MUSCLE ACTIVATION DOES NOT INCREASE AFTER A FATIGUE PLATEAU IS REACHED DURING 8 SETS OF RESISTANCE EXERCISE IN TRAINED INDIVIDUALS

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ABSTRACT

Finn, HT, Brennan, SL, Gonano, BM, Knox, MF, Ryan, RC, Sieglcer, JC, and Marshall, PWM. Muscle activation does not increase after a fatigue plateau is reached during 8 sets of resistance exercise in trained individuals. J Strength Cond Res 28(5): 1226–1234, 2014—The premise of eliciting the greatest acute fatigue is accepted and used for designing programs that include excessive, potentially dangerous volumes of high-intensity resistance exercise. There is no evidence examining acute fatigue and neuromuscular responses throughout multiple sets of moderate-to-high intensity resistance exercise. Fifteen resistance-trained male subjects performed a single exercise session using 8 sets of Bulgarian split squats performed at 75% maximal force output. Maximal force output (N) was measured after every set of repetitions. Electromyographic (EMG) activity of vastus lateralis was monitored during all force trials and exercise repetitions. Repetitions per set decreased from the first to the third set (p < 0.001). Maximal force output decreased from preexercise to set 4 (p < 0.001). Electromyographic amplitudes during exercise did not change. Secondary subgroup analysis was performed based on the presence, or not, of a fatigue plateau (<5% reductions in maximal force output in subsequent sets). Nine participants exhibited a fatigue plateau, and 6 did not. Participants who plateaued performed less first-set repetitions, accrued less total volume, and did not exhibit increases in EMG amplitudes during exercise. Initial strength levels and neuromuscular demand of the exercise was the same between the subgroups. These data suggest that there are individual differences in the training session responses when prescribing based off a percentage of maximal strength. When plateaus in fatigue and repetitions per set are reached, subsequent sets are not likely to induce greater fatigue and muscle activation. High-volume resistance exercise should be carefully prescribed on an individual basis, with intrasession technique and training responsiveness continually monitored.

KEY WORDS neuromuscular, Bulgarian split squat, volume, force, vastus lateralis

INTRODUCTION

Within the context of resistance exercise prescription, the total volume of exercise, typically defined by the number of sets, is often manipulated to increase the acute fatigue stimulus and subsequent training adaptation. The magnitude of acute fatigue and concomitant neuromuscular, hormonal, and protein signaling responses after a session of resistance exercise are thought to be important stimuli for the subsequent training adaptation (9,14,19,25). The premise of maximizing the acute fatigue stimulus has led to the utilization of high-volume accumulation methods in the powerlifting, bodybuilding, and recreational resistance training environment that may not be effective for training outcomes and place trainees at undue risk of overuse injuries and physiological overreaching. For example, programs such as the Smolov method use high-volume (in excess of 6 sets) moderate-to-high intensity (loads above 70% maximal strength) training sessions up to 4 times per week. In the context of bodybuilding, the goal to maximize the acute fatigue stimulus has led to numerous prescription techniques that increase total training volumes, including but not limited to superset or paired set prescription, drop-set techniques, and forced or assisted repetition training. Recent research has used the rationale of maximizing the acute fatigue stimulus to justify the prescription of any training intensity based on the unproven belief that fatiguing high volumes at low intensity will facilitate recruitment of high-threshold motor units (19). The confusion that exists over how to maximize the acute training stimulus may, in part, be owing to the absence of information regarding the progression of fatigue and concomitant neuromuscular responses during multiple sets of resistance exercise in a trained population.
There is debate about the optimal number of resistance exercise sets to prescribe for a trained population (15,16,21). Previous studies that have compared outcomes between multiple- and single-set programs in trained individuals are equivocal (12,17,20,23,24). Three of these studies observed benefits to multiset prescription in trained individuals (17,23,24). One study reported no difference between multiple- and single-set prescription but used a circuit prescription where successive sets on a given exercise were repeated after a full-body circuit of 9 other exercises (12). Therefore, the acute fatigue stimulus of performing multiple sets in succession was likely reduced. The other study with a null outcome for between-group differences compared 1, 2, or 4 sets of exercise performed 3 times per week (20). Recently, no difference in strength outcomes were observed between 1 and 4 sets of resistance exercise 2 times per week for 6 weeks, but greater strength gains were observed when 8 sets were prescribed (17). It may be likely that the acute fatigue and concomitant physiological stimuli of 4 sets is not sufficiently different from 1 set performed to exhaustion in trained individuals.

