*Medical Sciences*

# Differences between the Time Course of Changes in Neuromuscular Responses and Pretest versus Posttest Measurements for the Examination of Fatigue

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***Purpose:*** **The purposes of the current study were to examine the differences during the time course of changes in neuromuscular responses and pretest versus posttest measurements and to differentiate the information provided by these two methods (time course vs. pretest and posttest) regarding the motor unit activation strategies used to control force production during the process of fatigue.**

***Methods:*** **Twelve men performed concentric-only dynamic constant external resistance leg extensions to failure at 70% 1 repetition maximum (1-RM) and 1-RM measurements were taken before and after the fatiguing workbout.**

***Results:*** **The results indicated decreases in pretest versus posttest 1-RM strength and electromyographic (EMG) frequency, but no changes in EMG amplitude, mechanomyographic (MMG) amplitude, or MMG frequency. The time course of changes in neuromuscular responses during the 70% 1-RM protocol indicated 4 unique phases (1 to 20, 20-60, 60-80, and 80-100% of the repetitions to failure) that generally exhibited increases in EMG amplitude and MMG amplitude, but decreases in EMG frequency and MMG frequency.**

***Discussion:*** **These findings indicated that maximal pretest versus posttest measurements and the time course of changes in neuromuscular responses provide different information regarding the process of fatigue which may explain the reduction in maximal and submaximal force production.**

Electromyography | Mechanomyography | Resistance Training | Motor Unit Activation Strategies | Muscle Wisdom | Onion Skin Scheme

## 1. Introduction

Surface electromyography (EMG) and mechanomyography (MMG) have been used to examine neuromuscular responses and make inferences regarding the motor unit activation strategies used to control force production (1-4). For example, it has been suggested that a fatigue-induced increase in the amplitude of the EMG signal reflects greater muscle activation (5), while a decrease in the frequency content reflects a slowing of motor unit action potential conduction velocity (MUAP CV) (5). The MMG signal, however, has been described as the mechanical counterpart of the motor unit electrical activity as measured by EMG and quantifies the low-frequency oscillations of activated skeletal muscle fibers (6). Furthermore, under some conditions, the amplitude of the MMG signal reflects motor unit recruitment (6) and the frequency content is qualitatively related to the global motor unit firing rate of unfused, activated motor units (6). It has also been suggested that a fatigue-induced increase in MMG amplitude may indicate greater motor unit recruitment, while a decrease in MMG frequency is associated with a decrease in firing rate (7, 8). Thus, theoretically, simultaneous assessments of the time and frequency domain parameters of EMG and MMG signals can provide information regarding the characteristics of the motor unit activation strategies, such as the After-Hyperpolarization (AHP) theory (9), Muscle Wisdom (10), and the Onion Skin Scheme (2, 11), that control force production.

The AHP theory was based on stimulation studies by Eccles, Eccles (9), and Kernell (12), (13) and is characterized by fatigue-induced increases in muscle activation, motor unit recruitment, and firing rate. According to the AHP theory, a fatigue-induced buildup of metabolic byproducts causes a gradient shift from intracellular to extracellular potassium [$K^+$] which decreases the membrane potential below resting levels following depolarization which has been termed after-hyperpolarization (9, 12, 13). The metabolite shift which results in greater after-hyperpolarization then signals the central nervous system to increase motor unit recruitment and firing rate to maintain the required force production (14). Therefore, based on the AHP theory, the process of fatigue should be characterized by increases in EMG amplitude, MMG amplitude, and MMG frequency due to the increases in motor unit recruitment and firing rate.

The Muscle Wisdom theory was based on a stimulation study by Marsden, Meadows (10) and is characterized by fatigue-induced increases in muscle activation and motor unit recruitment, but decreases in firing rate. Specifically, during a fatiguing task the Muscle Wisdom theory (10) describes a progressive prolongation of relaxation time and a decrease in motor unit firing rate which, theoretically, allows for greater fusion of motor unit twitches and optimal force production. These findings were supported by Marsden, Meadows (10) and Bigland-Ritchie, Johansson (15) who demonstrated that stimulated motor units maintained the greatest force production during a sustained contraction when the frequency of the stimulation was progressively decreased. Therefore, based on Muscle Wisdom, the process of fatigue should be characterized by increases in EMG amplitude, MMG amplitude, but decreases in MMG frequency.

