RM for each back squat condition (partial and full). The subjects' feet were positioned at hip width and vertically aligned with the barbell position. The barbell was positioned on the shoulders (high-bar position) for all subjects and experimental conditions. A rest period of 30-min was provided between conditions. All measures were performed at the same hour of the day, between 9 and 12 AM, and by the same researcher.

## Measures

***Surface Electromyography (sEMG):*** The subjects' body hair was shaved at the site of electrode placement and the skin was cleaned with alcohol before affixing the sEMG electrode. Bipolar active disposable dual Ag/AgCl snap electrodes spanning 1-cm in diameter for each circular conductive area with 2-cm center-to-center spacing were used in all trials. Electrodes were placed on the dominant limb along the axes of the muscle fibers according to the SENIAM/ISEKI protocol (17): Gluteus Maximus (GM) at 50% of the distance between the sacral vertebrae and the greater trochanter; vastus lateralis (VL) at 2/3 of the distance between the anterior spina iliac and the superior aspect of the lateral side of the patella; rectus femoris (RF) at 50% on the line from the anterior spina iliac to the superior part of patella; vastus medialis (VM) at 80% on the line between the anterior spina iliac superior and the joint space in front of the anterior border of the medial ligament; biceps femoris (BF) at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia; and semitendinosus (ST) at 50% on the line between the ischial tuberosity and the medial epicondyle of the tibia; erector spinae (ES) at 2 finger width lateral from the process spinae of L1; and soleus (SL) at 2/3 of the line between the medial condylis of the femur to the medial malleolus. The sEMG signals were recorded by an electromyographic acquisition system (EMG832C, EMG system Brasil, São José dos Campos, Brazil) with a sampling rate of 2000 Hz using a commercially designed software program (EMG system Brasil, São José dos Campos, Brazil). EMG activity was amplified (bi-polar differential amplifier, input impedance = 2MΩ, common mode rejection ratio > 100 dB min (60 Hz), gain x 20, noise > 5 μV), and converted from an analog to digital signal (12 bit). A ground electrode was placed on the right clavicle.

EMG signals collected during all conditions were normalized to a maximum voluntary isometric contraction (MVIC) against a fixed strap resistance. Two trials of five-second MVICs were performed for each muscle with a one-minute rest interval between actions for the dominant leg. The first MVIC was performed to familiarize the participant with the procedure. For GM MVIC, subjects were in the prone position with their knee flexed at 90º and resistance placed on the distal region of the thigh with the pelvis stabilized. For ES MVIC, subjects were in the prone position with resistance placed on the distal region of the trunk. For VL, VM, and RF MVICs, subjects were seated with their knee flexed at 90º and resistance placed on the distal tibia. For BF and ST MVICs, subjects were seated with their knee flexed at 90º and resistance placed on the distal tibia. For SL MVICs, subjects were seated with their knee flexed at 90º and a vertical resistance placed on the distal femur. Verbal encouragement was given during all MVICs. The order of MVICs was counterbalanced to avoid any potential neuromuscular fatigue.

***Rating of perceived exertion (RPE):*** RPE (CR-10 scale) was assessed during each back squat set in both conditions (partial, and full). Standard instructions and anchoring procedures were explained during the familiarization session. Subjects were asked to use any number on the scale to rate their overall effort for each condition. A rating of 0 was associated with no effort and a rating of 10 was associated with maximal effort and the most stressful exercise ever performed. Subjects were shown the scale 30-min after each condition and asked: "How was your workout?"(13).

## Data analyses

sEMG data were analyzed with a customized Matlab routine (MathWorks Inc., Massachusetts, USA). All sEMG data were defined by the electrogoniometer data, characterizing both the concentric and eccentric phase of each repetition. The first repetition was removed from the data to ensure anybody adjustment or change in exercise cadence. The digitized sEMG data were band-pass filtered at 20-400 Hz using a fourth-order Butterworth filter with a zero lag. For muscle activation time domain analysis, RMS (150ms moving window) was calculated during the MVIC and the sEMG data. The sEMG data was then normalized to the RMS average of the two peak MVICs for each amplitude and muscle. The RMS analysis was defined from the average of the first three repetitions for each condition and muscle.

## Statistical Analyses

The normality and homogeneity of variances within the data were confirmed by the Shapiro-Wilk and Levene's tests, respectively. A 2x8 repeated-measures ANOVA (condition x muscle) was used to measure differences in RMS. Post-hoc comparisons were performed with the *Bonferroni* test. Cohen's formula for effect size (*d*) was calculated, and the results were based on the following criteria: <0.35 trivial effect; 0.35-0.80 small effect; 0.80-1.50 moderate effect; and >1.5 large effect, for recreationally trained subjects (31). Interrater reliability was assessed for the researcher who positioned and evaluated RMS tracings for all muscles and conditions. Reliability was operationalized using the following criteria: < 0.4 poor; 0.4 - < 0.75 satisfactory; ≥ 0.75 excellent. The ICCs ranged between 0.91 and 0.98 (excellent) for all RMS data. An alpha of 5% was used to determine statistical significance.

