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Original Article

Effects of fatiguing constant versus alternating intensity intermittent isometric muscle actions on maximal torque and neuromuscular responses

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Abstract

Objective: To determine the effects of constant versus alternating applications of torque during fatiguing, intermittent isometric muscle actions of the leg extensors on maximal voluntary isometric contraction (MVIC) torque and neuromuscular responses. **Methods:** Sixteen subjects performed two protocols, each consisting of 50 intermittent isometric muscle actions of the leg extensors with equal average load at a constant 60% MVIC or alternating 40 then 80% (40/80%) MVIC with a work-to-rest ratio of 6-s on and 2-s off. MVIC torque as well as electromyographic signals from the vastus lateralis (VL), vastus medialis (VM), and rectus femoris (RF) and mechanomyographic signals from the VL were recorded pretest, immediately posttest, and 5-min posttest. **Results:** The results indicated that there were no time-related differences between the 60% MVIC and 40/80% MVIC protocols. The MVIC torque decreased posttest (22 to 26%) and remained depressed 5-min posttest (9%). There were decreases in electromyographic frequency (14 to 19%) and mechanomyographic frequency (23 to 24%) posttest that returned to pretest levels 5-min posttest. There were no changes in electromyographic amplitude and mechanomyogrpahic amplitude. **Conclusions:** These findings suggested that these neuromuscular parameters did not track the fatigue-induced changes in MVIC torque after 5-min of recovery.

Keywords: EMG, MMG, Fatigue, Recovery, Submaximal

Introduction

Fatigue has previously been defined as a "...gradual decrease in the force capacity of muscle or the endpoint of a sustained activity, and it can be measured as a reduction in muscle force, a change in electromyographic activity or an exhaustion of contractile function." (p.12)[1]. The amplitude of the electromyographic signal represents muscle activation, and the frequency content is related to motor unit action potential conduction velocity during isometric muscle actions[2-5]. The mechanomyographic signal, however, reflects the mechanical counterpart of the motor unit electrical activity as measured by electromyographic and quantifies the low-frequency lateral oscillations of activated skeletal muscle fibers[5-7]. Under some conditions, the amplitude of the mechanomyographic signal represents motor unit recruitment, and the frequency content is qualitatively related to the global firing rates of unfused, activated motor units[6,7]. Therefore, simultaneous assessments of electromyographic and mechanomyographic signals have been used to examine fatigue-related neuromuscular responses and make inferences regarding motor unit activation strategies including muscle activation[2], motor unit action potential conduction velocity[2], motor unit recruitment[6,7], and global motor unit firing rate[2] from the time-dependent changes in electromyographic amplitude (root mean square), electromyographic frequency (mean power frequency), mechanomyographic amplitude, and mechanomyographic frequency, respectively.

Most occupational and sporting activities involve complex motor programs that include randomly ordered levels of force production, rest intervals, number of repeated

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contractions, durations of recovery, and modes of muscle actions, as well as the involvement of multiple muscle groups[8,9]. The interactions among these factors can affect force-related outcomes during fatiguing tasks as well as the patterns of responses for electromyographic and mechanomyographic time and frequency domain parameters[10]. To understand the mechanisms of fatigue as well as the time course of neuromuscular responses that describe the fatiguing process, most studies have assessed torque and neuromuscular responses while manipulating one or more of the influencing factors (i.e. force production and/or rest intervals), and controlling others (i.e. mode of muscle action and/or the muscles involved)[10-12]. For example, Seghers et al.[10] reported decreases in maximal voluntary isometric contraction (MVIC) torque and electromyographic frequency as well as increases in electromyographic amplitude from the biceps brachii after a fatiguing workbout consisting of 20-min of submaximal, intermittent isometric muscle actions of the forearm flexors at 25% MVIC. In addition, Kouzaki et al.[11] reported decreases in MVIC torque as well as electromyographic amplitude, electromyographic frequency, mechanomyographic amplitude, and mechanomyographic frequency from the vastus lateralis (VL), vastus medialis (VM), and rectus femoris (RF) during 50 maximal, intermittent isometric muscle actions of the leg extensors. Bigland-Ritchie et al.[12], however, reported decreases in MVIC torque, but increases in electromyographic amplitude from the VL following 10-min of submaximal, intermittent isometric muscle actions of the leg extensors at 50% MVIC. Fowles et al.[13] also reported increases in electromyographic amplitude from the VL after 30-min of submaximal, intermittent isometric muscle actions of the leg extensors at 60% MVIC. The electromyographic amplitude reported by Fowles et al.[13], however, returned to pretest levels after 4-hr of recovery, but MVIC torque remained depressed from pretest levels. No previous studies, however, have simultaneously measured electromyographic amplitude, electromyographic frequency, mechanomyographic amplitude, and mechanomyographic frequency to identify if these neuromuscular responses track the changes in MVIC torque immediately and after 5-min of recovery from fatiguing, submaximal, intermittent isometric muscle actions of the leg extensors. Therefore, the purpose of the present study was to determine the effects of constant versus alternating applications of torque during fatiguing, intermittent isometric muscle actions of the leg extensors on MVIC torque and neuromuscular responses. Based on previous studies[13-16], we hypothesized that the alternating protocol would result in greater decreases in MVIC torque, electromyographic amplitude, mechanomyographic amplitude, electromyographic frequency, and mechanomyographic frequency than the constant protocol. In addition, we hypothesized[13-16] that MVIC torque would remain depressed for both protocols after 5-min of recovery, but the constant protocol would recover to a greater extent than the alternating protocol.

