

The Impact of Resistance Exercise on Neurotransmission Failure within Trained Participants

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Abstract

Background: The purpose of this investigation was to determine neuromuscular failure via pre-to-post exercise amplitude changes of the M-wave following a Calf-Raise Exercise (CR).

Methods: In a balanced crossover design and separated by one week, eight participants (Males = 5; Females = 3) performed the CR with either one repetition (CR1) or five repetitions (CR5). Electromyography of gastrocnemius were recorded both pre- and post-CR1/CR5 in order to determine changes in M-wave amplitude.

Results: The main effect for exercise was not statistically significant ($p = 0.7590$) where the M-wave amplitude for CR1 (5.50 ± 6.16 mV) and CR5 (4.88 ± 5.59 mV) were similar when pooled across pre-/post-exercise. Likewise, the main effect for time was not statistically significant ($P = 0.6310$) where the M-wave amplitude for pre-exercise (5.24 ± 5.33 mV) and post-exercise (5.13 ± 5.08 mV) were similar when pooled across CR1 and CR5. The exercise x time interaction was not statistically significant ($P = 0.3440$) as M-wave amplitude did not change differently from pre- to post-exercise between the CR1 and CR5 trials.

Conclusion: We conclude that M-wave amplitude was not statistically different from pre-exercise to post-exercise for either one repetition or five repetitions of the CR exercise.

Keywords

Electromyography; Fatigue; Force/Power; M-wave Amplitude; Resistance Exercise

Introduction

Human performance is largely dependent upon both force and power generation, however, fatigue begins to set in during sustained muscle contractions [1]. Fatigue is defined as the

inability to produce a desired force or power output [2], and has been associated with alterations in both the central nervous system [3] and peripheral nervous system [4]. Although fatigue is a multi-faceted process, the loss in force/power following submaximal contractions with sufficient rest between each muscle action has been more closely attributed to the alterations in the peripheral nervous system [5]. Factors that are associated with peripheral fatigue include any disturbance at or below the neuromuscular junction, including: changes in energy supply [6], muscle fiber type distribution [7,8] muscle strength before fatigue [9,10] and the length of the muscle [11]. Additionally, peripheral fatigue may include failure of an action potential transmission along the motor nerve axon, sarcolemma, and T-tubules, and/or the efficiency of cross-bridge force production [4]. As for central nervous system fatigue, factors may include a progressive reduction in the voluntary activation of a muscle starting from the motor cortex [12] to the desensitization of moto neurons at the spinal level [13]. Additionally, central fatigue may result from an increased inhibition from group III and IV afferents [14].

The human nervous system is highly adaptive and can be modified in response to a variety of different motor experiences [15,16] with these modifications being argued to have a contribution to enhanced motor performance [17,18]. Electromyostimulation (EMS) has been widely utilized when investigating central and peripheral factors in relation to fatigue due to this technique recording muscle activation with no contributing involvement of the central nervous system [1]. Muscle activation is recorded following an electric stimuli being applied to the skin level that evokes an action potential in both the motor and sensory fibers, subsequently generating force production through the direct activation of motor axons and indirect activation of spinal moto neurons [19]. Neural adaptations have been reported with short-term EMS training, including increases in Electromyographic (EMG) activity [20], voluntary activation level [21], and significant cross-education effect [22]. Taken together, these techniques help

to determine whether the peripheral nervous system or central nervous system plays a larger role to the decrements in force/power production.

Both central and peripheral fatigue have been assessed during Maximal Voluntary Contractions (MVC) with the twitch interpolation technique by applying a supramaximal electrical stimuli to a mixed peripheral nerve and measuring the changes in muscle activation via EMG recordings [23,24]. Specifically, one such measure of failure surrounding the neuromuscular junction is through changes in the M-wave amplitude. The changes in M-wave amplitude is of importance when examining loss in force production this change may indicate a lack of responsiveness of the pathway between the site of stimulus (efferent axons of a muscle nerve) and the recording site (motor unit action potentials). Alterations in the M-wave response have been reported to be more sensitive to changes distal to the neuromuscular junction, particularly within the sarcoplasmic reticulum or T-tubules of the muscle [25,26]. Results have been varied in regards to the M-wave following muscle contractions, with some reporting increases in M-wave amplitude following resistance training [23,26] while some have reported no changes [27].

