

THE EFFECTS OF BIOFEEDBACK ON NEUROMUSCULAR RECRUITMENT
PATTERNS DURING FATIGUING SETS
OF BACK SQUAT

by

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ABSTRACT

This investigation analyzed neuromuscular recruitment patterns with and without the presentation of velocity-based biofeedback during a set of back squats to fatigue. This study followed a repeated-measures, randomized design in which each participant served as his own control completing all four experimental conditions. Subjects performed the back squat exercise to fatigue with and without biofeedback at 75% one-repetition maximum (1RM). During the biofeedback trials, a screen was placed in front of subjects during the exercise that provided real-time velocity feedback for each repetition. In these trials, participants were instructed to “explode out” of the bottom of the squat as to try and “beat” the previous velocity measurement with each subsequent repetition. Surface electromyography (EMG) was used to measure electrical activity during muscular contractions. Electrodes were placed along the bellies of the vastus lateralis (VL), gluteus medius (GM), and biceps femoris (BF) bilaterally. For the purpose of this paper, data pertaining to the subjects’ right side during the 75% 1RM trials will be analyzed and discussed. There was no main effect for condition for any of the muscles examined ($p > 0.05$). Further, no significant interaction with condition (biofeedback or no-biofeedback) was observed for any of the muscles examined ($p > 0.05$). A main effect for time of repetition (first, last) was observed for all three muscles (VL, $p = 0.001$; BF, $p = 0.027$; GM, $p = 0.024$). Results suggest that higher EMG values are observed during fatigue, but no differences exist with the presence of biofeedback.

INTRODUCTION

Sport is characterized by a high degree of competitiveness and an emphasis on the importance of winning, which is largely determined by athletic performance on the field. In many sports, the ability to generate power quickly is a functional and vital aspect of performance on the field.

Power generation is largely associated with velocity of a movement, with greater velocity demonstrating a greater power output (Oliver et al., 2015). Therefore, it is suggested that velocity is a useful measure by which to assess power. Consequently, in order to increase power on the field, we have increasingly seen an emphasis on velocity-based training mechanisms used by athletes.

Biofeedback technology is implemented in numerous strength and conditioning training programs. Biofeedback is used as a form of neuromuscular training designed to enhance movement techniques during training (Myer et al., 2011 & Myer et al., 2013). Specifically, velocity-based biofeedback is used as a mechanism to attempt to direct the athlete's attention externally during the movement. Research suggests that a more external focus during training, as opposed to internal, results in preferable movement mechanics over time (Benjaminse, A, Otten E, 2011 & Gokler et al., 2013). Stone et al. (2017) previously demonstrated that real-time biofeedback in the form of velocity results in higher average velocity during a set of back squats to fatigue. Therefore, further investigation is warranted to explain the mechanism by which a higher in-set velocity is elicited with the presence of velocity-based biofeedback.

A mechanism commonly employed to distinguish between contributing factors of fatigue (central or peripheral) is surface electromyography (EMG). EMG allows for a measurement of the amplitude of contractility in various muscle groups (Merletti et al., 1985). During an exercise trial to fatigue, an increase in the recruitment of motor units and/or neuronal firing rate as fatigue

approaches is expected. Therefore, an increase in EMG values is expected during repetitions when fatigue is present. The rise in EMG amplitudes during fatigue is consistent with literature findings (Masuda et al., 1999). To my knowledge, there has not been a study that involved a neuromuscular recruitment pattern analysis of the inclusion of velocity-based biofeedback during a set of back squats to fatigue. We hypothesize that the higher velocities observed with the presence of velocity-based feedback may be reflected in differing neuromuscular activity.

METHODS

Experimental Design

This study followed a repeated-measures, randomized design in which each participant served as his own control completing all four experimental conditions. The height, weight, body composition, resistance training history and injury report of each subject was collected. Afterwards, participants completed a familiarization session. At least 48 hours post-familiarization, subjects reported to the laboratory for determination of their one repetition maximum (1RM) following a dynamic warm-up. At least 72 hours after participants' 1RM determination, subjects completed the same experimental testing procedures under two conditions: 75% 1 RM with and without biofeedback. At least 72 hours separated each experimental visit.

