EXPLORING DIFFERENCES IN ELECTROMYOGRAPHY AND GROUND REACTION FORCES BETWEEN FRONT AND BACK SQUATS BEFORE AND AFTER A FATIGUING PROTOCOL

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Limited research has been conducted to explore differences in biomechanical and physiological demands of the front and back squat, especially in response to fatigue where technique may be altered. This study investigated differences in electromyography and ground reaction forces during a 3-repetition maximum back and front squat before and after a fatiguing protocol in 30 males. Mean and peak activation of the semitendinosus was greater in the back squat than the front squat ($p < 0.05$). There were no differences in quadricep activation between back and front squats. There were no differences in electromyography as a result of fatigue, however, force production decreased for back squats following fatigue ($p < 0.01$). This research disputed the notion that front squats have a greater quadricep focus, however lends support to the hypothesis that quadricep activation equal to the back squat can be achieved with lighter absolute load in a front squat. The finding that there were lower ground reaction forces for the back squat following the fatiguing protocol in addition to no differences in electromyography between front and back squats indicates greater effects of the fatiguing protocol on back squat performance.

KEYWORDS: Countermovement Jump, Force Platforms, Hamstrings, Quadriceps

INTRODUCTION: The front squat and the back squat both require the lower back, hip, and leg muscles to contribute to the movement and are regarded as very similar, however, the change in bar positioning produces variations in technique and different mechanical demands as well as possibly different muscle activation and force production (Gullet et al. 2009; Yavuz et al. 2015). For the back squat, the barbell is racked behind the neck, resting across the back of the shoulders on the trapezius. For the front squat, hands are placed just outside shoulder-width and the bar is racked across the front of the shoulders approximately at the level of the clavicles, the elbows are fully flexed with palms facing up holding the bar.

These two bar positions are likely to require different postural control to maintain the centre of mass projection within the base of support, placing differing demand on balance and stability, and consequently affecting load lifted. The positioning of the bar on the back creates an increased forward lean and in order to counteract it the lifter increases forces generated at the hip joint muscles compared to the knee. This contributes to a key kinematic difference in the squat types whereby front squats are more ‘knee-dominant’ while back squats are more ‘hip-dominant’. This is supported by the finding that energy generation in the knee is greater in the front squat (Braidot et al., 2007). The bar positioning of the front squat results in a more upright trunk position and allows a deeper squat which arguably imposes greater mechanical demand (Esformes & Bampouras, 2013) and could result in the front squat being more fatiguing. Conversely, the greater load employed in the back squat could induce more fatigue.

The front squat is employed much less frequently than the back squat in resistance training by the general population but is still a commonly employed alternative to the back squat compared to other techniques (Glassbrook et al., 2019). There is increasing evidence of the benefits of employing front squats, such as reducing lower back strain (Waller, 2007) or rehabilitating from lower limb injuries (Gullet et al. 2009). It is not known, however, whether one type is more fatiguing than the other, which is an important aspect of planning a training programme. The aims of this research were to compare muscle activation and ground reaction forces between the two squat types in addition to the differences in fatigability.

METHODS: 30 male participants (Table 1) with over 1 year of weight training experience using front and back squat participated in the study. Following ethical approval from the Faculty of Health and Medicine Research Ethics Committee of Lancaster University, subjects gave written informed consent and visited the laboratory on three different times. During the first visit, a screening questionnaire (based on American College of Sports Medicine, 2016) was completed, and height (via a stadiometer; 217, Seca, Hamburg, Germany), body mass (via scales; 799, Seca, Hamburg, Germany), body fat content (bioelectrical impedance; DC-430P, Tanita, Tokyo, Japan) were recorded, followed by blood pressure measurement and finally one repetition maximum (1RM) testing. For the latter, participants performed one repetition at increasing loads as they felt comfortable (with correct execution) until a failed attempt. Participants were allowed 3 minutes rest between attempts or as long as they felt they needed within reason. The maximum weight they achieved was recorded and this was used to calculate their three-repetition maximum (3RM) (Lander, 1984). All squat repetitions were performed with a 20kg Olympic barbell (Eleiko IWF Weightlifting Training Bar, Halmstad, Sweden) and plates (Eleiko Sport Training Discs, Halmstad, Sweden).

