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The Electromyographical Activity of Heavy Front and Back Squats at Varying Depths

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ABSTRACT

Many sports practitioners alongside anecdotal information believe front squats (FS) can isolate different muscles compared to back squats (BS). Which depth offers peak activation across muscles has also been disputed, specifically from parallel to "full" squats. Consequently, the purpose of this study was to measure mean and peak activity of 6 hip, trunk and thigh muscles while performing FS and BS at 3 depths. 12 participants performed randomized trials of BS and FS at partial, parallel and full depths using an 85% 1RM load. Electromyographic (EMG) surface electrodes were placed on Vastus Medialis (VM), Vastus Lateralis (VL), Rectus Femoris (RF), Biceps Femoris (BF), Erector Spinae (ESM) and Gluteus Maximus (GM). EMG data were quantified by integration, high pass filtered and expressed as percentages of peaks of each muscle across trials. Analysis of variance and Bonfferoni post hoc tests revealed significance ($p=\leq 0.05$) between BS and FS in BF, GM peak activity and BF, VL and ESM mean activity. Partial to parallel depths across muscles, parallel to deep for BF and GM, partial to parallel across muscles except for peak ESM and mean GM. Concluding depth and activity run linearly, however from parallel to deep, only BF and GM increase in activity.

Keywords: Parallel, Deep squat, Resistance training, Gluteus maximus, Biceps femoris.

INTRODUCTION

The back squat (BS) and its variants have been continually used throughout strength and conditioning programmes, physical therapist training prescriptions and within rehabilitation settings to increase physical power and strength [1], evaluate functional capacity [2] and to strengthen the knee joint [3,4]. The squat is commonly utilized in day to day tasks such as sitting, standing and picking items from the floor [5], for these reasons many health professionals often prescribe the exercise, not necessarily to improve physical attributes but improve daily living [6]. It is recognized as the "gold standard" when measuring lower body strength [3,4], due to the plethora of musculature stressed to perform the multi-joint exercise. The major muscles used are the hamstrings, gluteus maximus, quadriceps, and gastrocnemius [7], BS also rely on stabilizing muscles such as the abdominals, spinal erectors, muscles around ankle joints and the hip [8]. The BS has also been prominent for its ability to stress and develop other tissues in the body such as; ligaments and tendons [9,10], strength, speed [11] and bone density [12].

Due to the abovementioned benefits and physical attributes which have been found through performing the back squat [5,8,9], it is clear to see why it has such an unsurpassed use amidst training programs amongst all types of practitioners. However, there are many factors which have claimed to alter muscle activity during the squat such as; bar placement, front and back squats, foot placement, foot inclination, torso lean and squat depth [13]. Regarding foot placement or stance, the majority of research states there is no significant difference in muscle activity despite ranges of different widths used [3,4]. However McCaw and Melrose [14] concluded activity of the medial thigh and buttocks increased with changes in stance width, possibly due to differences in subjects as standard foot placements were utilized, perhaps modifying results due to different movement patterns being novel and thus a higher activation was seen, due to a new sense of balance being required for the squat.

Concerning foot inclination during the squat, Boyden et al. discuss that any degree of foot rotation did not affect muscle activity of the vast or Rectus Femoris (RM) agreeing. Although Signorile, Kwiatkowski, Caruso and Robertson found lateral rotation of the tibia brought about a greater root mean square of EMG than other foot positions across all muscles, however, subjects were required to change their technique to such an extent it significantly reduced stability, illustrating possible safety risks, even if increases in muscle activation were observed.

Regarding bar placement during BS, powerlifters utilizing low bar positions have been portrayed to apply a larger torso lean [15,16] which has been formerly stated to increase maximum loads lifted [10]. Due to the greater inclination of the torso, it has been found to increase muscle activity of the hamstrings and thighs [17-19], which could be attributed to higher loads which can be lifted through mechanical advantages, though the high bar squat has been attributed to increased shear forces through the knee joint [19]. However when utilizing the low bar variation, loads on the lower back are increased [20], as well as hip and trunk torques escalating the risk of injury [21]. It is for the aforementioned reasons the high bar variation is used by the majority of weightlifters and prescribed by health professionals [22], coupled with a higher transferability to the Olympic lifts due to the upright nature of the high bar squat [18].