Subjects

Thirteen participants (n=13) completed this study. Selection criteria included (a) men between the ages of 18 and 35 (b) with at least two years of current participation in a resistance training program (c) and no active lower extremity orthopedic injury not requiring surgery in the previous year or (d) no active lower extremity orthopedic injury requiring surgery in the previous three

years. Three subjects had to be excluded from the final data analysis due to EMG data outlier status. All procedures involving human participants were approved by the Institutional Review Board of Texas Christian University for the use of human participants in research. Written consent was obtained from all participants prior to participation.

Demographic Information Collection/Familiarization

Prior to the familiarization period, subjects' height and body mass were recorded to the nearest 0.1 cm and 0.1 kg, using a standing ruler and digital scale (Seca) with subjects required to remove their shoes. Subjects then underwent body composition determination through DXA (General Electric, Boston, MA) performed by a trained lab technician. Body composition was also collected via the seven-site skinfold method by a qualified member of the research team for validity and comparison with DXA measurements. Afterwards, all subjects participated in a familiarization session. After members of the research team demonstrated proper form for the back squat exercise, subjects were required to perform the exercise until proficiency was demonstrated.

One Repetition Maximum Testing

At least 48 hours after the familiarization session, having refrained from any activity outside of daily living, subjects returned to the laboratory for determination of 1RM in the back squat exercise. After performing a dynamic warm up, subjects performed 2 to 3 sets of 5 repetitions at 40-60% of estimated 1RM with 2-minutes of rest allocated in between sets. After completion of the last set at 40-60% 1RM, subjects were given 3-minutes of rest. Participants then performed 1 to 2 sets of 2 to 3 repetitions at 60-80% 1RM. Subjects then began executing single repetition sets of increasing loads until a 1RM was determined. Three to 5 minutes of rest were allocated

between each attempt, with all 1RM determinations made within 3 to 5 attempts. Subjects were required to reach a depth of each squat repetition where the top of the thighs were parallel to the floor, as measured by a member of the research team, for an attempt to be considered as successful. A subjects' 1RM was defined as the point at which the subject could no longer increase the load and complete a repetition while maintaining proper form. Safety bars were in place for each subject to aid in preventing injury.

Electromyography (EMG) and Biofeedback

Skin Preparation

Each electrode site was shaved, abraded, and disinfected with alcohol wipes to promote electrode adherence and proper conduction of EMG signals. Bipolar silver surface electrodes (10 mm) were placed along the bellies of the gluteus medius (GM), vastus lateralis (VL), and biceps femoris (BF) bilaterally, oriented along the direction of the muscle fibers. The electrodes were placed at a distance of 1/2 the line from the iliac crest to the trochanter for the GM, at 2/3 the line from the anterior superior iliac spine to the lateral side of the patella for the VL, and at 1/2 the line from the ischial tuberosity to the lateral epicondyle of the tibia for the BF. The placement of each surface electrode on all subjects was identified by a marker for repeat visits. Each subject wore wearable tape that was applied after each visit to minimize variability in electrode placement between trials.

Instrumentation

Raw EMG signals were measured using the wireless Noraxon EMG receiver and system. Once amplified, signals were processed through low- and high-pass filter bandwidths to produce root mean square (RMS), integrated EMG (iEMG) and mean electrical activity values for the

ascending phase of each squat repetition. RMS values were then used to rectify the EMG signal to smooth the data.

EMG Data Processing

All subjects completed an EMG normalization trial for each experimental condition. For the normalization trials, each subject was prescribed a load equivalent to 50% 1RM. The subjects were instructed to execute a series of 5 complete squat repetitions in cadence with a metronome (50 beats·min⁻¹). Subjects were allowed as many warm-up repetitions as necessary until the demonstration of proper technique and cadence, as determined by a member of the research team. EMG data from experimental trials were then rectified in accordance with the subjects' normalization data for that specific experimental condition. iEMG data was used as a means to monitor intrasubject variability throughout the experimental conditions.