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The Onion Skin Scheme was based on a model created by De Luca and Erim (11) and, like the Muscle Wisdom Theory, is characterized by fatigue-induced increases in muscle activation and motor unit recruitment, but decreases in firing rate (16). The Onion Skin Scheme suggests that at any time or force level, earlier recruited motor units have higher firing rates than later recruited motor units. This theory results in an orderly nesting of firing rate curves, which resembles the skin of an onion. Thus, higher threshold motor units require lower firing rates to produce their maximal force than do lower threshold motor units. It has been hypothesized (11) that the lower firing rates observed in high threshold motor units may be due to their greater fatigability compared to low threshold motor units. For example, Trevino, Herda (17) reported that individuals with greater type II myosin heavy chain of the VL had lower firing rates of the higher threshold motor units compared to those with greater type I myosin heavy chain. Therefore, theoretically, the neuromuscular system activates high threshold motor units at lower firing rates to balance maximal force production with the duration that the force can be sustained.

Enoka and Stuart (18) suggested that delineating the differences between motor unit activation strategies may allow for identification of the mechanisms that result in task failure. In the current study, three motor unit activation strategies (AHP, Muscle Wisdom, and Onion Skin Scheme) are being considered, however, each has limitations (2, 3, 19). For example, Fuglevand and Keen (19) suggested that Muscle Wisdom may not be an overall activation strategy during fatigue and that decreases in the frequency of stimulations may not optimize the duration of a fatiguing muscle action. In addition, De Luca and Contessa (2) suggested that the AHP theory does not always explain the process of fatigue because there is often, but not always, a decrease in firing rate. These studies used either stimulation (19) or simulation (2) models which have their own limitations and, therefore, no one theory can be disregarded based on stimulation or simulation studies alone. The Onion Skin Scheme, however, may have limitations due to the loss of data when analyzing the signal and the proprietary nature of the decomposition algorithm(2, 20, 21). In addition, Barry and Enoka (22) have suggested that the motor unit activation strategies used during a fatiguing task may be intensity-, mode-, and muscle-specific.

Neuromuscular parameters are often measured at the beginning (pretest) and end (posttest) of a fatiguing workbout and the direction and magnitude of changes have been used to infer about the motor unit activation strategy used to control torque production (23-26). Fatigue, however, is a process that occurs over time (27) and measuring pretest and posttest neuromuscular parameters may limit the ability to identify the time-dependent changes in motor unit activation strategies that occur during a fatiguing workbout. Thus, measuring the pretest versus posttest neuromuscular parameters may provide insight regarding maximal force production, but not the motor unit activation strategies used to control force production during a submaximal fatiguing workbout. No previous studies have examined the differences between the neuromuscular responses from pretest versus posttest measurements and the time-dependent changes in neuromuscular parameters during a fatiguing workbout. Therefore, the purposes of the current study were to examine the differences during the time course of changes in neuromuscular responses and pretest versus posttest measurements and to differentiate the information provided by these two methods regarding the motor unit activation strategies used to control force production during the process of fatigue.

## 2. Material and Methods

### *2.1 Subjects*

Twelve men (mean ± SD age 21.9 ± 2.4 yr; body mass 76.7 ± 9.3 kg; height 175.8 ± 4.3 cm) volunteered to participate in this study. The subjects ranged between 19 to 26 years of age and were free from any musculoskeletal injuries or neuromuscular disorders, and performed resistance training for at least 6 months prior to the study. This study was approved by the Institutional Review Board, and all subjects signed a written informed consent and completed a health history questionnaire prior to participation.