Surface electromyography (sEMG) is a noninvasive method of estimating gross neuromuscular responses in muscle during a resistance exercise session. A larger acute neuromuscular response is thought to be important for predicting the extent of neural adaptation and concomitant strength and power gains during a resistance training program (1,18,22). There are a number of factors that potentially contribute to the amplitude of the sEMG signal, including modulation of output from the α-motoneuron and changes in sarcolemma action potential propagation, in addition to methodology constraints such as concurrent summation of negative and positive phases of action potentials, thereby leading to signal cancellation (7,13). In the absence of M-wave normalization procedures, it is not clear whether any changes observed in a sEMG signal may be attributed to alterations in neural drive or the excitability of the muscle tissue. Notwithstanding these limitations, sEMG may be considered an approximate indicator of changes in function proximal to the neuromuscular junction that is accessible for real-world examination of acute training session responses.

A recent study by Walker et al. (28) examined changes in force output and properties of the sEMG signal before, during, and after 5 sets of 10 leg press repetitions at 80% of maximal strength in untrained individuals. The amplitude of the sEMG signal increased from set 1 to 4 concomitant to reductions in maximal force output. Moreover, the within-set increase in sEMG amplitude (difference from repetitions 2 to 8) increased from the first to fifth set (28). It is unclear whether a similar finding would be observed in a trained population. Resistance-trained individuals have demonstrated to have an increased ability to voluntarily activate muscle (4). Thus, there may be limited capacity to increase sEMG amplitudes over and above that elicited in an initial set of repetitions performed to volitional exhaustion, negating the need for additional sets. Considering research demonstrating no difference in training outcome between 1 and 4 sets of exercise in trained individuals (17,20), it may be likely that decrease in force output and changes in the sEMG signal are not different between 1 and 4 sets. Therefore, it is reasonable to believe that a greater volume of prescribed sets (>4 sets) is likely necessary to stimulate an acute fatigue and neuromuscular response that is significantly different from a single set. Finally, acute individual responsiveness in terms of acute fatigue and the concomitant neuromuscular changes have not been examined. High responders to resistance training have been identified across a range of prescribed volumes (17). Moreover, it has been suggested that training responsiveness is primarily determined by genetic factors (3,26). It may be likely that some individuals exhibit a more rapid fatigue and neuromuscular response that plateaus within the first few sets (e.g., between 1 and 4) of a training session, which negates the requirement for additional sets of exercise.

Therefore, the objectives of this study were to examine the acute fatigue and neuromuscular responses during 8 sets of resistance exercise in trained individuals and to explore whether some individuals exhibited a plateau in fatigue or sEMG amplitudes or both before the completion of the prescribed volume. We hypothesized that the decreases in maximal force output and concomitant increases in sEMG amplitude measured during exercise would be no different between 1 and 4 sets but greater after 8 sets.