Biofeedback

For the experimental conditions receiving biofeedback, the commercially available Gymaware (Australia) software was utilized to provide real-time velocity feedback for each repetition performed. A linear position transducer was attached to the right side of the barbell, enabling the tracking and transmission of velocity measurements for each repetition. Velocity of each repetition was displayed, in real-time, on a screen placed in front of the participant during the set.

Experimental Testing

Subjects reported to the data collection center having refrained from any lower body exercise 72 hours prior to each visit. There was a total of 2 experimental testing visits and each visit was separated by at least 72 hours. After a dynamic warm-up, subjects performed the back squat exercise to fatigue with and without biofeedback at 75% of their 1RM in a randomized order.

During the biofeedback trials, a screen was placed in front of subjects during the exercise that provided real-time velocity feedback for each repetition. In these trials, participants were instructed to “explode out” of the bottom of the squat as to try and “beat” the previous velocity measurement with each subsequent repetition. When a subject met the target velocity or exceeded the previous repetitions’ velocity, the Gymaware software audibly alerted the individual with a “ding” sound. If the event that the target velocity was not reached, the subject was made aware of it by a “thud” sound. Subjects were instructed to participate in the exercise until a repetition could no longer be completed, in which case subjects were instructed to release the weight from the back and onto pre-positioned stabilizing pads.

Statistical Analyses

Analyses were performed using Statistical Package for the Social Sciences (SPSS). A multifactorial analysis of variance (2 x 2 x 3) with repeated measures was used to determine statistical significance of the findings. The factors included condition (2 levels), first three and last three repetitions (2 levels), and total number of repetitions in each muscle (3 levels). The dependent measure was iEMG.

RESULTS

iEMG of the respective muscle and corresponding condition for the first and last repetitions is presented in Figures 1 - 3. There was no main effect for condition for any of the muscles examined ($p > 0.05$). Further, no significant interaction with condition was observed for any of the muscles examined ($p > 0.05$). A main effect for time of repetition (first, last) was observed for all three muscles (VL, $p = 0.001$; BF, $p = 0.027$; GM, $p = 0.024$). Similarly, a main effect for

repetition was observed for the VL ($p = 0.028$) and the GM ($p = 0.024$), but only approached significance for the BF ($p = 0.084$).