Table 1: Anthropometric characteristics and 1 repetition maximum loads for both squat types (n = 30), data presented as mean ± SD.

Measurement	Participants
Age (yrs)	21.1 ± 2.2
Height(cm)	178.4 ± 5.0
Body mass (kg)	83.1 ± 8.7
Experience(yrs)	3.5 ± 2.1
Body Mass Index	26.1 ± 2.7
Body Fat (%)	16.0 ± 4.3
Front Squat (kg)	115.8 ± 23.1
Back Squat (kg)	143.6 ± 25.1

For the experimental protocol, participants completed a set warm up protocol, followed by a maximal voluntary contraction whereby a barbell was maximally loaded at chest height and participants were directed to position themselves in a back squat position and push up maximally against the bar. This contraction was used as the reference contraction for EMG normalisation. Next, they performed a maximal countermovement jump (CMJ) (Optojump, Microgate SRL, Bolzano, Italy) with the jump height achieved to be used as the reference performance for fatigue. Although performing the jump on the force platforms would have subsequently provided some more information regarding the cause of the decline, the described experimental set-up was deemed more suitable for practical reasons such as safer spacing around the subject and immediacy of results. Subjects then performed their calculated 3RM front or back squat, followed by sets of six squats of the same squat type at 75% of 1RM and a CMJ. This was repeated until the CMJ height was decreased by 20% from the original jump height or a squat repetition was failed; they then performed another 3RM squat (Figure 1). To avoid inducing changes in execution and thus potentially altering motor patterns, participants were instructed to use either a parallel, defined as the top of the thigh being parallel to the floor and the hip joint aligned or below the knee joint, or below parallel squat. Participants selected based on the one they were more familiar with, and the technique was observed by a qualified instructor. Participants used the same depth throughout testing.

Electromyography data were collected by electrodes (SX230, Wired EMG Sensor, DataLOG, Biometrics, Virginia, U.S.A) on the vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), biceps femoris (BF) and semitendinosus (ST) of the right leg and the erector spinae (ES) placed in line with SENIAM guidelines (Hermens & Freriks, 2000), and ground reaction forces (GRF) measures by force platforms were taken during the 3RM squat attempts (PS2141, Pasco, California, U.S.A).

EMG was smoothed by converting to root mean square (RMS) with a 100ms window and normalised to each participant's EMG from the maximal voluntary isometric contraction trial for each muscle (Yavuz et al., 2015; Contreras et al. 2015). Peak EMG was calculated using the peak value for each muscle of each squat, mean EMG calculated for each muscle across each squat and then averaged. Force data were recorded at a sampling rate of 200Hz. The peak of each squat was taken for the force platform data and averaged to produce mean peak GRF. Where participants performed two or three squats the data was averaged, however, if only one squat was performed due to failure this was taken as the value. Fatigue was examined between squats in the same set (intra-set fatigue) and between sets of squats (inter-set fatigue). Data were analysed by two-way repeated measures analysis of variance (ANOVA) 2 (squat: front, back) x 2 (pre, post) for each muscle. For force data, a two-way repeated measures ANOVA was employed. All force data were normally distributed, however, EMG data that were not normally distributed were analysed using the appropriate non-parametric alternative (Friedman's two-way ANOVA). Some data points were missing (10% of EMG data, 7.86% of force mean peak, and 19.76% of force peaks) so the Markov Chain Monte-Carlo method (with 20 imputations) was used to replace the missing values to avoid a reduction in statistical power and avoid excluding pairwise comparisons.