Material and methods

Subjects

Sixteen healthy adults (11 men and 5 women, mean±SD age 22.0±2.6 yr; body mass 82.6±14.4 kg; height 177.3±7.4 cm) volunteered to participate in the investigation. The subjects regularly participated in physical activities such as resistance training, soccer, and bicycling. The study was approved by the University Institutional Review Board for Human Subjects, and all subjects completed a health history questionnaire and signed an informed consent document prior to testing.

Orientation session

The orientation session was used to familiarize the subjects with the testing procedures including maximal and submaximal isometric muscle actions of the leg extensors. All isometric muscle actions were performed using the dominant leg (based on kicking preference) at a knee joint angle of 120°, 180° being full extension, for maximal force production on a calibrated Cybex II dynamometer. In addition, the hip was aligned with a joint angle of approximately 90°. A warm-up consisting of 5-min on a cycle ergometer at a self-selected resistance was performed, as well as 5 to 10 submaximal isometric muscle actions of the leg extensors. After completion of the warm-up, 2, 6-s MVICs were performed followed by familiarization with repeated 60% MVIC, as well as alternating 40% then 80% (40/80%) MVIC.

Intermittent isometric protocols

A warm-up consisting of 5-min on a cycle ergometer at a self-selected resistance was performed prior to each testing session. In addition, the subjects performed 5 submaximal isometric muscle actions of the leg extensors at approximately 50% of their maximum effort, followed by 2-min of rest. After the warm-up, 2, 6-s MVICs were performed with a 2-min rest after each MVIC before performing one of the randomly ordered intermittent isometric protocols. At least 48-hrs were allowed between each of the protocols. The highest MVIC torque value on the second visit (immediately prior to the first protocol) was used to calculate the torque values at 40, 60, and 80% MVIC for both protocols. Pretest (prior to the fatiguing workbout), posttest (immediately after fatiguing workbout), and 5-min posttest (5-min after the end of the workbout) MVIC values were measured for each of the intermittent isometric protocols to track the fatigue-related changes in maximal isometric torque.

The 60% MVIC protocol consisted of 50, 6-s isometric muscle actions of the leg extensors followed by 2-s of rest (6:2 work to rest ratio) at 60% MVIC (totaling 50 repetitions at 60% MVIC each separated by 2-s of rest). The 40/80% MVIC protocol consisted of 50, 6-s isometric muscle actions of the leg extensors beginning with a 6-s repetition at 40% MVIC with 2-s of rest followed by a 6-s repetition at 80% MVIC with 2-s of rest. This alternating pattern continued until 50 repetitions were performed

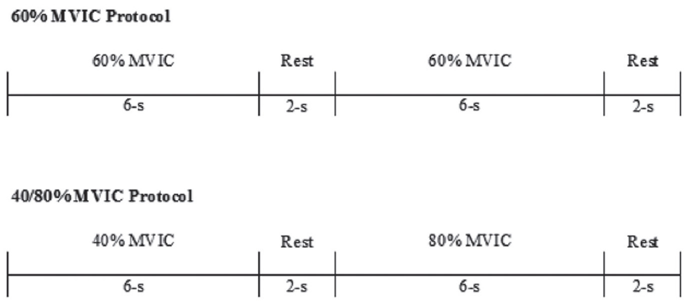

Figure 1. Depiction of the 60% and 40/80% maximal voluntary isometric contraction (MVIC) protocols. Each protocol consists of 50 intermittent isometric muscle actions of the leg extensors with equal average load.

