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Original Article

Performance Fatigability and Neuromuscular Responses Are Not Joint Angle Specific Following a Sustained Isometric Forearm Flexion Task Anchored to a High Perceptual Intensity in Women

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Abstract

Objectives: To examine the effects of joint angle (JA) on maximal voluntary isometric contractions (MVIC) and neuromuscular responses following a sustained, isometric forearm flexion task anchored to a rating of perceived exertion (RPE) of 8 (RPE=8). **Methods**: Nine women (age: 20.7±2.9 yrs; height: 168.8±7.2 cm; body mass: 66.3±6.8 kg) performed 2,3s forearm flexion MVICs at JAs of 75°, 100°, and 125° prior to and following a sustained, isometric forearm flexion task anchored to RPE=8 to task failure (torque reduced to zero) at JA100. Electromyographic (EMG) and mechanomyographic (MMG) signals were recorded from the biceps brachii. **Results**: The MVIC at JA100 (collapsed across Time) was significantly greater ($p<0.05$) than JA75 and JA125. The pre-test MVIC was significantly greater ($p<0.001$) than the post-test. For EMG amplitude (AMP) and EMG mean power frequency (MPF), pre-test values were significantly greater ($p<0.05$) than the post-test values, with no differences between JAs. For MMG AMP and MMG MPF, there were no significant ($p>0.05$) differences between Time or JAs. Pre-test neuromuscular efficiency (normalized MVIC/normalized EMG AMP) was significantly greater ($p=0.005$) than post-test. **Conclusion**: Following a sustained, isometric forearm flexion task anchored to RPE=8 at JA100, the fatigue-induced MVIC and neuromuscular responses were not affected by JA.

Keywords: Electromyography, Fatigue, Female, Mechanomyography, Ratings of Perceived Exertion

Introduction

Muscle fatigue limits exercise performance[1] and has been described[2] as "...an acute impairment of performance that includes both an increase in the perceived effort necessary to exert a desired force and an eventual inability to produce this force" (p.1631). Thus, both perceived fatigability and performance fatigability can influence task performance. Based on the model of Kluger et al.[3], Enoka and Duchateau[4] proposed a taxonomy of fatigue for human performance where perceived fatigability and performance fatigability are described as two separate domains that can influence each other[3]. Perceived fatigability involves the changes in sensations associated with performing a fatiguing task and can be influenced by modulating factors related to homeostasis and the psychological state of the individual[4]. Performance fatigability includes fatigue-induced changes in an objective measure of performance, such as a maximal voluntary isometric contraction (MVIC), and is influenced by modulating factors associated with contractile function and muscle activation[4]. Therefore, it is important to examine the interactions between perceived fatigability and performance fatigability to understand the task-dependent causes of fatigue[4].

The authors have no conflict of interest.

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Table 1. The time course of procedures.

Orientation Session	Testing Visit
1. Informed Consent. 2. Health History Questionnaire. 3. Age, height, and body mass recorded. 4. Familiarized with testing procedures. 5. Read the standardized anchoring instructions (OMNI-RES scale). 6. Standardized warm-up: 4, 3 s submaximal (50-75% of max effort) isometric forearm flexion muscle actions. 7. 2, 3 s isometric forearm flexion MVICs at elbow joint angles of 75°, 100°, and 125° to set a perceptual anchor of RPE = 10. Lay quietly and relaxed to set a perceptual anchor of RPE = 0. 8. Brief (~1 min) sustained isometric task anchored to RPE=8 at an elbow joint angle of 100°.	1. Standardized warm-up. 2. Read the standardized anchoring instructions (OMNI-RES scale). 3. Pre-test: 2, 3 s MVICs at elbow joint angles of 75°, 100°, and 125°, in a randomized order. 4. Sustained, isometric forearm flexion task anchored to RPE=8 (OMNI-RES scale) performed at an elbow joint angle of 100° until task failure. 5. Post-test: 2, 3 s MVICs at elbow joint angles of 75°, 100°, and 125°, in a randomized order.