### *2.2 Pretest and Posttest 1 RM Testing*

The pretest unilateral concentric (CON)-only 1 repetition maximum (1-RM) tests were performed using the dominant leg and in accordance with the National Strength and Conditioning Association's guidelines (28). The subjects performed a warm-up set of 5 to 10 repetitions at approximately 50% 1-RM, and 3 to 5 repetitions at approximately 75% 1-RM. The subjects then performed a series of single repetitions to determine the unilateral CON-only 1-RM within 1.13 kg. The unilateral CON-only 1-RM was defined as the greatest amount of weight that was moved through the full range of motion during the dynamic constant external resistance (DCER) leg extension. The posttest unilateral CON-only 1-RM tests were performed immediately following the 70% 1-RM protocol. Weight was added or removed until the greatest amount of weight that could successfully be moved through the full range of motion was determined (± 1.13 kg). This usually required 2 to 3 trials for the pretest 1-RM, and 1 trial for the posttest 1-RM.

### *2.3 Time Course of Changes during the 70% 1 RM Fatiguing Protocol*

During the 70% 1-RM protocol the subjects performed unilateral CON-only DCER leg extensions to failure with the dominant leg. Failure was defined as the inability to extend the leg to full extension during the CON phase of the leg extension or the inability to complete the CON phase of the leg extension within 1.5 seconds. During each repetition an investigator lowered the lever arm at the end of each CON phase of the leg extension to the starting position to eliminate the eccentric phase of the muscle action. All testing was performed on a Hammer Strength Iso-Lateral Leg Extension machine (LifeFitness).

### *2.4 Electromyography and Mechanomyography*

Bipolar electrode arrangements (Ag/AgCl, AccuSensor, Lynn Medical) were placed on the vastus lateralis (VL) of the dominant leg with an interelectrode distance of 30mm during the unilateral CON-only 1-RM tests and 70% 1-RM protocol. The skin was dry shaven, abraded, and cleaned with isopropyl alcohol prior to placing the electrodes. For the VL, the bipolar electrode arrangements were placed 66% of the distance between the anterior superior iliac spine (ASIS) and the lateral border of the patella and orientated at a 20° angle to approximate the pennation angle of the muscle fibers (29, 30). A reference electrode was placed over the ASIS. The MMG signal was measured using an accelerometer (EGAS-FT-10/V05, Measurement Specialties, Inc.) placed between the bipolar electrode arrangement on the VL using double-sided adhesive foam tape.

### *2.5 Signal Processing*

The EMG and MMG signals were zero-meaned and bandpass filtered (fourth-order Butterworth) at 10-500 Hz and 5-100 Hz, respectively. The EMG amplitude (root mean square: RMS), EMG frequency (mean power frequency: MPF), MMG RMS, and

MMG MPF values were calculated between knee joint angles of 110° and 160° during each unilateral CON-only 1-RM test, as well as for each repetition at every 10% of the repetitions to failure during 70% 1-RM protocol (180° being full extension). A goniometer was placed along the long axis of the femur and tibia of each subject to determine the knee joint angle throughout the range of motion. The EMG RMS, EMG MPF, MMG RMS, and MMG MPF values were normalized as a percent of the first repetition to examine the time course of changes in neuromuscular parameters during the unilateral CON-only DCER leg extensions to failure at 70% 1-RM. Repetitions were normalized as a percentage of the total repetitions completed and if the percent to failure was between repetitions, the repetition immediately following was selected (i.e. if 10% of the time to failure was at repetition 5.5, repetition 6 was used as the 10% of the time to failure). All signal processing was performed using custom programs written with LabVIEW programming software (Version 15.0, National Instruments).

### *2.6 Statistical Analysis*

#### *2.6.1 Strength and Neuromuscular Responses during the 1-RM measurement*

Five, separate, paired sampled *t*-tests were performed on the pretest versus posttest 1-RM EMG RMS, EMG MPF, MMG RMS, MMG MPF, and 1-RM strength.

#### *2.6.2 Time Course of Changes in Neuromuscular Responses Across the 70% 1-RM Protocol*

The time course of changes in neuromuscular responses involved combining polynomial regression analyses with ANOVA and post-hoc Student Newman-Keuls comparisons to identify the patterns of responses and time-points at which these values became different than the initial values. Polynomial regression analyses were used to determine the patterns (linear, quadratic, or cubic) for the mean, normalized (% of initial repetition) EMG RMS, EMG MPF, MMG RMS, and MMG MPF versus repetition relationships. Time course of changes in normalized EMG RMS, EMG MPF, MMG RMS, and MMG MPF from the initial repetition were identified by one-way repeated measures ANOVA 1 (neuromuscular parameters [EMG RMS, MMG RMS, EMG MPF, MMG MPF]) x 11 (repetitions [1, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50]) with post-hoc Student Newman-Keuls tests. The Student Newman-Keuls test was chosen for the post-hoc analyses because it is designed to analyze the time course of changes in repeated measure variables (31). An alpha of $p \leq 0.05$ was considered statistically significant for all statistical analyses (SPSS Version 22.0 ).