(totaling 25 repetitions at 40% MVIC and 25 repetitions at 80% MVIC each separated by 2-s of rest) (Figure 1). The 60% MVIC and 40/80% MVIC protocols performed equal, averaged load across the 50 repetitions (60% MVIC + 60% MVIC/2= 60% MVIC; and 40% MVIC + 80% MVIC/2= 60% MVIC). The subjects tracked their torque production on a computer monitor placed in front of them that displayed a real-time, digitalized torque signal overlaid onto a programmed template identifying their target torque value. The isometric template and real-time torque signal overlay used the raw voltage from the isokinetic dynamometer and was displayed using a custom written program in LabVIEW (LabVIEW version 13.0 National Instruments, Austin, TX).

Electromyographic and Mechanomyographic Measurements

Bipolar (20 mm inter-electrode distance) surface electrode (circular 4 mm diameter silver/silver chloride, BIOPAC Systems, Inc., Santa Barbra, CA) arrangements were placed over the VL, VM, and RF of the dominant thigh according to the recommendations from SENIAM[17] and Barbero et al.[18]. The bipolar electrode arrangement over the VL was placed 33% the distance between the lateral side of the patella and the anterior superior iliac spine, orientated 20° with respect to the reference line, and moved 5 cm laterally[17,18]. The bipolar electrode arrangement over the VM was placed 20% the distance between the medial side of the patella and the anterior superior iliac spine and orientated 50° with respect to the reference line[17,18]. The bipolar electrode arrangement over the RF was placed 50% of the distance between the superior side of the patella and the anterior superior iliac spine[17]. The reference electrode was placed over the iliac crest. The electromyographic signals were amplified (gain: 1000x) using differential amplifiers (EMG 150 BIOPAC Systems, Inc., Santa Barbra, CA,) and digitally bandpass filtered (fourth – order Butterworth) at 10-500 Hz.

The mechanomyographic signals were only detected from the VL using a miniature triaxial accelerometer (Measurement Specialties EGAS-FT 10, bandwidth 0-200 Hz, dimensions: 1.0 x 1.0 x 0.5 cm, mass 1.0 g, sensitivity 5504 mV/g) placed between the bipolar surface electrode arrangement located over the VL using double-sided adhesive tape. The locations of the bipolar electrode arrangement and accelerometer were marked with permanent black marker at the end of each testing session to ensure the same placements in subsequent sessions.

Signal processing

The raw electromyographic and mechanomyographic signals were digitized at 2000 Hz with a 16-bit analog-to-digital converter (Model MP150, BIOPAC Systems, Inc., Santa Barbra, CA) and stored in a personal computer for subsequent analysis. All signal processing was performed using custom programs written with LabVIEW programming software (Version 13.0, National Instruments, Austin TX). The electromyographic and mechanomyographic signals were zero-meaned and bandpass filtered (fourth-order Butterworth) at 10-500 Hz and 5-100 Hz, respectively. The electromyographic and mechanomyographic amplitude and frequency values were calculated from 2-s epochs corresponding to the middle 33% of each MVIC and normalized to the initial MVIC values.

Statistical analysis

All statistical analyses were performed on pooled data of men and women. Separate 2 [Protocol: 60%, 40/80%] x 3 [Muscle: VL, VM, RF] x 3 [Time: pretest, posttest, 5-min posttest] repeated measures ANOVAs were performed on the normalized electromyographic amplitude and normalized electromyographic frequency values from the MVICs. In addition, separate 2 [Protocol, 60%, 40/80%] x 3 [Time: pretest, posttest, 5-min posttest] repeated measures ANOVAs were performed on the MVIC torque, normalized mechanomyographic amplitude, and normalized mechanomyographic frequency values from the MVICs. When appropriate, Tukey post-hoc comparisons were performed. An alpha of $p \leq 0.05$ was considered statistically significant for all ANOVA analyses (SPSS Version 22.0, Armonk, NY).

