THE EFFECTS OF INCREASING LOAD ON ELECTROMYOGRAPHIC PARAMETERS IN SELECTED LOWER LIMB MUSCLES DURING THE PARALLEL SQUAT

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The aim of this study was to establish the effects of increasing load on selected electromyographic parameters during the parallel squat. Electromyograms were recorded from four lower limb muscles for ten male rugby forwards performing three parallel squats at each of three workloads (60%, 70% and 80% of one-repetition maximum). Significant differences ($p \leq 0.05$) between lowering and raising phases were found in: integrated muscle activity for vastus lateralis, biceps femoris and tibialis anterior; median frequency for vastus lateralis and biceps femoris; zero crossing rate for biceps femoris and tibialis anterior. The change between lowering and raising phases had a greater effect on muscle activation parameters than changes in load. Little evidence was found that working at higher percentages of one-repetition maximum is associated with increasing strength gains.

KEY WORDS: electromyography, squat, lower limb

INTRODUCTION: Weight training, once primarily the domain of bodybuilders and powerlifters, has now become an integral part of many athletes' training programmes. One sport for which weight training is regarded as a fundamental part of preparation at an elite level is rugby. Aspects of the game such as tackling and scrummaging can only be effective if players can generate sufficient force in the desired direction. One of the most commonly used exercises is the parallel squat, which comprises two functionally separate phases (lowering and raising), and which holds a unique position in the development of lower back, hips, buttocks and thighs (O'Shea, 1985).

When weight training, the objective for many athletes is to increase the tension-generating capacity of muscles. In order for an exercise to be effective in this way, muscle needs to be worked in the upper reaches of its maximum tension-generating capacity, normally no lower than 60% of one-repetition maximum.

According to Asmussen (1956), concentric contractions produce greater electromyographic amplitude than eccentric contractions. This is concurrent with Bigland and Lippold (1954), who noted that the slope of the regression line between integrated electromyogram and muscle tension was greater when the muscle shortened at a constant velocity than when it lengthened at the same velocity.

Various relationships between electromyographic parameters (normally integrated electromyogram) and muscle tension have been reported. Within this considerable body of literature, both linear (e.g. Lippold, 1952) and quadratic (e.g. Vredenbregt and Rau, 1973) increases in the electromyogram have been found.

The objective of this study was to examine the effect of increasing load on a series of electromyographic parameters in selected lower limb muscles during the lowering and raising phases of the parallel squat.

METHODS: Ten elite male rugby forwards (mean ± s: 1.81 ± 0.05 m; 104 ± 6 kg; 25 ± 4 yrs), who regularly utilised the squat exercise during training, volunteered for this study. Subjects attended two testing sessions at least 24 hours apart. The first session was used to establish each subject's one-repetition maximum, using the protocol of Kraemer and Fleck (1993).

The second testing session began with a warm-up of ten repetitions at 50% of each subject's one-repetition maximum. Squats were performed using the standard overgrip, with the bar centred across the shoulders just below the seventh cervical vertebra. Subjects' feet were positioned flat on the floor and spaced shoulder width apart, with the toes pointing forward.

The lowering phase was performed in a slow and controlled manner to a position where the

longitudinal axis of the thigh, defined by a line between the hip joint and the lateral condyle of the femur, was parallel to the floor (Signorile *et al.*, 1995). The repetition was completed with a controlled return to the initial standing position. Each phase lasted 2 seconds, and was controlled with a metronome. Three consecutive repetitions were performed, with a rest period of five minutes between trials. This protocol was repeated until each subject had performed at 60%, 70% and 80% of their one-repetition maximum.
Bipolar surface electromyography (1 000 Hz) was used to record median frequency (MF) and integrated electromyogram (IEMG) of vastus lateralis, biceps femoris (long head), tibialis anterior and gastrocnemius. The raw signal was high-pass filtered (0-500 Hz) and amplified (gain = 393) before storage. Loads were presented in a random order to avoid any temporal effects. Bilateral similarity was assumed, and electromyographic data were collected from the right leg only.
Data were analysed using a two-way analysis of variance with repeated measures on both factors (phase and load). A one-way analysis of variance for repeated measures was used to compare between loads and, where significant differences were indicated, individual paired t-tests were used to determine their location. Alpha was set at 0.05 for all tests.