Neural adaptations have been reported with both endurance [18,28] and strength training [17,26,29] however, to our knowledge, no investigations have been performed measuring changes in the M-wave amplitude following short duration maximal work. Additionally, changes in M-wave amplitude have not been investigated using traditional resistance exercises with traditional repetitions found within most training programs. Therefore, the purpose of this investigation was to determine pre-to-post exercise amplitude changes of the gastrocnemius M-wave following a calf-raise exercise. An additional purpose involved comparing the changes in M-wave amplitude following either a single repetition or five repetitions of the said exercise. Similar to the results presented by Aagaard et al., [26] it was hypothesized that M-wave amplitude would increase from pre- to post-exercise, with a greater increase being apparent following multiple repetitions.

Methods

Participants

Eight participants (Males = 5; Females = 3) were recruited (age: 21.1±1 y; height: 169±9.3 cm; weight: 76.5.4±12.9 kg). Participants had at least six months of weightlifting experience, and were recruited from kinesiology activity courses at Louisiana State University, as well as from commercial fitness facilities located in the Baton Rouge, LA area. The Louisiana State University Institutional Review Board approved the study, and each participant signed a written consent form after receiving an explanation of the purpose, potential risks, and benefits of participation in the study. Participants were excluded from the study if they reported a history of any lower extremity joint and/or back injuries. In addition, all potential participants completed a Physical Activity Readiness Questionnaire (PAR-Q) before inclusion into the study. Only those individuals who answered “no” to all PAR-Q questions qualified as research participants.

5RM testing procedures

The first day of testing consisted of completing each participant's 5-Repetition Maximum (5RM) for the Calf-Raise (CR) exercise to determine the amount of resistance to be used for the experimental trials. The procedures for acquiring a 5RM for the CR were performed according to the guidelines outlined by the National Strength and Conditioning Association® [30]. Upon arrival to the lab, participants performed a standardized warm-up of five min on a stationary cycle ergometer. Following the warm-up, participants were set up in a power-rack for proper height fitting for the CR.

All 5RM testing sessions used a standard Olympic style barbell (20.4 kg) and bumper plates. The Olympic bar and bumper plates were used to allow participants to drop the bar when performing the CR in order to ensure safety. The CR movement was executed by standing flat footed with the barbell placed on the upper trapezius and plantar-flexing as high as possible, followed then by returning to starting position of feet flat on the ground. The first set consisted of performing the CR for 10 repetitions with an unloaded bar. An estimated resistance that the participants believed they could perform five repetitions easily was then placed on the bar. Following this lift and a two min rest, 10-20% additional resistance was added to the bar. If the participant completed five repetitions successfully, a two min rest was given and additional resistance was added in similar increments. This process continued until the participant was unable to complete five repetitions or if the set was completed with improper technique.

Experimental trials

For the experimental trials, participants completed either one repetition (CR1) or five repetitions (CR5) of their 5RM in a balanced crossover design with each trial being separated by one week. All experimental trials used the same power rack set-up, cycle ergometer/unloaded bar warm-up used in the 5RM session. Following the warm-up, each participant began by performing the CR with either one repetition or five repetitions at 50% and 75% of their 5RM. There was a three min rest between each of the aforementioned warm-up sets. Once the two warm-up sets were completed along with a three min rest, participants performed the CR at 100% of their 5RM with either one repetition (CR1) or five repetitions (CR5). Stimulation of the tibial nerve was performed immediately pre-exercise and immediately following the final CR1/CR5 set in order to acquire the EMG recordings used to analyze changes in the M-wave amplitude.