Regarding activity of the hamstrings during the high bar variation, they have been found to be minimal [3,4], however, no other study looking at muscle activity and depth has agreed with the suggestion from Pauletto that deeper squats will activate the hamstrings moreover than a partial squat.

However, when considering levels of activation between the front and back squat, many coaches and athletes believe that both offer different levels of activation with regards to individual muscles, however, these beliefs are unsupported [23]. To date, only several papers have researched the difference between the two variants.

Gullet et al. established that bar position had no effect on EMG activity of any muscles, additionally noting decreases in the knee joint compressive and extensor moments in front squats. Concluding FS offer the same levels of muscle activation as the back squat, whilst being more attractive to those with previous knee joint issues [23].

Another paper observing differences in muscle activation between FS, BS, and lunges concluded EMG activity was higher in quadriceps during lunging than subsequent front and back squats. This study, in particular, used a small sample size, which could have given a poor approximation [24], however, these results would perhaps be more beneficial to those returning from injury from a rehabilitation standpoint as the load used was a 22.5 kg dumbbell.

Although Gullet et al. [23] concluded no differences in muscle activation between FS and BS they used an inhomogeneous group which could have skewed results as males and females have been found to have the different squatting technique [25,26].

Gullet et al. [23] used a 70% 1RM, similar to Caterisano et al. using 100%-125% body weight, both loads of which have been described as “medium intensities”, which are significantly less than loads prescribed for strength development [7,27,28], with Häkkinen, Komi, Alen and Kauhanen arguing that loads less than 80% 1RM lead to decreases in EMG activity of involved muscles, with subsequent decreases in muscle strength [29]. This becomes apparent as Caterisano et al. conclude their findings may only be coherent to lifting with submaximal loads and that future studies should use heavier loads, agreeing with Mcaw and Melrose [14].

When concerning squat depth, controversy still exists amongst practitioners as to which depth offers maximum safety regarding knee and back joints [30], though squat depths are typically seen as partial 45 degrees, parallel-90 degrees and “full” depth-greater than 100 degrees [4].

The concern for injury through performing a deep (>100°; Schoenfeld [22]) squat originated from Klein [31], studying weightlifters and powerlifters using orthopedic tests to determine medial and lateral knee stability, concluding deep knee bends experienced in a loaded deep squat stretched knee ligaments. Arguably Ariel’s [19] conclusion that shear forces in the knee increase by 33% using weightlifting squat techniques could be coupled with Klein’s [31] findings as shear forces act upon ligaments and tendons, weakening them over time [32,33]. However, performing squats which illicit less shear forces such as less anterior tibial translation can prevent the possible negative effects of a squat by decreasing the shear forces through the knee joint [34].

Contradictory to Klein's research [31], no other literature to date has also suggested increased laxity or instability of the knee joint [35]. Since previous findings, the "deep" squat has been found to increase knee stability [4,30], and consequently is being utilized by many rehabilitation specialists and strength and conditioning programmes [30]. However, the damaging effects of the "deep" squat found by Kleins [31] studies are still recognized and affirmed by many health professionals despite the body of literature against these claims [4,36,37].

Though health professionals may still coach athletes to parallel squatting depths in fears of degenerative knee joint issues, the need for "deep" squats has been debated by Schoenfeld [22] as peak muscle activity has been found to be 80-90 degrees of flexion [3,4], arguing "deep" squats past 100 degrees are unnecessary. This argument stems from research looking at correlations between squat depth and muscle activity, however, only a handful of papers have researched EMG activity versus depth with regards to back squats, only Caterisano et al. found significant differences in muscle activity with regards to GM increases as depth increased using depths of 135, 90 and 45 degrees.