RESULTS: A significant main effect for phase was found for IEMG in biceps femoris (p = 0.0004), vastus lateralis (p = 0.002) and tibialis anterior (p = 0.00001). For biceps femoris, the raising phase elicited the larger values, whereas for vastus lateralis and tibialis anterior, it was the lowering phase that was associated with the larger values.

Table 1 Electromyographic Parameters (± S.D.) at Each Load

	Vastus lateralis		Biceps femoris	
Phase and load	**MF (Hz)**[1]	**IEMG (μV s)**[2]	**MF (Hz)**[3]	**IEMG (μV s)**[4]
60%	61 ± 6	211 ± 45	50 ± 5	36 ± 6
Lowering – 70%	63 ± 5	229 ± 41	50 ± 5	41 ± 6
80%	64 ± 3	250 ± 41	48 ± 4	47 ± 9
60%	67 ± 6	132 ± 42	58 ± 12	46 ± 12[6,7]
Raising – 70%	71 ± 6	148 ± 42	59 ± 12	64 ± 12[6]
80%	69 ± 11	142 ± 28	59 ± 6	79 ± 17[7]
	Tibialis anterior		**Gastrocnemius**	
Phase and load	**MF (Hz)**	**IEMG (μV s)**[5]	**MF (Hz)**	**IEMG (μV s)**
60%	157 ± 16	124 ± 14	81 ± 10	29 ± 6
Lowering – 70%	153 ± 16	122 ± 14	81 ± 10	34 ± 6
80%	150 ± 11	132 ± 16	81 ± 7	34 ± 4
60%	138 ± 21	52 ± 16	79 ± 8	39 ± 13
Raising – 70%	134 ± 21	48 ± 16	81 ± 8	41 ± 13
80%	140 ± 18	57 ± 15	83 ± 13	44 ± 16

[1-5]significant main effects for phase: [1](p = 0.05); [2](p = 0.002); [3](p = 0.0004); [4](p = 0.0004); [5](p = 0.00001). [6,7]significant difference between like superscripts: [6](p = 0.004); [7](p = 0.003).

A significant main effect for phase was found for MF in vastus lateralis (p = 0.05), and biceps femoris (p = 0.0004). In both instances, the larger values were associated with the raising phase. No significant main effects were found for load, however, significant differences were found for IEMG in biceps femoris during the raising phase between 60% load and 70% (p = 0.004) and 80% (p = 0.003) loads. Gastrocnemius was the only muscle for which no significant differences between phases or loads were found.

DISCUSSION: Results for vastus lateralis did not support previous reports (e.g. Bigland and Lippold, 1954) that eccentric contractions are associated with lower integrated electromyograms. Greater integrated activity was found for the eccentric (lowering) phase for all loads, differences being sufficiently large to constitute a significant main effect (p = 0.05). The current findings may be attributed to the lowering phase including all movement up to the time at which the centre of mass was at its lowest point. As such, the integrated electromyogram must include the extra muscle activation required to reduce the body's downward velocity to zero. This explanation allows for the average muscle activation to be lower during the constant velocity portion of the lowering phase as compared to the corresponding part of the raising phase. Furthermore, it is likely that less muscle activity is required during the portion of the raising phase close to full extension, during which gravitational acceleration alone will reduce the upward velocity, as compared to the same portion of the lowering phase.

As the task in the current study was designed to minimise fatigue, any changes in median frequency were likely to be due to other factors. This will primarily be the recruitment of fibres with different conduction velocities in accordance with the size principle. The consistently higher values for median frequency in vastus lateralis during the raising phase at each load thus suggest that new fibres are recruited during the raising phase at higher frequencies.

The lack of significant change in integrated electromyogram between loads in vastus lateralis was unexpected. A basic principle of strength training is that resistance is positively related to the effort required to overcome it and, therefore, improvements in strength. The current finding may be due to a strategy by which an increase in load results in a modification of movement pattern in order to redistribute the workload among active musculature. This may include a change in the trunk angle, which displaces the bar in the horizontal plane and, as such, alters the resistive torque about the hip, knee and ankle (Harman, 1994).