## RESULTS

For RMS, there was a significant (*P*<0.001) main effect for muscles and conditions (*P*=0.044). The sEMG activity was significantly greater in the partial compared to full back squat for the GM (P=0.004, d=1.0, Δ%=29.37), BF (P=0.009, d=0.22, Δ %=11.78), and SL (P=0.031, d=0.27, Δ%=10.85) (Figure 1). No significant were noted in any of the other muscles studied

There was no significant difference for RPE between partial and full back squat exercise at 10RM (partial: 8±1 and full: 9±1, *P*>0.05).

*****INSERT FIGURE NEAR HERE*****

## DISCUSSION

The purpose of this study was to evaluate the muscle activation between partial and full back squat exercise when performed with the load equated on a relative basis. The main findings of this investigation were that both partial and full back squat demonstrated a similar overall level of muscle activation of the quadriceps femoris, while a higher muscle activation of the gluteus maximus, biceps femoris and erectors spinae was noted in the partial versus full condition.

The squat exercise simultaneously utilizes several muscles with different morphologies (monoarticular and biarticular) in a manner that produces "muscle coordination" (20, 30). A multi-joint task to strengthen the knee and hip extensors is more complex for the neuromuscular system as two joints work in concert to achieve the task (32). Also, since some muscles cross more than one joint, the complexity increases compared to an open chain terminal knee extension or isolated hip extension exercise (32). During the squat exercise, there are several biarticular muscles interacting including the hamstrings and RF (34). Biarticular muscles such as RF, BF and ST have intermediate activation when the muscles have agonistic action at one joint and antagonistic action at the other joint; this is in contrast to the high activation seen when a biarticular muscle works as an agonist for both joints simultaneously (30). Lombard (19) suggested that biarticular muscles of the lower extremity act in a “paradoxical” fashion when the movement is constrained or controlled (named *Lombard’s paradox),* it is observed with RF, BF, and ST. The extension seen from both the hip and knee is the result of the differential moment arms of the two muscles at each joint and range of motion. The present results showed higher muscle activation for BF in the partial back squat when compared to full condition, which may be explained by the fact that it acts as a joint stabilizer at the knee and a prime mover at the hip. Additionally, the partial back squat presents a longer moment arm at the hip and knee exactly in the sticking region, thereby creating a higher hip and knee extensor moment. Thus, the BF muscle allows for the extension of both the knee and hip (32). That said, the absolute activity of the BF was approximately half that of the quadriceps, likely due to the antithetical biarticular actions of the BF during the squat.

In comparison to the BF, the RF has a greater moment arm across the knee due to its attachment at the patella, which creates a strong extensor moment at the knee joint. Considering the present results, the RF showed similar muscle activation in both conditions. This may represent a higher effect on muscle activation during the initial phase of the back squat movement (between 20° to 90°) than after 90°, corroborating previous findings by Marchetti et al.(20). Additionally, all muscles may be affected by a sticking point which is considered a poor mechanical force position in which the lengths and mechanical advantages of the muscles involved are such that their capacity to exert force is reduced in this region, and where the lifter experiences difficulty in exerting force against the barbell (11, 35, 37-39). Cardinale et al., (5) displayed that the higher muscle activation during the squat exercise occurs at 90º of knee joint-angle position, which is considered the sticking region.

During the squat exercise, several monoarticular muscles contribute to movement including the soleus, vasti (lateralis, medialis and intermedius), and GM (34). The present results showed that muscle activation of the VM and VL did not differ between partial and full back squat condition. Additionally, the highest muscle activation was observed in the partial condition for GM and SL. When monoarticular muscles perform as agonists, their activation generally increases as the joint moment increases (30). Our findings support this theory as all monoarticular muscles analyzed (SL and GM) presented lower values of activation during full back squat. In this specific full position, it is feasible to speculate that changes in muscle length (e.g. GM and SL) modify muscle contractile abilities and, in turn, modify sEMG-force and sEMG-moment relationships (30, 40). Alternatively, afferent signals from muscles could decrease motoneuronal firing frequency (i.e. Golgi tendon reflex) during contractions when the muscle fibers are in an elongated position (14). Similar to our results, Robertson et al., (32) reported that the GM muscle activity level was reduced at maximum full (deep-knee) squat depth. Robertson et al., (32) also concluded that the biarticular muscles (BF, ST, RF) functioned mainly as stabilizers of the knee and hip joints during the eccentric and concentric phases of a dynamic squat. The authors hypothesized that the reduced GM activity level at maximum squat depth was because the GM was not needed to maintain stability or perhaps that it permitted an extra degree of hip flexion that created a deeper counter-movement immediately before the ascent phase.

The ankle complex helps to maintain support and balance during squat exercise (9, 34). The gastrocnemius has been primarily studied in squat exercise and presents a moderate level of activation (34). On the other hand, the SL is a pure plantar flexor, monoarticular muscle, with an important role mainly in promoting balance in upright tasks. Toutoungi et al. (36) showed that the SL was more active than gastrocnemius at high degrees of knee flexion. The present study observed a lower muscle activation of the SL in the full versus partial condition. This may be due to the fact that a higher SL length caused by the full back squat affects the maintenance of balance (e.g. center of pressure) and consequently interferes with sEMG-forces, sEMG-moment relationships (30, 40) and afferent signals from Golgi tendon reflex.