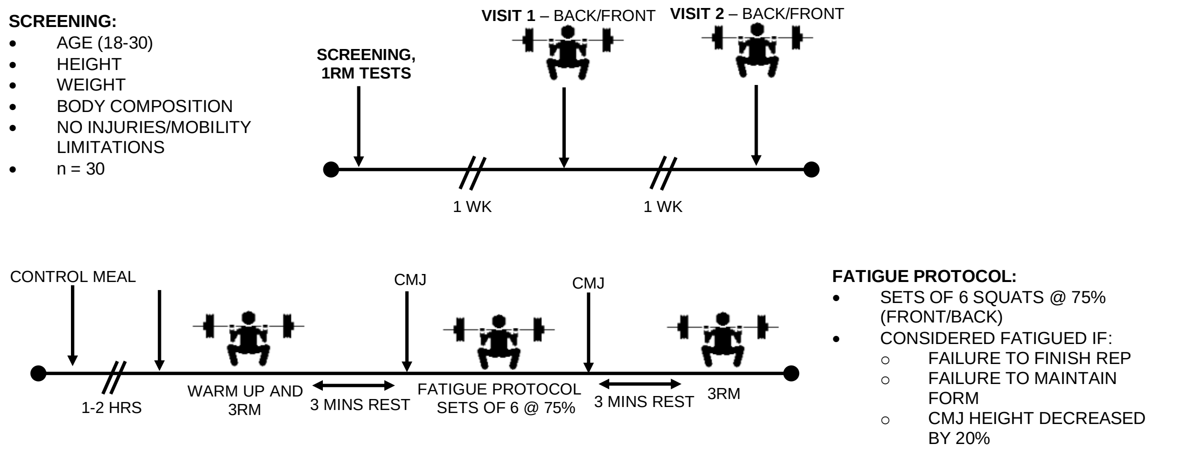

Figure 1: A schematic representation of the screening visits and experimental procedure.

RESULTS: Activity of the ST was greater in the back squat than the front squat, with significant differences between front pre- and back pre-fatiguing protocol for both mean and peak activation ($p < 0.05$; Figure 2). There were no other significant differences for electromyography

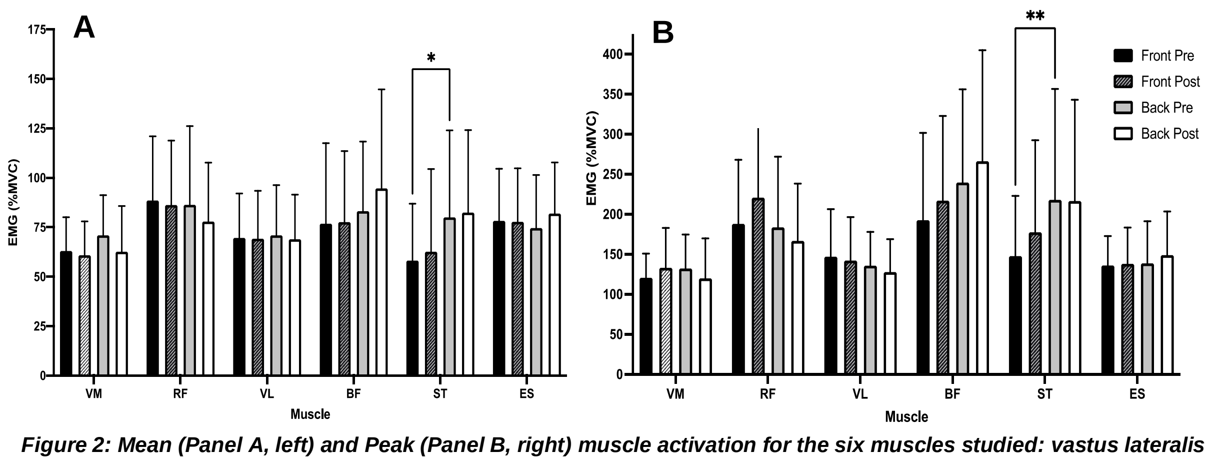

Figure 2: Mean (Panel A, left) and Peak (Panel B, right) muscle activation for the six muscles studied: vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), biceps femoris (BF), semitendinosus (ST) and erector spinae (ES). Data is presented as %MVC for each condition. Vertical bars denote SD. *p < 0.05, ** p < 0.01

between front and back squat and no differences between pre- and post-fatiguing protocol conditions in the same squat type for mean and peak electromyography.

There was significantly lower GRF in the front squat than the back squat for both pre- and post-fatiguing protocol conditions ($p < 0.001$), and mean GRF decreased by 76N following the fatigue protocol in the back squat ($p < 0.01$; Table 2).