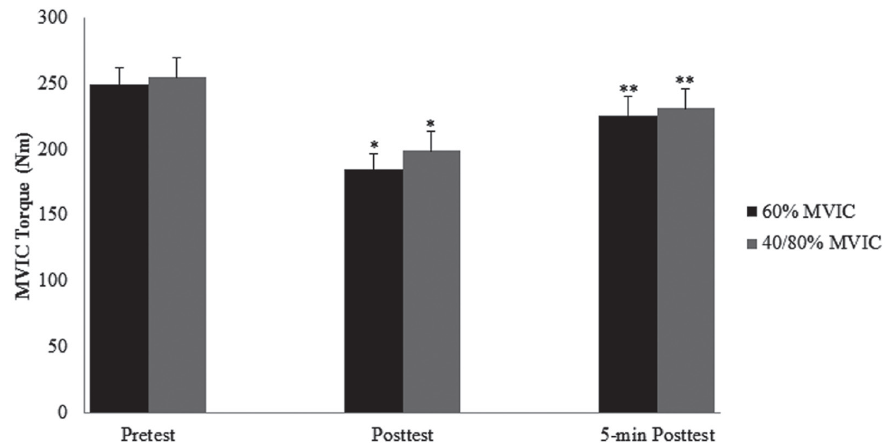

Figure 2. Maximal voluntary isometric contraction (MVIC) torque (Nm) values for the 60% MVIC and 40/80% MVIC protocols. (*Note: There were no significant (p>0.05) differences between the protocols for MVIC torque. * Significantly (p≤0.05) different from pretest. ** Significantly (p≤0.05) different from pretest and posttest).*

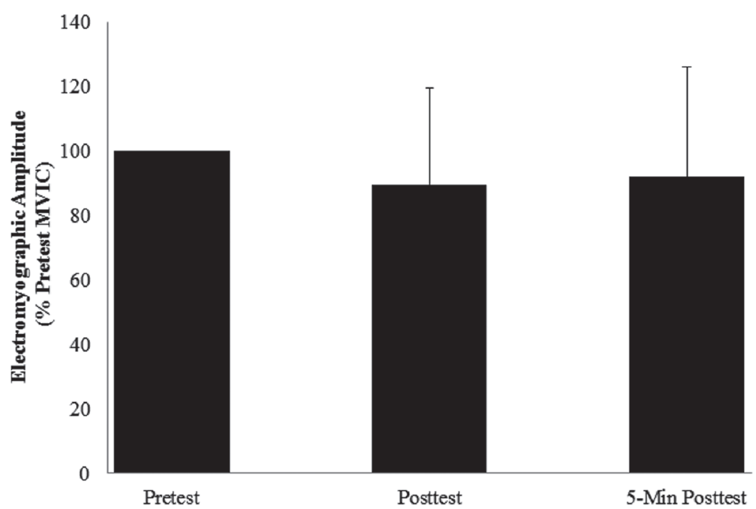

Figure 3. Normalized marginal means for electromyographic amplitude (root mean square) collapsed across protocol and muscle. (*Note: There were no significant (p>0.05) protocol or muscle-related differences or changes across time for electromyographic amplitude following 50 intermittent isometric muscle actions of the leg extensors at 60% maximal voluntary isometric contraction (MVIC) or 40/80% MVIC).*

Results

Figure 2 includes the mean±SD and the results of the ANOVA analyses for the MVIC torque for the 60% and 40/80% MVIC protocol at the pretest, posttest, and 5-min posttest measurements. The MVIC torque decreased from pretest to posttest and 5-min posttest for both protocols. In addition, the 5-min posttest MVIC torque values from both protocols were greater than posttest values, but did not recover to pretest values (Figure 2). The 2 x 3 ANOVA (protocol by time) for the MVIC torque values resulted in a non-significant interaction and main effect for protocol, but a significant main effect for time. Post-hoc comparisons for MVIC torque values (collapsed across protocols) indicated that pretest > posttest, pretest >5-min posttest, and 5-min posttest >posttest (Figure 2).