Others have also investigated muscle activation during the squat by comparing different knee joint angles in the dynamic squat. Caterisano et al., (6) measured the relative contributions of GM, BF, VM, and VL muscles of ten experienced lifters while performing dynamic squats at 3 depths (full-depth, the partial, and parallel), using 100–125% of body weight as resistance. Caterisano et al. (6) found that during the concentric phase of the dynamic squat, the GM activation was higher during full-depth (35.4%) compared to the partial (16.9%) and parallel (28.0%) squat exercise and that the BF, the VM, and the VL did not change. The results suggested that the GM, rather than the BF, the VM, or the VL, becomes more active in concentric contraction as squat depth increases, however, the external load was the same in all conditions, affecting the time under tension and the level of muscle activation.

On the other hand, Contreras et al. (7) compared the mean and peak electromyography amplitude of the upper gluteus maximus, lower GM, BF, and VL of front, full, and parallel squats at an estimated 10 RM; no significant differences were seen between full, front and parallel squats for all tested muscles. And, Gorsuch et al.,

(15) measured the muscle activity during partial and parallel squats at 10 RM. The RF and ES activity were higher during parallel squat than partial squat condition. In the present study, the ES presented high muscle activation during the partial back squat due to the forward trunk inclination aiming to control the center of pressure during the range of motion.

Other studies have shown superior muscular hypertrophy when squatting throughout a full versus a partial range of motion (4, 27). The greater cross-sectional area of the muscles found by Bloomquist (4) may be more related to time under tension than the muscle activation. However, without muscle activation data, this remains speculative. Alternatively, the hypertrophic superiority of full squats may be due to training at long muscle lengths, which has been shown to promote greater increases in cross sectional area compared to training at shorter muscle lengths (28). Our study is limited by the inclusion of of healthy, well-trained men only, which therefore precludes the genralizability of our findings to other populations. Our sample size was also fairly small and the study thus may have been underpowered to identify differences between muscles and conditions. Finally, we did not control for hip and knee angles to create a more realistic squat performance.

**PRACTICAL APPLICATION**

Performing the back squat at different depths with the load equated on a relative basis alters muscles activation of the prime mover (gluteus maximus), and stabilizers (soleus and biceps femoris). The partial back squat generates the highest muscle activation when compared to full back squat. Alternatively, muscle activation of the knee extensors and knee flexors are unaffected by squat depth.

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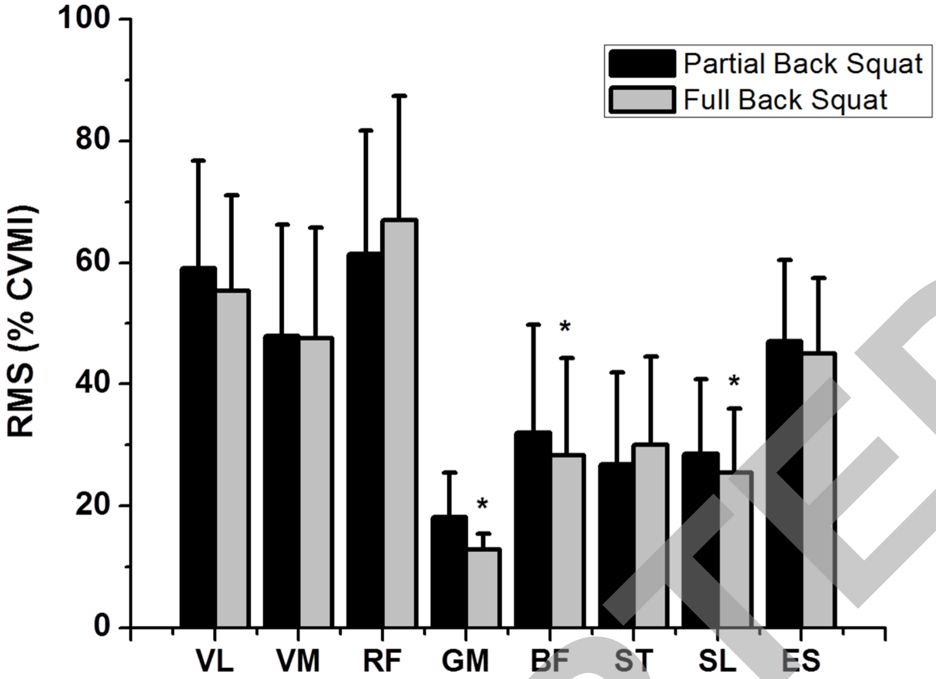
## FIGURE LEGEND

**Figure 1**. Mean and standard deviation of RMS EMG in different back squat conditions (partial and full). *Means significantly less between amplitudes, *P*<0.05.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