Gorsuch et al. [38] found increases in muscle activity between partial and parallel squats amongst males and female cross country runners in RF and ESM. However, Gorsuch et al. [38] looked at BF, RF, ESM, and Gastrocnemius, possibly neglecting GM. Nevertheless, both papers agree on no differences in BF activation at any depth, which is attractive as both papers used different subject populations, perhaps a general consensus that BF activity is not enhanced as depth increases. Additionally, squat depth has found to have no effect on hamstring activation as well as either fast, which is consistent with the bi-articular structure of the hamstrings, as the length stays fairly constant throughout the movement [39].

However, hamstrings have been found to be most active during the simultaneous knee and hip extension seen in the squat, [40], where athletes are driving to push the hips through, known by power lifters as the "sticking point" represented by decreases in velocity from the bottom position [41,42]. Peak hamstring activity has been found between 10-70 degrees of flexion [43], possibly correlating with the "sticking point" assuming a longer duration or higher intensity during the "sticking point" the higher the activation of the hamstring, which has not been found to date, supporting Pauletto's [44] suggestion.

In reviewing beliefs of coaches and athletes in differences of muscle activation between FS and BS and disputed research of which depth offers the highest muscle activation using submaximal loads. The purpose of this study was to investigate the effect of using an 85% 1RM load for the front and back squat at three depths, partial (135°), parallel (90°) and deep (45°) on the electromyographical activity of muscles in the quadriceps, hamstrings and lower back. It was hypothesized that with an increase in depth would bring increases in activity across all muscles, BF activity would be higher through the partial squat and that ESM activity would be higher during the back squat.

METHODOLOGY

Subjects

Twelve males volunteered as subjects for this study, with individuals having histories of lower limb injuries or surgeries excluded from the study. Descriptive characteristics of the subjects consisted of: age=21.5 ± 2.07 years, body mass=85.14 ± 9.51 Kg and height=179.98 ± 6.93 Cm (Mean ± standard deviation). All subjects had an experienced training history utilizing free weights (≥2 years' experience), and all had experience in performing to the required squat depths as part of training (135°, 90° and 45° at the knee). The subjects read and signed informed consent forms, and St Mary's university college ethics committee approved all procedures.

Subjects were required to come to the lab three times. The first session found one repetition maximums from each participant in the front and back squat. The second session demonstrated the equipment and familiarised subjects with the study protocol. Lastly, the third session was used for data collection.

One repetition max testing (first session)

Participants performed BS using the high bar position; with the bar resting on top of the posterior deltoids, middle of the trapezius utilizing a handgrip slightly wider than shoulder-width apart [7]. Then FS where the bar rested on the anterior deltoid and clavicles, fully flexing the elbows to position the upper arms parallel to the floor using a closed pronated grip, slightly wider than shoulder-width apart [7]. For each trial, participants were instructed to maintain a consistent upper body position, keeping the same torso angle with regards to the femur, so the coaching cue "Big chest" was used to prevent the angle of the torso altering [8]. 1RM, familiarisation, and data testing were all performed in the biomechanics laboratory. All participants received the standardized warm up (Table 1)

Table 1: Standardised warm up, including squat build ups.

Standardised warm up-exercise	Reps/Duration
Stationary jogging	2.5 minutes
Body weight squats	10
Lunges-Each leg (EL)	10
Side Lunges-EL	10
Leg swings-EL	10
Spidermans-EL	10
Hamstring walks-EL	10
Calf Walk outs-EL	10
Back squat build ups	Reps/Recovery
50% 1RM	5 reps
Rest	3 minutes
65% 1RM	3 Reps
Rest	3 minutes
75% 1RM	2 Reps
Rest	3 minutes
commence testing at 85% 1RM	

After warming up (Table 1), subjects 1RM was established in line with guidelines set by Baechle and Earle [7] determining scores for the front then back squat [23], using a lightweight and increasing the weight by estimating a near maximal load which the participant can complete 3-5 repetitions, a 2 minute rest, with a load increase 2-3 repetitions, providing a 2-4 minute rest and one last increase, instructing the participant to attempt a 1RM.