Table 2: Peak ground reaction forces (N) ± SD. *Significance between front and back squats is highlighted with *, differences between pre and post are highlighted by the p value. Significant values are marked with * to indicate significance levels (* p < 0.05, ** p < 0.01, ***, p < 0.001), ns indicates p > 0.05.*

	Pre (N)	**Post (N)**	***p* Value**
Front	2185 ± 317****	2119 ±441****	ns
Back	2437 ± 318****	2361 ± 373****	0.002**

DISCUSSION: This study set out to explore differences in electromyography and ground reaction forces between front and back squats before and after a fatiguing protocol. ST activation was greater in the back squat than the front squat but there were no differences in the other muscles studied despite the greater absolute load in the back squat. There were no differences in electromyography as a result of fatigue, however, force production decreased for back squats following fatigue.

This study suggests that the back squat does increase hamstring activation compared to the front squat and does not support the theory that front squats have considerably greater quadricep activation. The findings corroborate those of Gullet et al. (2009) and Contreras et al. (2015) whilst also supporting the work of Yavuz et al., (2015) by confirming greater activation of the ST in the back squat in comparison to the front. This is likely a result of increased hamstring activation, due to a) increased need for stabilisation of the knee and hip compared to the front squat, and b) greater forward lean in the back squat compared to the front squat as a result of bar positioning; the no difference in ES activation, however, is making the first mechanism more likely.

GRF was significantly higher in the back squat than the front squat as a result of the greater load lifted. The ability to lift heavier loads in the back squat is related to a number of factors including bar placement, stability, joint angles and subsequent muscle-tendon unit lengths, and differing demands on muscle group. The lower GRF in front squats may indicate a lesser force on joints and on muscles through tendons, linking with Gullet et al. (2009) who have previously noted lower net compressive forces and fewer knee extensor moments in the front squat. If this is the case, then the front squat may be a better exercise choice for those with previous joint injuries and in rehabilitation, however, further research needs to study forces on joints at maximal percentages of 1RM such as those used in this study.

The present findings show no differences in GRFs as a result of intra-set fatigue, as there was no evidence of the force production of the final squat being affected by acute fatigue. However, when examining inter-set fatigue, GRFs were lower following the fatiguing protocol for back squat, suggesting a slower descent into the bottom position (Bentley et al. 2010). There were no differences in EMG between pre- and post-fatiguing protocol conditions of the same squat type, suggesting no change in muscle fibre recruitment. However, taken with the finding that there were decreased ground reaction forces in the back squat following the fatiguing protocol, it demonstrated a fatiguing effect suggesting differences in fatigue between the two types of squats.

LIMITATIONS: Kinematic analysis would enable investigation of the different technical characteristics between the two squat types as well as any changes in each type due to the fatiguing protocol. Unfortunately, it was unavailable to the author at the time of study. Although the lack of an external marker for standardisation of the squat depth does not allow us to completely exclude the possibility of small changes in the depth used pre- and post-fatiguing activities, the experience of the lifters and the constant visual inspection of their squat depth by the qualified instructor, make it unlikely that impactful changes took place. Finally, time constraints did not allow for standardisation of GRF to participants' bodyweight. This would have resulted in more robust comparisons between front and back squats, accounting for the difference in load lifted.

Kinematic analysis would have also enabled identification of possible reasons for differing muscle activation between front and back squats such as knee flexion, hip and knee dominance, and joint loading as well as exploring differences in compressive and shear forces between squat types. This would also have allowed for standardisation of squat depth to parallel, however it is important to note that doing this may affect the established motor control patterns of lifters. It is unlikely that squat depth would have affected within condition differences i.e., pre and post conditions, however, may have varied between front and back squat conditions due to kinematic differences as discussed earlier. Additionally, GRF was not standardised to bodyweight of participants, this would have been too time consuming within the time restraints of the study however may have yielded different results for differences in GRF between front and back squat that were not just a result of the heavier weight lifted.

CONCLUSION: There were significant differences in hamstring recruitment between front and back squat highlighted by greater peak ST muscle activation in back squats. This higher activation could be related hip extension and stabilisation. There were no differences in quadricep muscle activation disagreeing with the notion that front squats are more quadricep focused. Significantly higher ground reaction forces in the back squat compared to the front squat were assumed to be the product of a heavier weight used, as well as contributions of stability, speed and joint angles. However, the back squat was evidenced to be more affected by fatigue, evidenced by reduced GRF following fatigue protocol. These findings may change how squats are prescribed in injury rehabilitation and in training programmes, with a greater shift towards the front squat to elicit similar muscle activation at a lower load.

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