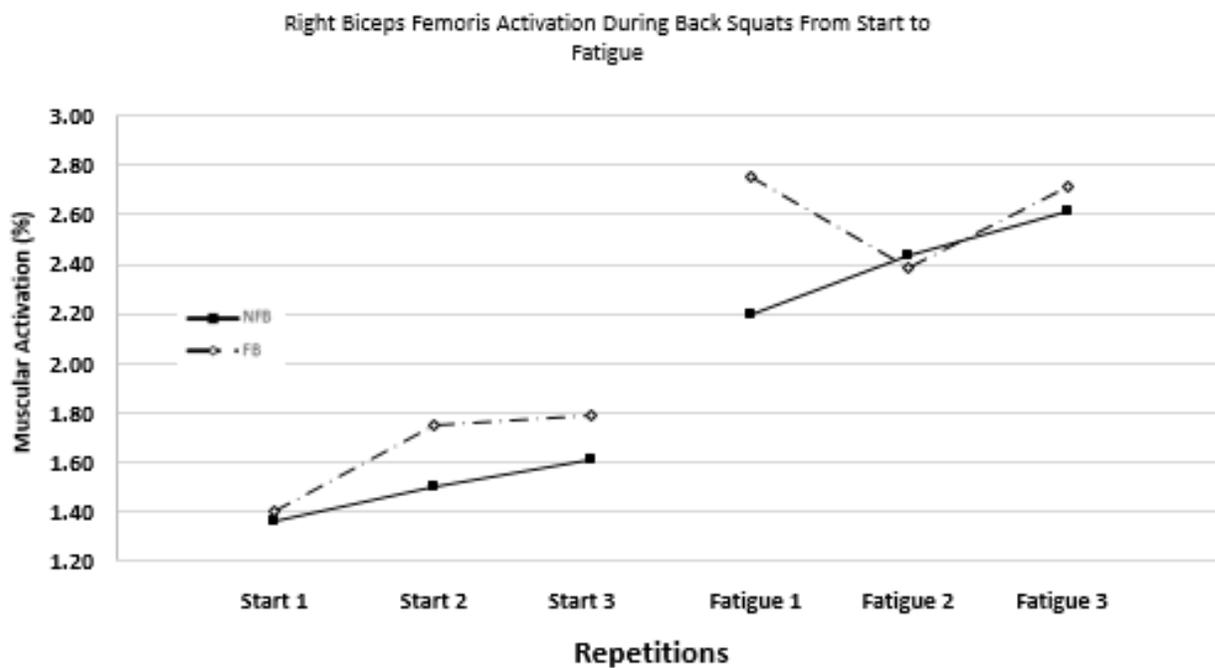


Figure 1. Right BF iEMG activity (%) during back squats from start to fatigue. No significant differences were observed by condition ($p > 0.05$). Main effect of repetition approached significance ($p = 0.084$).

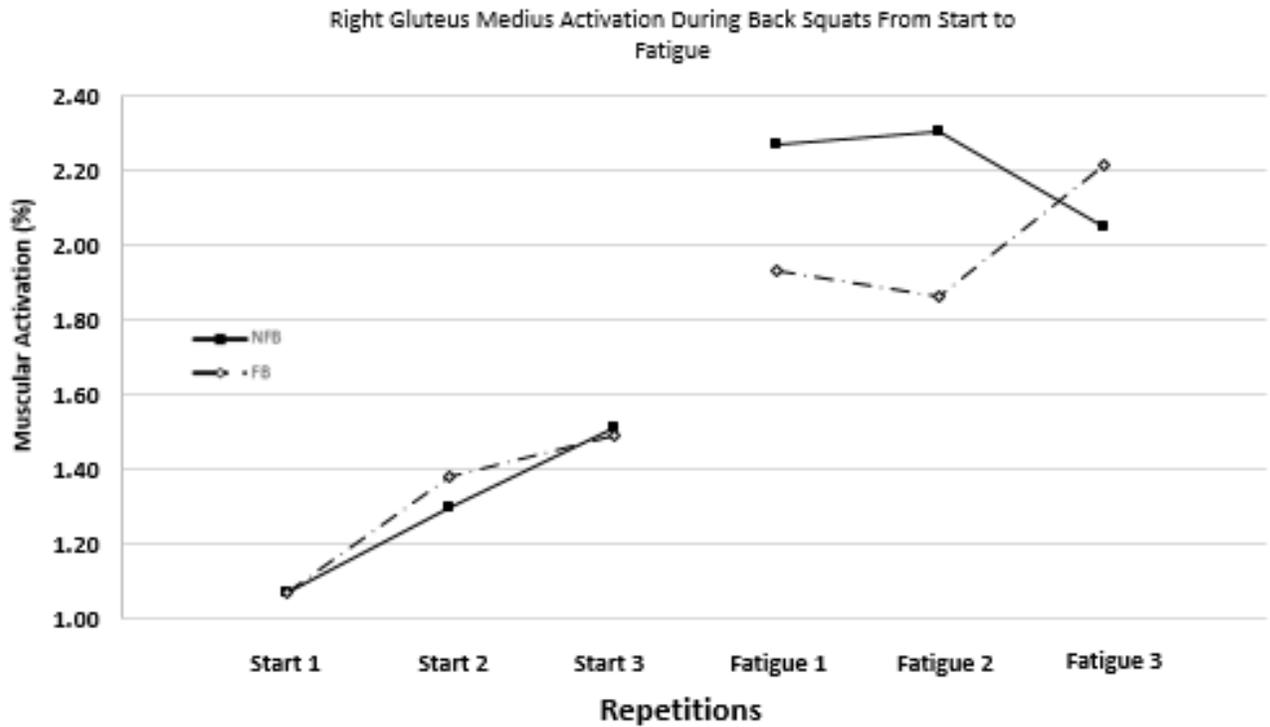


Figure 2. Right GM iEMG activity (%) during back squats from start to fatigue. No significant differences were observed by condition ($p > 0.05$). Main effect of repetition was significant ($p = 0.024$).