**METHODS**

**Experimental Approach to the Problem**

This was a single-session cross-sectional study. The test protocol consisted of 8 sets of rear foot elevated split squats (also known as Bulgarian split squat [BSS]) with a training load of 75% maximal force output, 2 minutes interset rest intervals, and every set performed to volitional exhaustion. Primary-dependent variables measured throughout the exercise session were maximal BSS isometric force output (maximal voluntary contraction, MVC; N) and the activation of the vastus lateralis (VL) from continuous sEMG recordings. Postprocessing sEMG-dependent variables calculated were the maximal sEMG signal during all MVCs, and during all dynamic contractions, and median frequency (MF) measurement from the sEMG signal during the MVC as an estimate of muscle fiber conduction velocity changes. Within the context of this study, the independent variable was the number of sets performed. Participants were familiarized with the BSS exercise and testing procedure at the start of the session. The BSS MVC was measured immediately before exercise, after each set, and immediately after the completion of the eighth set. Vastus lateralis sEMG was recorded throughout all isometric trials and dynamic repetitions. We chose the BSS exercise model because this focused the exercise onto a single leg, with less scope for biomechanical variability in terms of any hip hinge or lumbar
Acute Fatigue and Neuromuscular Responses

Figure 1. Changes in repetitions per set for participants in this study. Results are subgrouped according to whether a fatigue plateau was observed (<5% variation in force output measured in all subsequent sets). For the whole group result (n = 15), there were no reductions after the third set for repetitions completed. For the subgroup analysis, the plateau subgroup exhibited no further reductions after the third set. For the no-plateau subgroup, repetitions decreased from the first to fifth set (p < 0.001). * indicates a significant difference between subgroups for repetitions performed in the first set (p < 0.001).

hinging strategy that would likely manifest during fatiguing bilateral squat exercise. Thus, the choice of the BSS was to minimize any likely technique errors that may become evident during a bilateral squat (front or back squat), which may confound any observed changes in muscle activation. The BSS exercise is easily performed and monitored to ensure that an upright trunk is maintained throughout all repetitions performed. Moreover, we chose the BSS to allow greater generalizability to real-world application as compared with using an isolated knee extension model.

Subjects
Fifteen resistance-trained male subjects provided written informed consent to take part in this study (mean ± SD; age, 23 ± 1.6 years; height, 180.7 ± 6.8 cm; weight, 91.9 ± 8.8 kg). All participants were screened before testing and presented no known musculoskeletal injuries, and all had at least 12 months of resistance training experience with a frequency of at least 3 times per week. Although experienced with squatting techniques, no participant regularly performed the BSS as part of their training program. All testing was performed during the Spring season, in the morning between 0900 and 1100 hours for all participants. The study was conducted according to the Declaration of Helsinki, and ethical approval was granted by the local human research ethics committee.

Procedures
Participants reported to the laboratory in a 2-hour postprandial state and immediately had their anthropometric measurements recorded (height, weight). Subsequently, the position for the sEMG electrodes on VL were measured according to SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles) guidelines and marked with a permanent felt-tip pen on the participant’s right leg. Participants were familiarized with the dynamic BSS exercise using bodyweight only, as a warm-up before maximal force testing.

Vastus lateralis electrodes were a pair of silver and silver-chloride electrodes (Maxensor; MediMax Global, Sydney, Australia) with a 10-mm diameter and 10-mm interelectrode distance that were positioned after careful skin preparation using disposable razors to remove excess hair, skin abrasion using fine sandpaper, and isopropyl alcohol swabs to reduce skin electrode impedance to below 5 kΩ. Vastus lateralis electromyographic (EMG) signals were continuously recorded during maximal force testing and during the dynamic exercise trials (common mode rejection ratio of EMG bioamplifier >85 dB at 50 Hz, input impedance 200 MΩ, 16-bit analog to digital conversion, sampled at 2,000 Hz, Powerlab; ADInstruments, Sydney, Australia). Raw signals were initially filtered with a fourth-order Bessel filter between 20 and 500 Hz. All collected signals were subsequently digitally band pass filtered (between 10 and 500 Hz), then rectified and smoothed using a root-mean-square (RMS) calculation with a 100-millisecond window.