The significant main effect for phase found in integrated electromyogram for biceps femoris ($p = 0.0004$) contrasted with the finding for vastus lateralis, in that the raising phase elicited the larger values. This suggests that biceps femoris has a smaller role in reducing the downward velocity in the lowering phase. There is little supporting evidence for relaxation of biceps femoris during the decelerative portion of the raising phase, despite the finding of quiescence at full extension by Furlani *et al*. (1977). In contrast with vastus lateralis, the significant increases in integrated activity for biceps femoris with respect to load during the raising phase suggest that there are potential benefits to be gained in terms of strength increases by increasing load.

A significant main effect for phase was found for integrated activity in tibialis anterior ($p = 0.00001$). As was the case for vastus lateralis, the greater values were found during the lowering phase. Tibialis anterior is a prime mover in ankle dorsi-flexion, and a simple kinesiological analysis shows that during the lowering phase, the observed motion at the ankle is dorsi-flexion, which is consistent with the joint action tendency of the acting forces. Thus, it would be expected that the dorsi-flexors would be relatively inactive during the lowering phase, while the plantar flexors contract eccentrically to control the rate of dorsi-flexion. During the subsequent raising phase, plantar flexion against external forces occurs at the ankle and, again, tibialis anterior has no agonist role. The relatively low values found during the raising phase are indicative of a stabilising role at the ankle joint while its antagonist is active.

The lack of significant change with respect to load in either phase for median frequency contradicted the data of Broman *et al*. (1985), who found significant ($p < 0.05$) increases for contraction intensities between 10% and 100% of maximum values for the same muscle. As Broman *et al*. (1985) used isometric contractions, the nature of the contraction may go some way to explaining this difference.

The non-significant changes in MF and IEMG for gastrocnemius suggest that this muscle plays little part in the squat. However, inter-individual differences were considerable. MF data for all muscles supported the findings of Bilodeau *et al*. (1994), who found 'relatively consistent' values between 60% and 80% of maximum voluntary contraction. In this study, MF is primarily affected by the number of active fibres. This led us to conclude that it was the firing rate of active fibres that was the cause of differences in integrated activity between phases for vastus lateralis, biceps femoris and tibialis anterior, and between loads during the raising phase for biceps femoris.

The relationship between the integrated electromyogram and muscle force has received considerable attention in the literature. Basmajian and De Luca (1985) concluded that it is independent of contraction velocity and muscle-specific, being linear for small muscles and

non-linear for the larger muscles of the limbs. Thus, a non-linear relationship would be expected for the muscles used in the current study. With the exception of the raising phase for biceps femoris, all differences with respect to load were non-significant. It must be concluded, therefore, that the relationship for the latter muscles is linear. Despite the significant differences between loads for biceps femoris during the raising phase (which indicate *some* trend to the relationship), trend analysis revealed a significant linear trend ($p < 0.01$) but a non-significant quadratic trend.
Linear relationships are inconsistent with the statement of Basmajian and De Luca (1985), especially for vastus lateralis and biceps femoris, as they are among the larger muscles of the body, although they did not specify what constitutes a large muscle. It is possible that the relatively large standard deviations for vastus lateralis, tibialis anterior and gastrocnemius may have masked the true nature of the relationship(s). It must also be noted that the range of contraction intensity was limited, and that a wider range may have elicited different relationships. Finally, and perhaps most importantly, it should be recognised that not only is the squat a dynamic movement, but it also has more than one group of active muscles between which it has been shown that the load distribution may have been altered.

CONCLUSION: Changes in the direction of movement had a greater effect on muscle activation than changes in load. Biceps femoris was the only muscle studied for which changes in load elicited significantly greater activity and, hence, the only muscle for which increased strength gains could be expected. Vastus lateralis and biceps femoris responded differently to changes in load and direction of movement. As the two muscles that are widely held to be the major beneficiaries of the parallel squat, the current evidence suggested that this theory be re-evaluated. To conclude, the relationship between the integrated electromyogram and applied load was linear for all muscles.

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