Figure 3 and 4 include the mean±SD and the results of the ANOVA analyses for the electromyorgaphic amplitude and frequency for the 60% and 40/80% MVIC protocol at the pretest, posttest, and 5-min posttest measurements. There were no changes in electromyographic amplitude from the

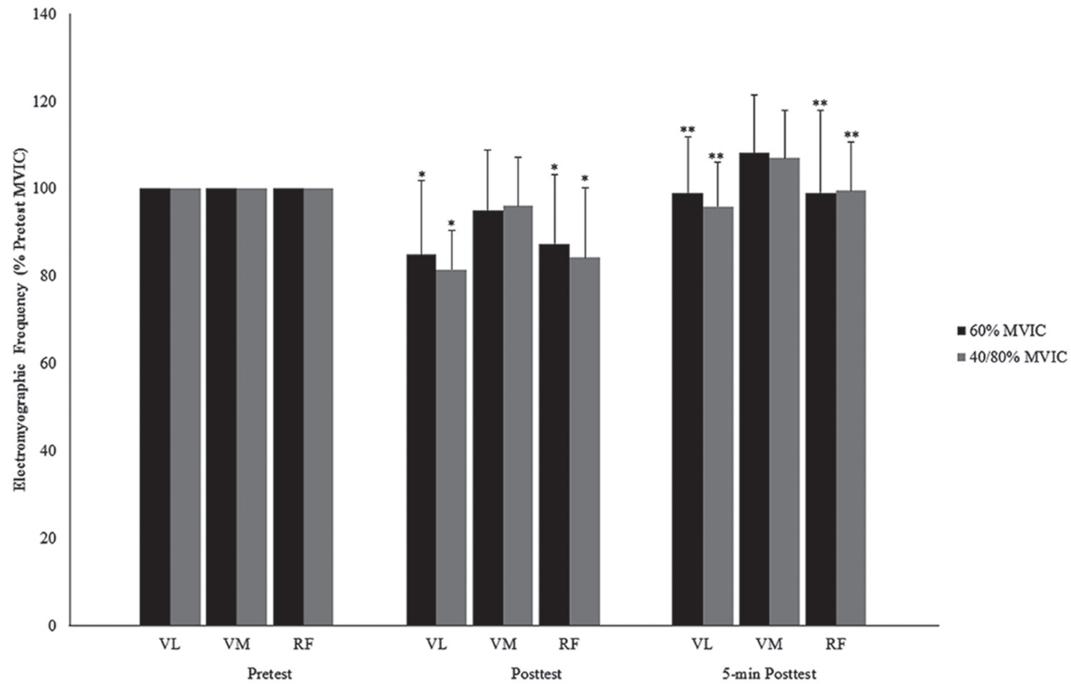

Figure 4. Normalized marginal means for electromyographic frequency (mean power frequency) from the vastus lateralis (VL), vastus medialis (VM), and rectus femoris (RF). *(Note: There were no significant (p>0.05) differences between the VL and RF following 50 intermittent isometric muscle actions of the leg extensors at 60% maximal voluntary isometric contraction (MVIC) or 40/80% MVIC. * Significantly (p≤0.05) different from pretest. ** Significantly (p≤0.05) different from posttest).*

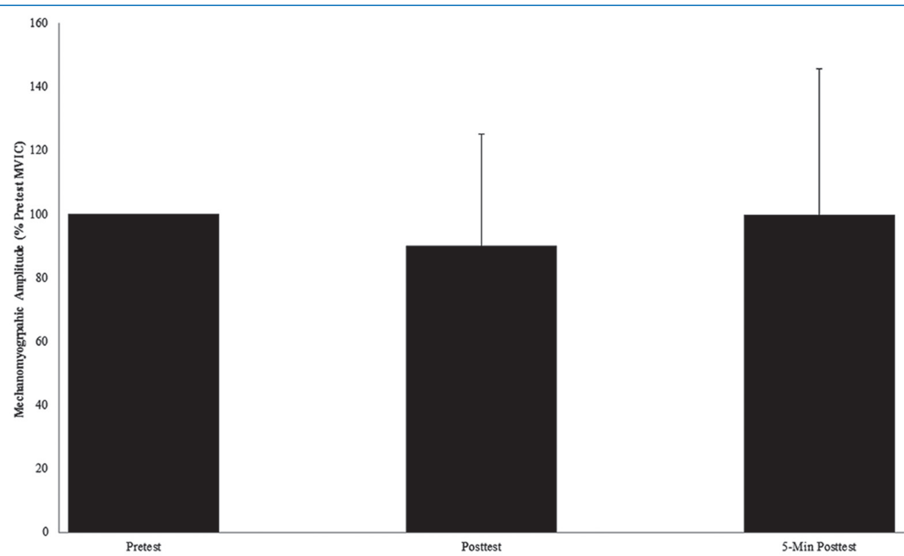

Figure 5. Normalized marginal means for mechanomyographic amplitude (root mean square) from the vastus lateralis collapsed across protocol. *(Note: There were no significant (p>0.05) protocol-related differences or changes across time for mechanomyographic amplitude following 50 intermittent isometric muscle actions of the leg extensors at 60% maximal voluntary isometric contraction (MVIC) or 40/80% MVIC).*