Maximal isometric force (MVC) was measured for the BSS using a Smith Press with the horizontal bar restrained and fixed upon the shoulders. Two linear force transducers (PT Global, Ltd., Sydney, Australia) were fixed on either side of the horizontal bar. Force output was sampled at 1,000 Hz using an analog to digital converter (16-bit analog to digital conversion, Powerlab; ADInstruments). Before any data collection, all recorded force signals were calibrated to convert the output signal (in millivolts) to newtons (N). Transducer signals were corrected for the combined bodyweight of the bar and participant in the test position. Force signals were smoothed using a fourth-order, digital low-pass filter at 10 Hz before data analysis. The average output from the 2 transducers was used for data analysis.

The BSS test position was standardized by having the feet placed shoulder width apart with the height of the rear (left) foot positioned in line with the tibial tuberosity (standing height) and the front (right) leg positioned to achieve 45° of knee flexion (where 0° indicates normal upright standing) with the tibia perpendicular to the floor. Participants were
required to perform submaximal attempts at 25, 50, and 75% of the perceived maximal effort with 30-second rest between efforts. A total of 3 maximal contractions were subsequently performed with 2 minutes of rest between attempts. Intertrial reliability of MVC attempts was an intraclass correlation coefficient (ICC) $r = 0.90$. During each contraction, the participant was required to exert maximal effort for 3 seconds, and strong verbal encouragement was provided. MVC was determined from the trial with the highest force output. Loading for subsequent exercise was calculated as 75% of MVC.

For the BSS exercise repetitions, the same stance width was used as for MVC testing (anteroposterior and mediolateral distances). Repetitions began from an upright position with the front knee fully extended. Dumbbells were held in each hand to provide loading, with the 75% training load divided equally between the hands. We chose a dumbbell exercise model as in pilot testing, and we observed less postural deviation at the trunk and hip during multiple sets to exhaustion compared with using the bar on the shoulders. For each repetition, the participant lowered himself or herself until the front leg reached 90° flexion, before ascending back to the starting position. Cadence was a 2:1 verbally controlled tempo. Wrist straps were supplied to participants who were unable to hold the dumbbells during the exercise, so that exhaustion was owing to lower leg demand rather than issues with grip (strength or sweat). Two research assistants stood on either side of the participant during the exercise session to provide verbal encouragement and ensure that an upright trunk posture was maintained for every repetition. Each set was performed until volitional exhaustion, and all completed repetitions were counted. The set of repetitions was terminated if the participant was unable to return to the start position, could not meet depth, or could not maintain the required upright trunk posture. Verbal encouragement was provided throughout by the 6 research assistants conducting and monitoring every testing session.

During MVC measurements, maximal VL EMG amplitude (in millivolts) was calculated as the highest 100 millisecond of RMS data (intertrial reliability of maximal VL amplitude, ICC $r = 0.85$). Maximal EMG amplitudes after each set were normalized to the maximal activity recorded during the highest preexercise MVC. Vastus lateralis MF was calculated by the identification of the point that divided the area of the EMG power-density frequency spectrum in half. Electromyographic MF is an estimate of electrical conduction properties in the underlying tissue, which is associated with changes in muscle fiber conduction velocity (i.e., reductions in conduction velocity are associated with reductions in MF) ($5,8$). The EMG frequency spectrum was

<table>
<thead>
<tr>
<th>Participant</th>
<th>Maximal force output (N)</th>
<th>Set force plateau observed</th>
<th>Set sEMG amplitude plateau observed</th>
<th>Total repetitions performed</th>
<th>Repetitions completed first set only</th>
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<td>610</td>
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<td>Nil</td>
<td>91</td>
<td>19</td>
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</table>

**TABLE 1. Participant maximal force output preexercise, set number when a force output fatigue plateau, and surface electromyography (sEMG) amplitude plateau were observed.*