M-wave amplitude

Stimulation of the lateral gastrocnemius was performed by electrically stimulating the tibial nerve in the popliteal fossa with the negative electrode positioned proximal to the positive electrode. Stimulation was administered using a BSLSTM Voltage Stimulator connected to a MP36 data acquisition unit (Biopac Systems, Inc., Goleta, CA). Muscle EMG data were collected at 2000 Hz. The EMG recordings were filtered at a band width of 30-1000 Hz. Participants were shaved and wiped with an antiseptic alcoholic wipe to cleanse the desired locations, and self-adhering Ag-AgCl bipolar

surface electrodes were placed with an inter-electrode distance of two centimeters. The electrodes were secured over the lateral gastrocnemius muscle belly in line with the muscle fibers using adhesive tape, and then were wrapped using a self-adhesive elastic sports bandages. The electrode placement of the gastrocnemius was determined from the Surface EMG Non-Invasive Assessment of Muscles (SENIAM) guidelines. To determine the voltage required to achieve an EMG response, participants laid prone on a bench with the voltage of the stimulation starting at 40 V and increased until a plantar flexor response was observed at the foot, or stimulation maxed out at 100 V. Three stimulations were delivered at pre-exercise and immediately post-exercise with each stimulation separated by 10 sec. M-wave amplitude was calculated as the difference between peak maximum and peak minimum of the M-wave amplitude response. In order to ensure a proper representation of the EMG recordings, data were averaged with a minimum of two out of three measures. Additionally, any data with a presence of low frequency noise or non-responsive EMG signals were removed.

Statistical analysis

A two-way (exercise x time) repeated-measures Analysis of Variance (ANOVA) was used to identify statistical differences between trials (CR1, CR5) across exercise time (pre-/post-) in M-wave amplitude (mV). If needed, appropriate post-hoc tests were used to make all pairwise comparisons for specific differences across the experimental trials and/or time points. The experiment-wise error rate ($\alpha = 0.05$) was maintained throughout all post-hoc tests for specific differences. Finally, a generalized eta squared was used for effect size determination.

Results

The main effect for exercise was not statistically significant ($p = 0.7590$, $\eta^2 = 0.014$) where the M-wave amplitude for CR1 (5.50 ± 6.16 mV) and CR5 (4.88 ± 5.59 mV) were similar when pooled across pre-/post-exercise. Likewise, the main effect for time was not statistically significant ($P = 0.6310$, $\eta^2 = 0.035$) where the M-wave amplitude for pre-exercise (5.24 ± 5.33 mV) and post-exercise (5.13 ± 5.08 mV) were similar when pooled across CR1 and CR5. The exercise x time interaction was not statistically significant ($P = 0.3440$, $\eta^2 = 0.128$) as M-wave amplitude did not change differently from pre- to post-exercise between the CR1 and CR5 trials (Figure 1).

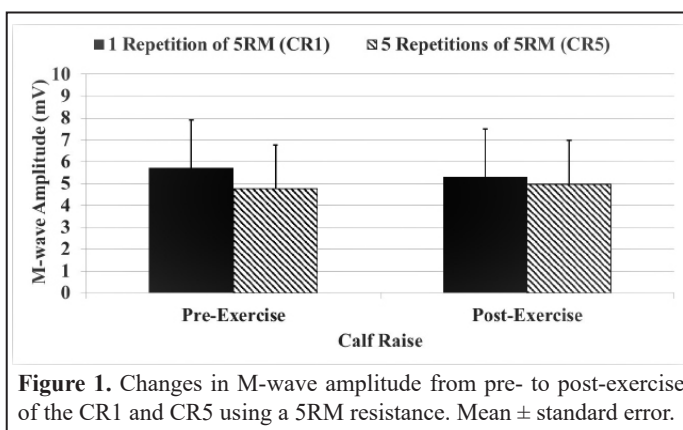


Figure 1. Changes in M-wave amplitude from pre- to post-exercise of the CR1 and CR5 using a 5RM resistance. Mean \pm standard error.

Discussion

The current investigation's purpose was to determine changes in muscle activity when performing repetitions commonly found within strength and conditioning programs. Our findings appear to follow the literature in regards to having no change in M-wave amplitude from pre-exercise to post-exercise. Despite the lack of statistical significance within the current investigation, the need to understand the role the nervous and muscular systems have upon fatigue is still warranted. A disclaimer must be said that our findings are only in relation to the gastrocnemius and cannot be extrapolated to any other muscles that are involved in many upper body human movements, such as those that surround the glenohumeral joint. Therefore, more research should continue to investigate muscles that are used extensively in human movements, such as the gastrocnemius. Investigating only the gastrocnemius and no other muscles is one major limitation of this project. Larger muscle groups may respond differently than the muscle used in the current investigation, therefore, future research incorporate multiple muscle groups. Additionally, protocols should utilize dynamic movements rather than isometric contractions when investigating mechanisms of neuromuscular fatigue in order to be more applicable to the field of strength and conditioning.