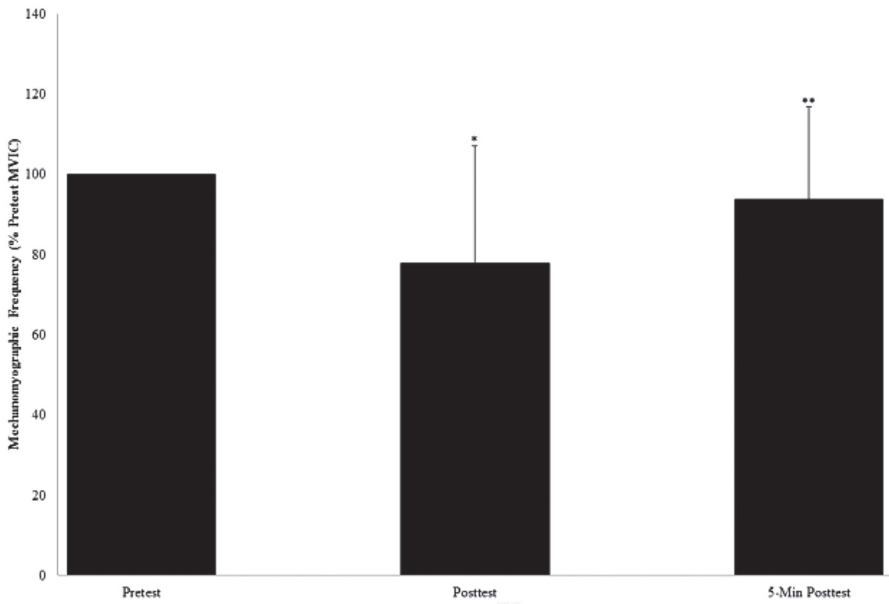

Figure 6. Normalized marginal means for mechanomyographic frequency (mean power frequency) from the vastus lateralis collapsed across protocol. *(Note: There were no significant (p>0.05) protocol-related differences following 50 intermittent isometric muscle actions of the leg extensors at 60% maximal voluntary isometric contraction (MVIC) or 40/80% MVIC. * Denotes significantly (p≤0.05) different from pretest. ** Denotes significantly (p≤0.05) different from posttest).*

VL, VM, and RF from pretest to posttest and 5-min posttest for either protocol (Figure 3). In addition, there were no changes in electromyographic frequency from the VM, but were decreases for the VL and RF (Figure 4). Specifically, both protocols indicated that the pretest values for electromyographic frequency from the VL and RF were lower than posttest and 5-min posttest values, however, after 5-min of recovery the electromyographic frequency was greater than posttest values (Figure 4). The 2 x 3 x 3 ANOVA (protocol by muscle by time) for the normalized electromyographic amplitude values measured during the MVIC resulted in no significant interactions or main effects. The 2 x 3 x 3 ANOVA (protocol by muscle by time) for the normalized electromyographic frequency values measured during the MVIC, however, resulted in no significant three-way interaction, but significant two-way interactions for protocol by muscle and muscle by time. Therefore, the model was decomposed in 3 separate 2 x 3 ANOVAs (protocol by time), one for each muscle (VL, VM, and RF). The follow-up 2 x 3 ANOVAs (protocol by time) for the normalized electromyographic frequency values from the VL and RF resulted in non-significant two-way interactions and main effects for protocol. There were, however, significant main effects for time for both the VL and RF muscles. Post-hoc comparisons for the normalized electromyographic frequency values indicated that for both the VL and RF muscles, pretest >posttest and 5-min posttest >posttest. The follow-up 2 x 3 ANOVA (protocol by time) for the normalized electromyographic frequency values from the VM, however, resulted in a non-significant two-way interaction, but a significant main effect for protocol (60% MVIC protocol >40/80% MVIC protocol).