## 3. Results

### *3.1 Pretest and Posttest Strength and Neuromuscular Responses during the 1-RM Measurements*

Table 1 shows the results from the pretest versus posttest 1-RM measurements. There were no differences in EMG RMS ($p = 0.80$), MMG RMS ($p = 0.63$), and MMG MPF ($p = 0.17$) from the pretest versus posttest 1-RM test. There were, however, significant decreases in EMG MPF ($p < 0.01$) and 1-RM strength ($p = 0.04$).

### *3.2 Time Course of Changes in Neuromuscular Parameters During 70% 1-RM Protocol*

Figure 1 shows the results of the polynomial regression analyses and significant one-way repeated measures ANOVAs (1 x 10) with post-hoc Student Newman-Keuls tests for the normalized EMG RMS ($p < 0.01$; $\eta_p^2 = 0.89$), EMG MPF ($p < 0.01$; $\eta_p^2 = 0.82$), MMG RMS ($p < 0.01$; $\eta_p^2 = 0.67$), and MMG MPF ($p < 0.0$; $\eta_p^2 = 0.74$) versus repetition relationships from the VL at 70% 1-RM. There were significant cubic relationships for the EMG RMS ($p < 0.01$; $R^2 = 0.98$) and MMG RMS ($p = 0.01$; $R^2 = 0.89$) versus repetition from the VL at 70% 1-RM that were greater than the initial repetition from 10 to 100% of the total repetitions (Figure 1). There was a significant negative quadratic relationship for EMG MPF ($p < 0.01$; $R^2 = 0.98$) versus repetition from the VL at 70% 1-RM that decreased from the initial repetition from 60 to 100% of the total repetitions (Figure 1). There was a significant cubic relationship for MMG MPF ($p < 0.01$; $R^2 = 0.90$) versus repetition from the VL at 70% 1-RM that decreased from the initial repetition from 10 to 100% of the total repetitions (Figure 1).

**Table 1. Pretest and posttest parameters (mean ± SD) during the 1-RM measurements.**

| | Pretest | Posttest |
|---|---|---|
| EMG RMS (μV) | 760 ± 209 | 790 ± 347 |
| MMG RMS (m·s$^2$) | 0.59 ± 0.28 | 0.67 ± 0.46 |
| EMG MPF (Hz) | 78.13± 8.70* | 57.50 ± 8.82 |
| MMG MPF (Hz) | 20.42 ± 6.49 | 16.53 ± 6.77 |
| 1-RM Strength (kg) | 45.55 ± 7.52* | 29.20 ± 6.45 |

* $p < 0.05$, pretest > posttest., EMG, Electromyography; MMG, Mechanomyography; RMS, root mean square; MPF, mean power frequency; 1-RM, 1- repetition maximum.

## 4. Discussion

### *4.1 Neuromuscular Responses During the Pretest versus Posttest 1-RM Measurements*

In the current study, there was a 36% decrease in 1-RM strength as a result of the fatiguing submaximal, DCER workbout that was accompanied by a 26% decrease in EMG MPF, but no changes in EMG RMS, MMG RMS, and MMG MPF. These findings were in agreement with Pincivero et al. (32) who reported no pretest versus posttest changes in EMG RMS during 1-RM measurements, but decreases in EMG MPF from the VL, vastus medialis (VM), and rectus femoris (RF) after DCER leg extension muscle actions to failure at 50% 1-RM. The current findings were also in agreement with Akima et al. (33) who reported no changes in EMG RMS from the VL, VM, and RF after DCER leg extension muscle actions to failure at 50 and 70% 1-RM. It has been suggested (32, 33) that the decrease in pretest versus posttest strength, without changes in EMG RMS, were the result of excitation-contraction coupling failure. Thus, the current findings were in agreement with previous studies (32, 33) which suggested no changes in muscle activation (EMG RMS), but decreases in MUAP CV (EMG MPF) during the 1-RM measurements following submaximal, DCER leg extension muscle actions to failure.