<table>
<thead>
<tr>
<th>Force plateau</th>
<th>Total repetitions completed first set only</th>
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<tr>
<td>$n = 9$</td>
<td>49.3 $\pm$ 12.5</td>
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<tr>
<td>No Plateau</td>
<td>$n = 6$</td>
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<tr>
<td>$r = 0.89$</td>
<td>18.7 $\pm$ 3.3</td>
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*A plateau was determined when subsequent sets were within $\pm 5\%$ of the force output or sEMG amplitude. Training volumes (total repetitions during the 8 sets) and repetitions in the first set are displayed, and mean values are presented according to the subgrouping by fatigue plateau.
obtained by fast Fourier transformation of the most stable 1-second epoch during the force plateau of each MVC trial, using a cosine-bell 1,024-point window with 50% overlap between processing windows (intertrial reliability of VL MF measures, ICC $r = 0.89$).

Electromyographic signals during each repetition were recorded, and the peak of 100-millisecond VL RMS activity was used for analysis. The average amplitude of the first 3 repetitions of the first BSS set was calculated. The last 3 repetitions of the first set and all subsequent sets were averaged and expressed as a relative percentage of the average activity for the first 3 repetitions of the first set.

Statistical Analyses
Kolmogorov-Smirnov testing demonstrated that all dependent variables were normally distributed; therefore, parametric testing methods were used. Repeated-measures analysis of variance (ANOVA) procedures were used to examine between-set changes for the dependent variables (MVC, EMG during MVC, EMG during repetitions, repetitions completed during each set). Post hoc tests with Bonferroni’s adjustment were used when a significant main effect was observed. First-set volume and total volume (repetitions performed) were used as covariates in the analysis of all variables apart from repetitions completed per set. Plateaus in force and EMG amplitude reached during the final 3 repetitions of each set were determined when all subsequent sets were within a range of $\pm 5\%$. Pearson’s correlation coefficient was used to examine the association between the set reached when a force and EMG plateau (whether an increased or decreased EMG amplitude) were observed. Group results were then subgrouped according to those classified as exhibiting a force plateau. Subsequently, repeated-measures ANOVA were run on previously described dependent variables with the between-subject factor of group (PLAT vs. NO-PLAT). Data are represented as mean $\pm SD$. The significance level for statistical testing in this study was $p \leq 0.05$.

RESULTS
Overall Group Results
The number of repetitions completed per set significantly decreased from the first...
(13.4 ± 5.5 repetitions) to the second (9.5 ± 3.9 repetitions; \( p = 0.005 \)), to the third set (72 ± 3.0 repetitions; \( p = 0.014 \)). There were no further reductions in repetitions per set (Figure 1). Repetitions completed in the first and second sets were significantly different from all other sets (\( p < 0.001 \)). In all subsequent analyses, first set volume and total session volume were not significant covariates.

Maximal isometric force decreased by 24.8 ± 13% from preexercise after set 1 (\( p < 0.001 \)). Maximal isometric force after set 4 (343 ± 90 N) was significantly different from set 1 (441 ± 108 N; \( p < 0.001 \)). Decreases in maximal force output plateaued from sets 5 through 8. Maximal force after set 8 (269 ± 102 N) was significantly different from sets 1 and 4 (\( p < 0.001 \)). Maximal sEMG amplitude during the isometric force trial decreased after the first set (44.1 ± 23.1% decrease; \( p < 0.001 \)), and no further reductions were observed. No changes in sEMG MF were observed during the protocol (\( p = 0.88 \)).

During the BSS repetitions, sEMG amplitude during the last 3 repetitions of all sets was not different from the average activity of the first 3 repetitions of the first set (\( p = 0.69 \)).

**Fatigue Plateau**

A plateau in maximal force output reduction during the exercise protocol was observed in 9 participants (Table 1). A plateau in sEMG amplitudes reached during the final 3 repetitions of the exercise sets was observed in 7 participants; however, only 4 of these participants also exhibited a plateau in force output reductions. A weak, nonsignificant correlation was observed between the set reached when a force and sEMG amplitude plateau was observed (\( r = -0.17; \ p = 0.75 \)).