Figure 5 and 6 include the mean±SD and the results of the ANOVA analyses for the mechanomyographic amplitude and frequency for the 60% and 40/80% MVIC protocol at the pretest, posttest, and 5-min posttest measurements. There were no changes in the mechanomyographic amplitude from the VL from pretest to posttest and 5-min posttest for either protocol (Figure 5). Both protocols indicated that the pretest mechanomyographic frequency values from the VL were lower than posttest values, however, after 5-min of recovery the mechanomyographic frequency recovered to pretest levels (Figure 6). The 2 x 3 ANOVA (protocol by time) for the normalized mechanomyographic amplitude values measured during the MVIC resulted in no significant two-way interaction or main effects. The 2 x 3 ANOVA (protocol by time) for the normalized mechanomyographic frequency values, however, resulted in no significant interaction or main effect for protocol, but a significant main effect for time. Post-hoc comparisons indicated that pretest > posttest and 5-min posttest >posttest.

Discussion

In the present study, there were no differences between the 60% MVIC and 40/80% MVIC protocols for MVIC torque responses measured pretest, posttest, and 5-min posttest (Figure 2). The MVIC torque decreased by 26 and 22% immediately following the fatiguing 60% MVIC and 40/80% MVIC protocols, respectively, and remained depressed from pretest levels by 9% for both protocols at 5-min posttest. These findings were in agreement with Fowles et al.[13] who reported 41, 28, and 26% decreases in MVIC torque immediately, 1-hr, and 4-hrs following 30-mins of intermittent isometric muscle actions of the leg extensors at 60% MVIC, respectively. Although the MVIC torque of Fowles et al.[13] did not return to pretest levels following 4-hrs of recovery, the values at 1-hr and 4-hrs following the fatiguing workbout were greater than immediately posttest. In addition, Saugen et al.[19] reported 44, 30, 27, and 21% decreases in MVIC torque, immediately, 10-min, 20-min, and 30-min following intermittent isometric muscle actions of the leg extensors to exhaustion at 40% MVIC. Thus, the findings of this investigation and previous studies[1,9,13] indicated that MVIC torque was decreased by up to 44% immediately following fatiguing, intermittent, isometric muscle actions of the leg extensors, and remained depressed by up to 26% for 4-hr. The magnitude of the fatigue-related decreases in MVIC torque following the workbouts as well as the lengths of time that MVIC torque remained depressed were likely due to the volume of work performed during the intermittent isometric protocols.

In the present study, the 60% MVIC and 40/80% MVIC protocols had no effects on electromyographic amplitude from the VL, VM, and RF, or mechanomyographic amplitude from the VL immediately or 5-min posttest. Thus, varying the patterns of muscle loading (repeated 60% MVICs versus alternating 40 and 80% MVICs), while maintaining an equal average muscle loading (60% MVIC) across the 50 intermittent isometric muscle actions did not affect the amplitude responses of the electromyographic or mechanomyographic signals measured during the posttest and 5-min posttest MVICs. These findings were in partial agreement with those of Seghers et al.[10] who reported 15.2 and 15.3% decreases in MVIC torque, but no changes in electromyographic amplitude from the biceps brachii following 20-min of intermittent isometric muscle actions of the forearm flexors at 25 and 50% MVIC, respectively. Therefore the present findings, in conjunction with Seghers et al.[10] suggested that fatigue-related decreases in MVIC torque as a result of submaximal, intermittent isometric muscle actions were not accompanied by changes in muscle activation (electromyographic amplitude) from the superficial muscles of the quadriceps femoris or the biceps brachii. Furthermore, the fatiguing, intermittent isometric protocols had no effect on motor unit recruitment as indicated by the lack of change in mechanomyographic amplitude from the VL.