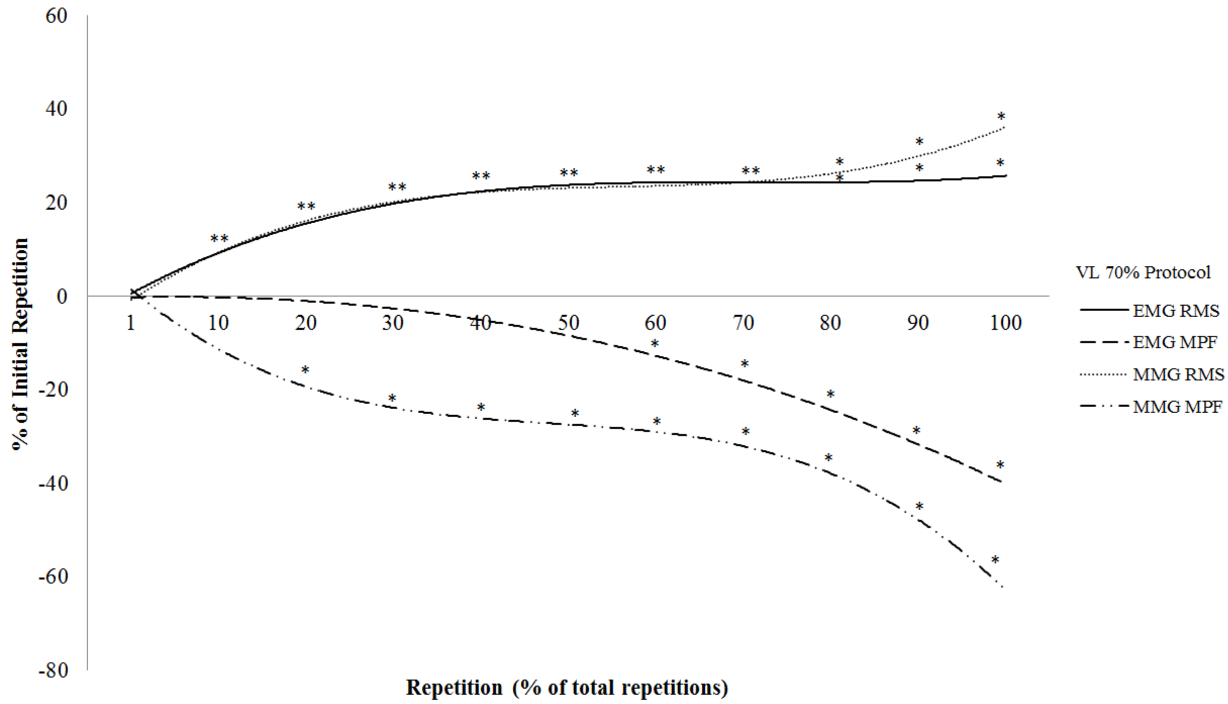


**Figure 1.** Time course of changes in neuromuscular parameters during the 70% 1 repetition maximum protocol from the vastus lateralis (VL). Electromyographic (EMG) root mean square (RMS), EMG mean power frequency (MPF), mechanomyographic (MMG) RMS, and MMG MPF. * Significantly different ($p < 0.05$) from the initial value.