Second session

After warming up (Table 1), subjects were manipulated into the correct depths required using a goniometer; partial squats where the angle between the femur and tibia was approximately 135 degrees, parallel squats, approximately 90 degrees between the femur and tibia and full squats, approximately 45 degrees between the femur and tibia.

Resistance bands were used to define each depth for each trial, with subjects being manipulated into the correct depths using a goniometer; this enabled subjects to know when the correct depth was achieved (Appendix 3).

Third session

EMG activity was collected using a Biopac system MP150 (Biopac Systems Inc. CA, USA), recorded using Biopac Acknowledge (version 3.73, Biopac Systems Inc. CA, USA) and sampled at 1000Hz. Participants had their skin cleansed and shaved if necessary for electrode placement on the belly of each muscle using the Seniam placement protocol (Appendix 1.) on muscles of interest (Appendix 2.) The EMG activity of each muscle was measured using a set of three disposable electrodes placed in a bi-polar configuration with the centres 2cm apart running linearly with the fibres of each muscle, with the third placed on a bony landmark as a reference electrode (Appendix 1). After electrode placement, participants underwent back squat build ups (Table1).

All trials were randomized for effect order, once the participant at the start of each squat was comfortable, the term squat was used to indicate the start of data collection as well as the descent of each squat. Participants performed three squats to the randomized depth followed by a three-minute recovery [7] until all specified depths have been completed for both the front and back squat using the same recovery period.

Data analysis

EMG data was acquired during both the eccentric and concentric phase of each squat; the raw data was then rectified and filtered using a high pass frequency filter and normalised to the peak of each muscle across all trials [45].

The EMG data were averaged across all three trials for each squat depth and analyzed using repeated measures ANOVA. A Bonferroni post hoc analysis was then carried out through PASW statistics (v.18, SPSS: An IBM Company the software package SPSS for Windows) with differences in the muscular activity being assessed for statistical significance ($p<0.05$).

RESULTS

12 participants completed data collection sessions, squatting 85% 1RM in a randomized order for all trials. Peak and Mean (PAM) values of muscle activity for VL, VM, RF, BF, ESM, and GM are expressed as percentages of normalized peaks for each muscle over trials shown in Figures 1-4. Figures 1 and 2 show PAM values with standard deviations for differences in activity against depth and Figures 3 and 4 showing PAM values with standard deviations for differences in activity for BS versus FS.

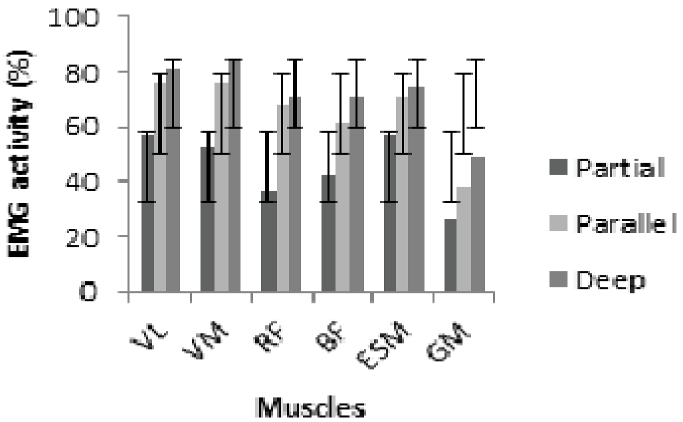

Figure 1: Peak values for differences in activity against depth. (normalised peak muscle activity at three squat depths).

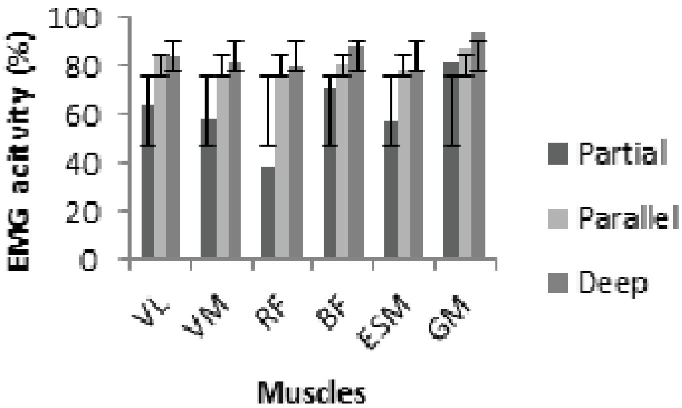

Figure 2: Mean values for differences in activity against depth.