Before exercise, no differences were observed between subgroups for maximal force output (Table 1). Participants who exhibited a force plateau (PLAT) performed less repetitions in the first set (Figure 1; Table 1) and less total repetitions compared with participants who did not exhibit a force plateau (NO-PLAT). For the PLAT subgroup, there was no difference between the repetitions performed in set 3 (5.8 ± 2.5 repetitions) compared with set 8 (4.9 ± 1.9 repetitions). For the NO-PLAT subgroup, there was no difference between the repetitions performed in set 5 (7.7 ± 2.6 repetitions) compared with set 8 (7.0 ± 1.9 repetitions).

A set x subgroup interaction was observed for reductions in maximal force output (Figure 2; \( p = 0.038 \)). In the PLAT group, force output was reduced from preexercise after set 2 (32.1 ± 10.7% decrease; \( p = 0.002 \)), and no further reductions were observed. In the NO-PLAT group, force output was similarly reduced after set 2 (28 ± 6.8%; \( p = 0.014 \)) and was further reduced until set 5 (no difference from sets 6 to 8). The final reduction in maximal force output after the eighth set was 62.7 ± 14.7% in the NO-PLAT group, which was significantly different from the 49 ± 11.6% reduction observed in the PLAT group (\( p = 0.03 \)). Total volume was not a significant covariate in the analysis. No set x subgroup interactions were observed for maximal sEMG and MF.

The average sEMG amplitude during the first 3 repetitions of set 1 was not different between the subgroups (\( p = 0.51 \)). A set x subgroup interaction was observed for changes in sEMG amplitude during BSS repetitions (Figure 3; \( p = 0.038 \)). Surface electromyography amplitudes were increased from the first 3 repetitions of set 1 to the last 3 repetitions of set 8 by 39.7 ± 38% (\( p = 0.048 \)) for the NO-PLAT group compared with 0.4 ± 32.3% for the PLAT group.

**DISCUSSION**

The main findings of this study were (a) for the whole group (\( n = 15 \)), reductions in maximal force output were significantly greater after 8 sets of exercise compared with 4 or 1 but were not accompanied by increased VL muscle activity; (b) participants where the training intensity may be described as a 9-repetition maximum (RM) (\( n = 9 \), based on repetitions performed in the first set) exhibited a fatigue plateau (in force output reductions and repetitions performed per set) after the second set of exercise and did not exhibit increases in muscle activation during the exercise session; and (c) participants where the training intensity approximated a 19RM (\( n = 6 \), based on repetitions performed in the first set) exhibited significant reductions in maximal force output and repetitions performed until the end of the fifth set and demonstrated increased VL muscle activation throughout the exercise session.

Notwithstanding limitations to the use of the sEMG method, the results of this study suggest that the manipulation of fatigue through an increased prescription of resistance exercise sets was not associated with increased muscle activation. This suggests that increased motor unit recruitment during moderate-to-high intensity resistance exercise, where the intensity remains constant, is not facilitated by increasing the extent of fatigue. Increased sEMG amplitudes from the first repetitions of set 1 were only observed at the end of the eighth set in participants who performed 19 repetitions in the first set. For these participants (\( n = 6 \)), maximal force output was not statistically different from the end of the fifth to the eighth set, indicating that fatigue was not associated with the observed sEMG increase. Thus, the premise of prescribing any submaximal training load (19), as long as fatigue is maximized, to facilitate maximal motor unit activation is not supported here. Indeed, inspection of the literature typically used to justify the premise that any load performed to exhaustion will necessitate near-maximal motor unit (19) recruitment proves this is a faulty assumption.