***4.2 Neuromuscular Responses Across the 70% 1-RM Protocol***

In the present study, there were 4 unique phases (1 to 20, 20 to 60, 60 to 80, and 80 to 100% of the repetitions to failure) for the neuromuscular responses from the VL during the 70% 1-RM protocol (Figure 1). During the first 20% of the repetitions to failure, there were increases in EMG RMS and MMG RMS, but no changes in EMG MPF or MMG MPF. These findings were similar to Akima et al. (33) who reported increases in EMG RMS from the VL during the first 25% of the repetitions to failure of DCER leg extension muscle actions at 70% 1-RM. These findings were not in agreement with Croce et al. (4), however, who reported an increase in EMG RMS, but decreases in MMG RMS, EMG MPF, and MMG MPF from the VL during the first 15% of maximal, CON-only isokinetic leg extension muscle actions to failure. Thus, the current study and previous studies (4, 33) suggested intensity- (maximal versus submaximal) and mode-specific (isokinetic versus DCER) differences during the first 15-20% of leg extension repetitions to failure. The neuromuscular responses to submaximal DCER muscle actions to failure in the current study and that of Akima et al. (33) may have reflected increases in muscle activation (EMG RMS) and motor unit recruitment (MMG RMS), but no changes in global motor unit firing rate (MMG MPF) or MUAP CV (EMG MPF). The neuromuscular responses of Croce et al. (4) suggested, however, that the maximal CON-only isokinetic muscle actions were characterized by increases in muscle activation (EMG RMS), but decreases in motor unit recruitment (MMG RMS) as well as MUAP CV (EMG MPF) and global motor unit firing rate (MMG MPF).

From 20 to 60% of the repetitions to failure in the present study, there were increases in EMG RMS and MMG RMS, a decrease in MMG MPF, and no change in EMG MPF. These findings were in agreement with Masuda et al. (34) who reported an increase in EMG RMS, but no change in EMG MPF from the VL during 20 to 60% of the repetitions to failure of DCER leg extension muscle actions at 50% 1-RM. In addition, the current findings were in agreement with Akima et al. (33) who reported an increase in EMG RMS from the VL during 25 to 75% of the repetitions to failure of DCER leg extension muscle actions at 70% 1-RM. The neuromuscular responses from 20 to 60% of the repetitions to failure in the present study may have reflected increases in muscle activation (EMG RMS) and motor unit recruitment (MMG RMS), a decrease in global motor unit firing rate (MMG MPF), but no change in MUAP CV (EMG MPF).

During the third phase (60 to 80% of the repetitions to failure) there was a plateau in EMG RMS and MMG RMS, and decreases in EMG MPF and MMG MPF. These findings were in agreement with those of Croce et al. (4) who reported a plateau in EMG RMS and MMG RMS, but decreases in EMG MPF and MMG MPF from the VL during 60 to 75% of the repetitions to failure of maximal isokinetic leg extension muscle actions. These findings suggested that from 60 to 80% of the repetitions to failure there was no change in muscle activation (EMG RMS) or motor unit recruitment (MMG RMS), but decreases in global motor unit firing rate (MMG MPF) and MUAP CV (EMG MPF).

From 80 to 100% of the repetitions to failure there was a plateau in EMG RMS, an increase in MMG RMS, and decreases in EMG MPF and MMG MPF. These findings were in agreement with Pincivero et al. (32) who reported a plateau in EMG RMS and decreases in EMG MPF from the VL during DCER leg extension muscle actions to failure at 50% 1-RM. Thus, from 80 to 100% of the repetitions to failure there was an increase in motor unit recruitment (MMG RMS) which was accompanied by decreases in global motor unit firing rate (MMG MPF) and MUAP CV (EMG MPF). Therefore, during the 70% 1-RM protocol, the VL exhibited 4 unique phases (1 to 20, 20 to 60, 60 to 80, and 80 to 100% of the repetition to failure) of fatigue-induced neuromuscular responses that contributed to the overall force production during the CON-only DCER leg extension muscle actions to failure at 70% 1-RM.

### *4.3 Neuromuscular Responses During the Pretest versus Posttest 1-RM Measurements Versus Time Course of Changes in Neuromuscular Responses During the Fatiguing Workbout*

Examination of the neuromuscular responses during the pretest versus posttest 1-RM measurements and the time course of neuromuscular responses during the fatiguing workbout provided different information regarding the characteristics of fatiguing submaximal, DCER leg extension muscle actions to failure. The neuromuscular responses during the 1-RM measurements suggested that there were no fatigue-induced changes in muscle activation (EMG RMS), motor unit recruitment (MMG RMS), or global motor unit firing rate (MMG MPF) following CON-only DCER leg extension muscle actions to failure. There was, however, a decrease in EMG MPF, possibly due to a buildup of metabolic byproducts that decreased MUAP CV (35). These neuromuscular responses suggested that excitation-contraction coupling failure was responsible for the decrease in 1-RM strength following the fatiguing workbout (Table 1).