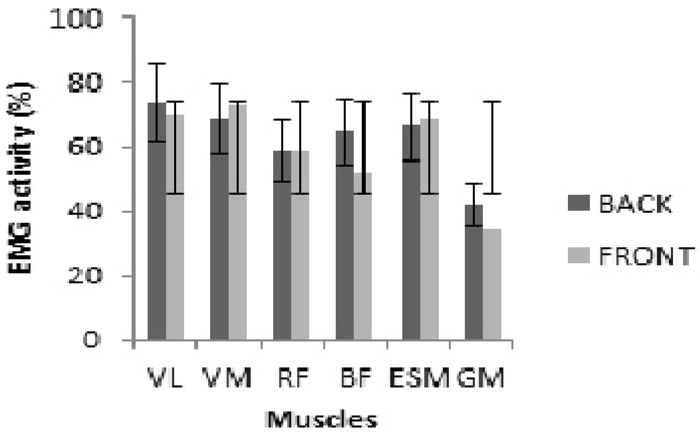

Figure 3: Peak values for FS v BS.

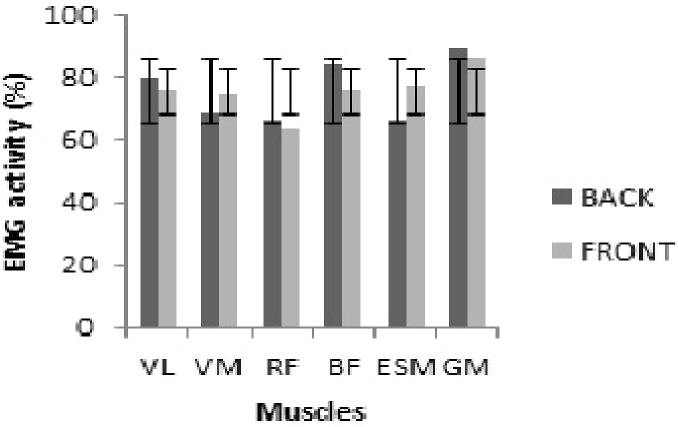

Figure 4: Mean values for FS v BS.

Peak

Peak muscle activity against depth showed significant difference for BF (1.242, 13.666=69.376, p=0.001), VM (2, 22=29.333, p=0.001), ESM (2, 22=12.490, p=0.001), GM (2, 22=29.123, p=0.001), RF (1.208, 22.567=22.567 , p=0.001) and VL (2, 22=40.159, p=0.001) . basically look at my graphs for the significant difference between depths.

Mean

Mean muscle activity of BF (1.266, 13.925=31.123, p=0.001), VM (1.801, 19.811=21.498, p=0.001), ESM (1.363, 14.933=41.480, p=0.001), GM (2, 22=8.272, p=0.002), RF (1.287, 14.160=35.673, p=0.001) and VL (1.199, 13.188=21.560, p=0.001) were also significant against depth.

Through pairwise comparisons, peak values for deep versus parallel trials (DVPLT) showed significance for BF (p=0.001) and GM (p=0.001) whilst VM (p=0.203), ESM (p=0.670), RF (p=0.635) and VL (p=0.230) were not significant. Peak values for Deep Versus Partial Trials (DVPT), across all muscles were significant, BF (p=0.001), VM (p=0.0001), ESM (p=0.0001), GM (p=0.0001), RF (p=0.001) and VL (p=0.0001). Parallel Versus Partial Trials (PLLVP) for peak values were significant for BF (p=0.001), VM (p=0.001), GM (p=0.003), RF (p=0.001) and VL (p=0.001), whilst ESM was non-significant (p=0.07).