Fallentin et al. (6) examined single motor unit recordings during exhaustive isometric elbow flexion at 10 and 40% MVC. Only during the prolonged (111.3 minutes) 10% contraction, the authors’ observed new motor units being recruited that exhibited larger amplitude spikes (suggestive of higher-threshold motor units) to those observed at the start of contraction (6). During the 40% contraction (2.3 minutes), no new motor units were observed to be recruited during the
Acute Fatigue and Neuromuscular Responses

The authors concluded that during the 40% contraction, force output was maintained by those units recruited at the start of the task and that reflex feedback from the muscle likely impaired the ability to recruit additional motor units (6). Examination of the motor unit histograms between the end of the 10% and start of the 40% contraction indicate relatively little overlap for the motor unit spectrum recruited, suggesting that the 10% contraction did not achieve maximal recruitment. Similarly, research by Fuglevand et al. (11) is incorrectly interpreted to demonstrate that near-maximal motor unit recruitment is achieved when lighter loads are prescribed to the point of failure or fatigue. This article primarily (11) reported changes in M-wave properties, reflecting alterations in muscle tissue excitability not motor unit recruitment. Surface EMG amplitudes reached during 2 submaximal conditions performed to failure (20 and 35% MVC) did not reach the sEMG amplitudes recorded during the higher intensity (65% MVC) contraction (11). Indeed, the authors’ interpretation of their results with consideration for the involvement of fast-twitch motor units suggested that the low-intensity conditions (20 and 35% MVC) did not activate these units.

Recently, it has been suggested that volume, over and above manipulation of intensity, is the key resistance exercise variable associated with predicting the acute protein signaling response and subsequent hypertrophic adaptation (1,19). However, strength, particularly in a trained population, seems to be a function of both intensity (19) and volume (17). Excessive volume at very high intensity is commensurate with overreaching responses (10,27). High volumes of resistance exercise (e.g., 8 sets at 80% 1RM performed twice per week for 6 weeks) (17), while generally more successful than 4 or 1 set, does not guarantee success for all trainees. Therefore, the “golden program” in terms of optimal hypertrophy and strength responses is a delicate balance between these related prescription variables that must be tailored to the individual. The results of this study suggest that participants who performed 19 repetitions in the first set and exhibited a later and smaller (>5% variation in force output during subsequent sets) fatigue plateau are likely to achieve better hypertrophy outcomes than the plateau subgroup owing to the substantial difference in total accrued training volume (80 vs. 49 repetitions; \( p = 0.002 \)). That this volume was also accrued at a prescribed intensity of 75% 1RM with greater acute neuromuscular responses during exercise would also suggest a better expectation for strength outcomes. What is unclear from this study is whether observed responses for the 2 subgroups are related to individual differences in physiology that allow a greater volume to be performed at the same intensity or because the training intensity was actually different between the subgroups. We cannot be sure that reducing the training load to elicit a 19RM in the plateau subgroup would increase both the training volume and fatigue response. Conversely, we cannot be sure that increasing the loading to a 9RM in the nonplateau subgroup would reduce both the total volume accrued and neuromuscular response. The results of this study suggest that similar to observed training responses (17), there are individual differences in acute responses to percentage-based resistance exercise prescription. Repetition maximum (e.g., 3RM, 10RM, 20RM)–based prescription may provide more uniform findings across a range of participants and allow better examination of the relationship between acute and chronic training responses.

The identification of subgroups based on existence (or not) of a fatigue plateau raises questions about the practicality of prescription based on percentages of a 1RM and the ability to predict likely training gains. The clear separation of subgroups may be a function of the relative training intensity (75% maximal isometric force output, measured at the strongest point during the movement) being invalid across the participants. The premise that testing and prescription lacked internal validity is supported by the initial repetition level in the first set being approximately a 10RM load for the plateau sub-group, but a 19RM load for the subgroup that did not plateau. It must be noted that maximal strength before exercise was not different between the subgroups; therefore, the absolute, and relative training, load was the same for both the subgroups (force output trials had high reliability, \( r = 0.90 \)). Moreover, average sEMG amplitude during the first 3 repetitions of the first set was the same between the subgroups, suggesting comparable initial neuromuscular demand and therefore comparable relative loading. Therefore, we are confident in the internal validity of the relative loading prescribed within this study.