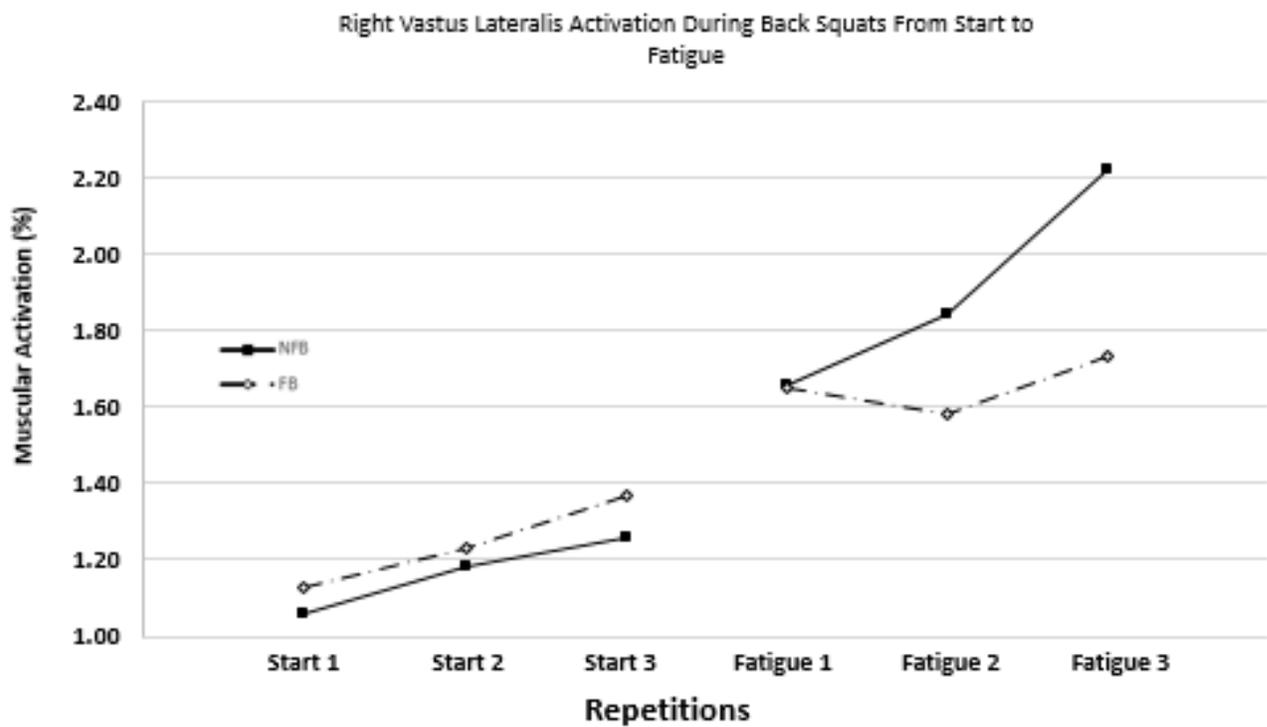


Figure 3. Right VL iEMG activity (%) during back squats from start to fatigue. No significant differences were observed by condition ($p > 0.05$). Main effect of repetition was significant ($p = 0.028$).

DISCUSSION

We have previously demonstrated that in-set velocity is higher when biofeedback in the form of velocity is presented (Stone et al., 2017). Consequently, we hypothesized that the higher velocities observed may be reflected in differing neuromuscular activity. However, contrary to our hypothesis, the main findings of this study were that higher EMG values are observed during fatigue, but no differences exist with the presence of biofeedback.