Mean values for DVPLT showed non-significance across all muscles, BF (p=0.06), ESM (p=1.000), GM (p=0.063), RF (p=1.000), VL (p=1.000), VM (p=0.552). Mean values of DVPT across all muscles were significant, BF (p=0.0001), ESM (p=0.0001), GM (p=0.002), RF (p=0.0001), VL (p=0.0001) and VM (p=0.0001). Mean values of PLLVP trials were significant for BF (p=0.0001), ESM (p=0.0001), RF (p=0.0001), VL (p=0.0001) and VM (p=0.0001) were significant whilst GM was non-significant (p=0.472).

Peak activity for BS versus FS showed no significant difference in RF (p=0.961), VM (p=0.236), ESM (p=0.543) and VL (p=0.64) however BF (1.000, 11.000=19.200, p=0.001) and GM (1,11=21.443, p=0.001) showed significance. Mean activity for BS versus FS, showed no significant difference in GM (p=0.186), RF (p=0.320) and VM (p=0.153), however BF (p=0.002), ESM (p=0.021) and VL (p=0.004) showed significance.

Peak values of squat by depth interactions showed no significance VL (p=0.545), VM (p=0.518), RF (p=0.310), GM (p=0.177), BF (p=0.102) and ESM (p=0.068). Mean values of squat by depth interactions demonstrated no significance through VL (p=0.633), VM (p=0.895), RF (p=0.877), GM (p=0.284), and BF (p=0.264), however ESM (df=2, 22=7.857, p=0.003) showed significance. Paired sample T-tests revealed mean ESM activity was significant through partial BS versus partial FS (t=-6.795, df=11, p=0.0001) although parallel (t=-1.450, df=11, p=0.175) and deep trials (t=-4.52, df=11, p=0.660) were insignificant.

DISCUSSION

The results from this study show for peak values that as depth increases from a partial to deep squat, there are significant increases of activity across all muscles. There are also significant increases across all muscles except ESM from a partial range to parallel; agreeing with findings of RF increased activity from Gorsuch et al. [38] although ESM activity in the current study was found to be insignificant, possibly due to the different populations used. For example, a well-trained weightlifting population might demonstrate differences in technique when compared to a running population, such as a higher forward lean thus activating ESM further, whereas the weightlifting population has been attributed to a more upright nature.

However, from a parallel to deep depth, only GM and BF were significant, in conflict with the findings of Gorsuch et al. [38] for BF, again the difference in findings could have been attributed to differences in subject populations utilized. Although this paper agrees with the findings of Caterisano et al. that GM activity increases as depth increases, the current study also agrees with Wrettenberg et al. [18], who found no significant difference with regards to VM and VL from a parallel to a deep squat.

Although the current study agrees with Pauletto's [44] suggestion that as depth increases, BF activity also increases; the findings of the current study could be related to the concentric or eccentric phase as kinematic data was not obtained throughout this methodology. However during the eccentric phase of the back squat, depth has been found to affect BF activity, although only in the initial phase; up to 60 degrees knee flexion, with peak BF activity being found between 10-70 degrees of knee flexion [22], whilst increasing depth past 70 degrees flexion has been found to reduce BF activity [4]. Findings of increased BF activity in the current study could be attributed to an increased co-contraction and or higher concentric hip extensor contribution, due to the hamstrings function of knee flexion and synergistic co-contractors [46] which could have been exuberated through the use of the 85 1RM load as suggested by Häkkinen et al. [22].

Regarding the mean values, as depth increased from a partial to deep squat, all muscles significantly increased in activity disagreeing with the findings of Caterisano et al. who found no significant difference between depths with concerns to BF, VMO and VL, which could be attributed to the vastly different loads used between studies [22].