Limitations of this study must be acknowledged. It may be likely that other muscles not measured in this study, such as the gluteus maximus, exhibited different acute neuromuscular responses during the exercise repetitions. We are unable to determine why sEMG amplitudes for the entire group did not increase, and we are unable to explain the large and rapid decrease in sEMG amplitude measured during the maximal force task, which did not change after the initial first set decrease. For the former, peripheral changes in muscle excitability that depress sEMG amplitudes may have been compensated for by increased drive to the muscle proximal to the neuromuscular junction. Regarding the latter, reductions in maximal sEMG may indicate reduced central drive (i.e., central fatigue) or depression of muscle excitability or both. The lack of decrease in MF, a measure often associated with changes in properties of muscle excitation (2,5,8), may suggest that muscle is not the primary site of fatigue. The sEMG method used in this study does not allow delineation of central and peripheral fatigue mechanisms. Finally, the results of this study are only generalizable to single-leg squat exercise. Although there are many options of single-leg squat, these results may be generalizable to (e.g., static split squats, static or walking lunges, weighted step-up) performance of standard bilateral squat or deadlift techniques that may not elicit similar results to this study.
Moreover, it may be likely that the performance of a more technical lift is likely to introduce greater variability in performance from set to set, which may lead to different patterns of muscle activation changes to that observed in this study.

**Practical Applications**

The extent of muscular fatigue elicited from 8 sets of resistance exercise was greater than that from 4 sets or 1 set but was not associated with an increased neuromuscular response. Thus, the commonly observed prescription goal of maximizing acute fatigue at any intensity to ensure full motor unit recruitment is not supported in this study. Of interest for practitioners are the individual differences observed within the prescription of a fixed intensity, as described as the percentage of a 1RM. The expectation that all resistance-trained individuals will perform the same number of repetitions and accrue the same session volume using 1RM-based prescription is problematic and does not consider individual responsiveness to a given stimulus. There is considerable confusion in the literature and within clinical practice, as to the best combination of volume and intensity to prescribe to optimize training outcomes. This confusion may, in part, be explained by a lack of consideration for individual responsiveness to a prescription that inherently allows variation (e.g., 8 sets to volitional exhaustion at 75% 1RM in this study).

Within the group in this study, participants who performed approximately 10 repetitions in the first set exhibited early plateaus in fatigue and neuromuscular responses and accrued a total session volume of approximately 50 repetitions across 8 sets. In contrast, participants who performed approximately 20 repetitions in the first set at the same relative intensity (who also had the same strength levels and muscle activation levels during the first 3 repetitions of the first set) exhibited a later (and smaller) fatigue plateau; greater total force output reductions had elevated muscle activation patterns during exercise and accrued a total volume of approximately 80 repetitions across the 8 sets. It is reasonable to believe that participants in this study who exhibited a greater fatigue response, increased muscle activation, and accrued higher total training volumes would be more likely to have better training outcomes in terms of strength and hypertrophy.

The prescription of high volumes as the single answer for the most effective strength and hypertrophy program raises feasibility and practicality questions. Not all resistance-trained individuals are responsive to high-volume prescription (16). Conversely, resistance-trained individuals are not necessarily responsive to a low volume such as 1 set performed to exhaustion (16). Conditioning coaches should be aware that individuals who exhibit plateaus in repetition levels per set after as few as 2 sets, or as many as 5 or 6 sets, are not experiencing greater neuromuscular recruitment patterns and muscular fatigue if additional sets are performed.

Cessation of resistance exercise sets when repetitions per set are not changing, when using a 1RM percentage prescription model, will reduce the likelihood of fatigue-induced injury during more complex exercise models (e.g., a bilateral back or front squat, a deadlift) and potentially offset the severity and duration of delayed onset muscle soreness that may impair training sessions on subsequent days.

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**References**


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