Unlike during the pretest versus posttest neuromuscular responses from the 1-RM measurements, the time course of changes in neuromuscular responses may provide information regarding the motor unit activation strategies used to maintained force production during the submaximal fatiguing DCER leg extension muscle actions to failure. Specifically, there were increases in EMG RMS and MMG RMS throughout the fatiguing workbout that became significantly greater than the initial repetition at 10% of the repetitions to failure (Figure 1). The regression analyses for MMG MPF, however, indicated decreasing patterns throughout the fatiguing workbout that became significant at 20% of the repetitions to failure (Figure 1). In addition, EMG MPF decreased from the initial value at 60% of the repetitions to failure. Therefore, these time course of changes in neuromuscular responses suggested increases in muscle activation (EMG RMS) and motor unit recruitment (MMG RMS), but decreases in global motor unit firing rate (MMG MPF) during the submaximal fatiguing DCER leg extension muscle actions. These patterns of neuromuscular changes were not consistent with the AHP theory (9), which would predict increases in motor unit firing rate (MMG MPF) during the initial phase of a fatiguing workbout. The increases in MMG RMS and decreases in MMG MPF, however, could be explained by both Muscle Wisdom (10) and the Onion Skin Scheme (11) which would predict fatigue-induced increases in motor unit recruitment, but decreases in firing rate. The mechanisms underlying the expected decrease in motor unit firing rate, as reflected by MMG MPF, however, differ between Muscle Wisdom (10) and the Onion Skin Scheme (11). Muscle Wisdom (10) suggests that the central nervous system employs a specific activation strategy that includes decreases in motor unit firing rate to maintain force production during fatigue. The Onion Skin Scheme (11), however, suggests a natural reserve of motor units and that earlier recruited motor units have higher firing rates than later recruited ones. Therefore, as the process of fatigue occurs, motor unit recruitment increases and firing rate decreases.

In the current study, the neuromuscular responses during the pretest versus posttest 1-RM measurements and time course of changes in neuromuscular responses provided different information regarding the process of fatigue. The neuromuscular responses during the pretest versus posttest 1-RM measurements indicated that excitation-contraction coupling failure likely caused the decrease in maximal strength, but the time course of changes in neuromuscular responses suggested that Muscle Wisdom (10) or Onion Skin Scheme (11) may have explained the changes in neuromuscular responses required to maintain submaximal force production during the fatiguing workbout.

## 5. Conclusions

In summary, during the pretest versus posttest 1-RM measurements there was a decrease in EMG MPF, but no changes in EMG RMS, MMG RMS, or MMG MPF which suggested the decrease in 1-RM strength was a result of excitation-contraction coupling failure (Table 1). The time course of changes in neuromuscular responses during the submaximal fatiguing workbout, however, indicated 4 unique phases (1 to 20, 20 to 60, 60 to 80, and 80 to 100% of the repetitions to failure) that were characterized by increases in EMG RMS and MMG RMS, but decreases in EMG MPF and MMG MPF. These time course of changes in neuromuscular responses suggested the maintenance of force during the fatiguing workbout were associated with increases in muscle activation (EMG RMS) and motor unit recruitment (MMG RMS), but decreases in MUAP CV (EMG MPF) and global motor unit firing rate (MMG MPF). Furthermore, these patterns of neuromuscular responses and motor unit activation strategies were consistent with Muscle Wisdom (10) and the Onion Skin Scheme (11), but not the AHP theory (9). Thus, the pretest versus posttest 1-RM measurements provided information regarding the neuromuscular responses associated with the decrease in maximal strength that occurred as a result of the fatiguing workbout. The time course of changes in neuromuscular responses, however, described the fatigue-induced changes in neuromuscular responses during the process of fatigue. Therefore, the neuromuscular responses during the pretest versus posttest 1-RM measurements provided information regarding the effects of the fatiguing workbout on maximal force production. The time course of changes in neuromuscular responses, however, provided information regarding the process of fatigue and allowed for inferences on the motor unit activation strategies used to maintain force production during the fatiguing workbout.

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