The current investigation was unable to report any statistically significant changes in M-wave amplitude following either one repetition or five repetitions of the calf-raise exercise. The M-wave has been utilized to measure changes in muscle activation, however, findings are controversial regarding the exact changes in M-wave amplitude following exercise. One explanation for the inconsistencies in M-wave findings could be that neural adaptations are task dependent [31-33]. For example, the majority of investigations have utilized maximal voluntary contractions when investigating changes in M-wave amplitude, with studies reporting the M-wave to increase [34], decrease [35-38], or to remain constant [39]. Although MVCs are a common method of assessing changes in M-wave amplitude, holding a contraction maximally may not exert an exercise stimulus sufficient to elicit neural adaptations. Thus, the use of MVCs may be a reason why there are inconsistencies in M-wave amplitude changes in regards to neuromuscular fatigue. The current investigation attempted to deliver a sufficient exercise stimulus by having participants perform a plantar-flexing movement under a heavy load. Despite being unable to report a statistical significant change in M-wave amplitude, our protocol did follow previous research which observed no changes in M-wave amplitude following a high load weight training session [40,41]. Therefore, the exercise stimulus within the current investigation may have been insufficient to warrant any significant neural adaptations within the gastrocnemius.

Resistance training sessions have been reported to induce acute decreases in muscle strength and changes within the neuromuscular system [42]. An increase in EMG amplitude have been reported within human plantar flexor muscles [5,19,43,44] however, with respect to changes in M-wave amplitude, results remain inconsistent. For example, some have reported a decrease in M-wave amplitude following maximal [45] or submaximal contractions [44], while others reported no changes following maximal [40] or submaximal contractions [41]. Hatzikotoulas et al., compared central and peripheral fatigability between men and boys during maximal

voluntary contractions [1]. Although not statically significant, the authors did report the M-wave to decrease in both groups. On the other hand, twitch torque was decreased significantly in the men compared to the boys. Based upon these findings, the authors concluded that peripheral factors might be the primary cause to fatigue compared to central factors [1]. Our results of no statistically significant changes in M-wave amplitude follows those that reported no change [40,41] therefore, more research is warranted to better understand the responses in M-wave amplitude following exercise. Investigating changes in M-wave amplitude are important for understanding how neural activity is altered under times of fatigue, thus, future research would be of importance to those working with athletes.

An interesting contrast to the above notion is that despite being under a heavy load, the gastrocnemius displayed no statistically significant signs of fatigue. This might indicate that the gastrocnemius has a greater ability to withstand the onset of fatigue, despite being primarily composed of fast-twitch motor units, which are known to be more fatigable compared to slow twitch motor units [46]. Due in part to the gastrocnemius being activated extensively in lower body human movements, there is a possibility that they are more resistant to fatigue than previously understood. However, this is speculative due to only one working set being performed within the current investigation, thus, being one major limitation to this investigation. Nonetheless, future research should include a greater exercise stimulus to investigate whether or not the gastrocnemius are more fatigue resistant.

Conclusion

Although the current investigation was unable to demonstrate statistical significance, the results do reveal that the neuromuscular system is highly resistant to an acute resistance exercise session. One of the major benefits of the current investigation was that the protocol utilized was that of a common resistance exercise performed in both strength & conditioning programs and the general fitness community. Investigation into how the neuromuscular system either adapts or is altered to training should be at the utmost importance due in part to this system is known throughout the strength & conditioning profession to be one primary system that is fatigued when training. However, the mechanisms of neuromuscular system fatigue and how this system is altered throughout exercise still remains to be unknown. Therefore, future research should continue exploring this area, with protocols utilizing exercises found within both the strength & conditioning and general fitness communities. Lastly, future research should continue investigating how the M-wave responds to a fatiguing protocol, for the M-wave can be beneficial in understanding how the body alters the nervous and muscular system under fatiguing conditions to ensure proper force/power production.

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