Unlike electromyographic amplitude, there were muscle- and time-related differences for electromyographic frequency as a result of the fatiguing, intermittent isometric protocols. For the VL and RF, there were no differences between the electromyographic frequency responses for the 60% MVIC and 40/80% MVIC protocols. For both protocols, electromyographic frequency decreased from pretest to posttest (14 to 19%), but returned to pretest levels after 5-min of recovery (Figure 4). For the VM, however, there were no time-related changes in electromyographic frequency for either protocol, but the mean electromyographic frequency (collapsed across time) for the 60% MVIC protocol was greater than the 40/80% MVIC protocol. Thus, the fatiguing, intermittent isometric protocols had no time-related effect on electromyographic frequency from the VM measured during the MVICs. These results suggested muscle-specific, fatigue-related responses as indicated by decreases in electromyographic frequency for the VL and RF muscles, but not the VM. These findings were in agreement with Linssen et al.[20] who also reported no change in electromyographic frequency from the VM following fatiguing, submaximal (80% MVIC), intermittent isometric muscle actions of the leg extensors. In addition, the current findings were in partial agreement with those of Kouzaki et al.[11] who reported decreases in electromyographic frequency from the VL, VM, and RF (11 to 24%) immediately following 50 maximal intermittent isometric muscle actions of the leg extensors. The differences between the electromyographic frequency responses from the VM in the present study and that of Linssen et al.[20] versus those of Kouzaki et al.[11] may be attributable to differences in the intensity of the muscle actions (maximal versus submaximal). Kouzaki et al.[11] utilized maximal intermittent isometric muscle actions, while the present study and that of Linssen et al.[20] used submaximal (40 to 80% MVIC) muscle actions. It is also possible that the differences in electromyographic frequency responses for the VL and RF versus VM in the present study were due to muscle-specific muscle fiber type characteristics. Johnson et al.[21] reported that, on average, the VM was composed of 61.5% type I fibers, while the VL and RF were characterized by 46.9 and 42.8% type I fibers, respectively. Thus, the VM may be more fatigue-resistant than the VL and RF. Perhaps, the repeated maximal muscle actions used by Kouzaki et al.[11] were sufficiently fatiguing to cause decreases in electromyographic frequency in all three superficial muscles of the quadriceps femoris, while the submaximal muscle actions in the present study and that of Linssen et al.[20] were not. Differences in knee joint angles can also affect torque production as well as electromyographic amplitude and electromyographic frequency responses from the VL and VM[22]. Therefore, it is possible that differences in the knee joint angles between the present study (120°) and that of Kouzaki et al.[11] (90° from full extension) may have contributed to the muscle-specific electromyographic frequency responses as a result of the fatiguing protocols. Future studies should examine the effects of fatiguing, intermittent isometric protocols at various knee joint angles on the torque and neuromuscular responses of the leg extensors.

In the present study, there were no differences between the 60% MVIC and 40/80% MVIC protocols for mechanomyographic frequency responses from the VL measured pretest, posttest, and 5-min posttest (Figure 6). The mechanomyographic frequency decreased by 24 and 23% immediately following the fatiguing 60% MVIC and 40/80% MVIC protocols, respectively, and then returned to pretest levels after 5-min of recovery. These findings were in agreement with Kouzaki et al.[11] who reported 18 to 26% decreases in mechanomyographic frequency from the VL, VM, and RF immediately following 50 maximal intermittent isometric muscle actions of the leg extensors. Therefore, the present findings, in conjunction with Kouzaki et al.[11], suggested that fatigue-related decreases in MVIC torque immediately following the fatiguing, intermittent isometric muscle actions were accompanied by changes in the global motor unit firing rate (mechanomyographic frequency) from the superficial muscles of the quadriceps femoris rather than decreases in motor unit recruitment (mechanomyographic amplitude). After 5-min of recovery MVIC torque remained depressed by 9% from pretest levels, however, mechanomyographic frequency returned to pretest levels. It is plausible that MVIC torque remained depressed by 9% after 5-min of recovery due to excitation-contraction coupling failure. Thus, the decreases in global motor unit firing rate (mechanomyographic frequency) tracked the decreases in MVIC torque immediately following the fatiguing protocols, but not after 5-min of recovery.

In summary, MVIC torque decreased immediately following the fatiguing, intermittent isometric muscle actions, and remained depressed after 5-min of recovery for both the 60% MVIC and 40/80% MVIC protocols. Of the neuromuscular parameters measured during the MVICs in the present study, electromyographic frequency from the VL and RF and mechanomyographic frequency from the VL tracked the fatigue-induced decreases in MVIC torque immediately following the 60% MVIC and 40/80% MVIC protocols. These neuromuscular parameters, however, returned to pretest levels following 5-min of recovery, while MVIC torque remained depressed by 9%. Furthermore, there were no changes in electromyographic amplitude from the VL, VM, and RF, or mechanomyographic amplitude from the VL for either the 60% MVIC or 40/80% MVIC protocols. Thus, there were no time-related differences between the 60% MVIC and 40/80% MVIC protocols for the neuromuscular or torque responses and these neuromuscular parameters did not track the fatigue-induced decreases in MVIC torque immediately and/or 5-min posttest.

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