Masuda et al. (1999) has previously examined neuromuscular activity during repetitions to fatigue. Results indicated that mean EMG amplitude increased from the beginning to the end of the exercise. In agreement with the previous findings by Masuda et al., we observed a similar pattern in our results. Our data revealed a statistically significant difference ($p < 0.05$), seen in all three muscles being examined, when comparing repetitions at the start of the exercise and fatiguing repetitions at the end of the exercise. Fatiguing repetitions consistently resulted in higher EMG values when compared to unfatigued repetitions performed at the start of the exercise. Both studies evidenced increased EMG values during fatigue in the VL muscle. However, Masuda et al. did not investigate these changes in the BF or GM muscles as our study did. Masuda et al. also completed the investigation while examining the leg extension exercise, as opposed to the back squat exercise we used in our investigation.

Behm and Sale investigated the effects of intended, rather than actual, movement velocity on velocity-specific training adaptations (1993). For the low-velocity group, participants were

instructed to move as quickly as possible through the range of motion for the exercise, but a resistance was applied that did not allow the weight to move quickly. Similar adaptations were observed between subjects that actually moved weight fast (with lower weight) and subjects that intended to move quickly (higher weight). These results suggest that the main stimuli for high-velocity training adaptations are the intention to perform high-velocity repetitions and the ensuing high rate of force development that occurs. In the current study, all participants were instructed prior to initiation to perform all repetitions as explosively as possible. Therefore, it may be that the intention to move quickly was responsible for the higher in-set velocities observed with the presence of biofeedback (Stone et al., 2017) and that this was reflected in the EMG data that revealed no change in neuromuscular recruitment levels between conditions.

In a study in which the effects of a power training program (PT) versus a traditional resistance training program (TRT) on muscular power were investigated, subjects assigned to the PT condition were instructed to perform each repetition as fast as possible. A significantly greater improvement in muscular power was observed in the PT group when compared to the TRT group (Bottaro et al., 2006). Since greater muscular power is driven by greater velocity during the movement (Oliver et al., 2015), it is logical to conclude that the PT group also showed a greater increase in velocity. These findings provide further evidence to suggest that the lack of change observed in the EMG data per condition, in an attempt to explain the greater in-set velocities observed with biofeedback, may be due to the intention to move the weight quickly.

In the current study, considerable variation was observed in surface EMG data values for all three muscles, which resulted in exclusion of many data points from the final statistical analysis due to outlier status. With subjects that exhibited particularly high sweat rates, surface EMG sensor adhesion became a problem, also resulting in the exclusion of the corresponding data for

such trials. The EMG limitations experienced during this investigation are somewhat consistent with other literature (Fauth et al., 2010 & Goodwin et al., 1999). Studies have demonstrated that EMG data recorded from isometric exercises have increased reliability when compared to athletic, or dynamic movements. Specifically, Fauth et al. (2010) evidenced that the BF and VL EMG data consistently yielded lower intraclass coefficients of variation values during the isometric tasks than the ballistic tasks. Authors have also reported that EMG data from ballistic BF activation are relatively unreliable (Goodwin et al., 1999). It is possible that the rapid movement associated with the instructions to move “as explosively as possible” out of the bottom of the squat explains the wide range of variability observed in our EMG readings.

The main findings of this study did not support our hypothesis that the higher velocities observed with the presence of biofeedback may be reflected in differing neuromuscular activity patterns. Results indicated that while there was a significant increase in EMG values observed during fatigue when compared to non-fatigued repetitions, there was no significant difference in EMG readings between the two biofeedback conditions. Further research is warranted to address the mechanisms responsible for specific neuromuscular training effects in response to high-velocity training and biofeedback. Specifically, the extent to which the adaptations seen in response to high-velocity movements and the presence of biofeedback reflect changes in neuronal recruitment patterns or muscle-level changes should be investigated.

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