Whilst between parallel and partial squats as depth increased, all muscles except GM increased significantly in activity, which is consistent for RF and ESM from the findings of Gorsuch et al. [38], however disagreeing with the findings of GM from Caterisano et al. The difference in results could be attributed to variations in experience across subject populations, the current study used participants with 2 or more years' experience, whereas Caterisano et al. used participants with more than 5 years' experience possibly modifying results though increases in squat proficiency and ergo differences in technique [47]. Concerning the parallel to deep trial, there was no significant difference across all muscles, consistent with the findings of Caterisano et al. for BF, VMO, and VL.

Relating the FS versus BS in terms of peak activation across all depths, only BF and GM showed the significance of the back squat eliciting higher activity than the FS, conflicting with the findings of Gullet et al. [23] who assessed RF, VL, VM, BF and ESM who found no significant difference. Whilst the current study disputes a higher activity of BF through the BS, which could be attributed to both studies using different subject populations, in addition Gullet et al. [23] used both males and females as a collective group which could have resulted in skewing there results, as males and females have been found to have different squatting techniques [25,26]. Furthermore, the vast differences in loads lifted; with the 85% 1RM eliciting higher activity [29] could explain the differences in results.

Regarding mean values for the FS versus BS in terms of activity across all depths, BF and VL showed a significant increase in activity whilst participants performed the BS variation, again disagreeing with the findings of Gullet et al. [23], however the FS elicited a higher significant activation of the ESM than the BS, which could be attributed to the inhomogeneous group used by Gullet et al. [23] possibly skewing results due to differences in technique due to gender [25,26]. Whilst also disagreeing with the suggestion from Garhammer [48], that FS requires less muscular force in the lower back than the performing BS, possibly due to the often higher loads lifted resulting in high levels of activity. Regarding any squat by depth, interaction observed, through peak values across all muscles was insignificant, although, through mean values, ESM was significant with the partial FS showing the higher activity of the ESM than the partial BS.

In conclusion, the results of the current study support the hypothesis that increasing the squatting depth from partial (135 degrees between the femur and tibia) to deep (45 degrees between the femur and tibia), has a significant effect on the activity of VL, VM, RF, BF, ESM, and GM. However, between the depths of parallel (90 degrees between the femur and tibia) to deep (45 degrees between the femur and tibia) concerning peak values, only GM and BF were significant. Whilst FS offers higher ESM activity than BS, the BS offers higher activity of BF and GM.

Practical applications

Although anecdotal information between coaches, athletes and publications suggest higher activation of the quadriceps during the front squat, results from the current study suggest otherwise. The quadriceps do not appear to be more active during the FS, in fact, it appears to be the BS which elicits higher activity of the VL, as well as BF and GM although the FS activates the higher activity of ESM than the BS. Regarding depth, the current study suggests that "deep" squats elicit higher activity from VL, VM, RF, BF, ESM and GM than partial squats however the increase in depth from parallel to "deep" only increase the activity from GM and BF.

It is important to note the limitations of the current study to further improving the quality of future investigations. Firstly, subject experience, if this was increased for future studies, perhaps activation patterns seen might be somewhat different, due to the increased learning effect and skill level whilst performing the FS and BS [49]. Secondly, kinematic data could have been used to separate trials into eccentric and concentric components, which would illustrate at which knee; hip or torso angle did the peak activity each muscle take place [50-54].

Further studies could replicate the current study whilst using kinematic data to attribute differences in muscle activity through alterations in participant's technique, for example, torso lean could be linked to increases in ESM activity, whilst the upright nature of the FS could aid in explaining differences in quadriceps activity [55,56]. Additionally, the use of kinematic data would enable joint angles to be coupled with peak activity of independent musculature to give further insight into the biomechanics and activation patterns of muscles during the BS and FS. Also, kinetic data along with kinematic data could be useful to calculate internal forces via inverse dynamics such as shear and compression forces through the knee, hip, and back, whilst using an 85% 1RM to demonstrate if the results seen from Gullet et al. [23] can be mirrored using the increased load.

Despite the limitations of this study, these results may be beneficial to coaches and physical therapists, looking to design weight training programmes. These results may also be useful to coaches, personal trainers or physiotherapists, looking to target individual muscles, or those rehabilitating and "prehabbing" athletes from injury [57,58].

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