The interactions between perceived fatigability and performance fatigability have previously been examined during sustained, isometric fatiguing tasks anchored to torque or force by assessing fatigue-induced changes in ratings of perceived exertion (RPE) and neuromuscular responses, including the amplitude (AMP) and mean power frequency (MPF) of electromyographic (EMG) and mechanomyographic (MMG) signals[5–7]. Recent studies[5,8–18], however, have examined the interactions between perceived fatigability and performance fatigability during tasks anchored to perceptual intensities based on the RPE Clamp Model of Tucker[1]. Fatigue-induced neuromuscular responses when anchored to torque or force are typically characterized by increases in EMG AMP and MMG AMP, but decreases in EMG MPF and MMG MPF, which reflect the ability to maintain the prescribed torque[19,20]. Neuromuscular responses when anchored to RPE, however, are less consistent and likely represent the ability to maintain the prescribed RPE[11,13,15].

Joint angle-specific force production capabilities and neuromuscular responses have been attributed to the degree of actin and myosin cross-bridge overlap[21,22]. In the middle of a range of motion, the overlap of actin and myosin is optimal, while at smaller and larger joint angles there are disadvantageous overlaps of actin and myosin[22,23]. It has been suggested that the greatest force production during isometric forearm flexion tasks occurs between elbow joint angles of 90° and 120° with decreases toward each end of the range of motion[24–27]. It is unclear, however, if the joint angle at which an MVIC is performed can affect the fatigue-induced torque and neuromuscular responses following sustained, isometric forearm flexion tasks anchored to a constant perceptual intensity. In addition, the torque and neuromuscular responses following a fatiguing isometric task anchored to a constant RPE at an elbow joint angle of 100° have previously been examined in men[8]. Due to previously identified sex-specific differences in fatigue, however, it is unknown if these responses are similar in women[28]. Therefore, the purpose of the present study was to utilize the RPE Clamp Model of Tucker[1] to examine the effects of joint angle on MVIC and neuromuscular responses following a sustained, isometric forearm flexion task anchored to an RPE of 8 at an elbow joint angle of 100° in women. Based on previous studies[21–23], it was hypothesized that there would be joint angle-specific differences in MVIC torque production. In addition, based on the recent study of men by Arnett et al.[8], it was hypothesized that: 1) There would be no joint angle-specific differences in performance fatigability; and 2) there would be joint angle-specific decreases in EMG AMP, but not EMG MPF, MMG AMP, or MMG MPF.

Materials and Methods

Subjects

Nine women (Mean±SD: age: 20.7±2.9 yrs; height: 168.8±7.2 cm; body mass: 66.3±6.8 kg) volunteered to participate in this study. The subjects were university students and recreationally active[29], which included participating in resistance and/or aerobic exercise at least 3 d·wk^{-1}. In addition, all subjects were right hand dominant (based on throwing preference), and all testing was performed using the dominant arm. The subjects were free of upper body pathologies that would affect performance. Based on the previously reported performance fatigability data of Keller et al.[5], a priori sample size calculation (G*Power version 3.1.9.4, Düsseldorf, Germany) indicated that a power of 0.96 required 9 subjects. The subjects in the present study were part of a large multiple independent and dependent variable investigation[8–10,18,30,31], but none of the current data have been previously published. All subjects completed a Health History Questionnaire and signed a written Informed Consent document prior to testing.

Time Course of Procedures

The subjects visited the laboratory on two occasions (orientation session and testing visit) separated by 24–96 hours. The initial visit was an orientation session, and the next was a testing visit that included the standardized warm-up, pre- and post-test MVIC measurements at elbow joint angles of 75° (JA75), 100° (JA100), and 125° (JA125), and a sustained, isometric forearm flexion task of the dominant arm (based on throwing preference) anchored to an RPE of 8 (RPE=8) at JA100 (Table 1). During the sustained forearm flexion task, EMG and MMG signals were simultaneously recorded from the biceps brachii (BB) muscle of the dominant arm.

OMNI-RES Scale Standardized Anchoring Instructions

The anchoring instructions used in the present study for the sustained, isometric tasks anchored to RPE=8 were originally developed by Gearhart et al.[32] as a standardized method to gauge training intensity during lower body tasks and were modified for use during isometric forearm flexion tasks[15]. To promote the proper use of the OMNI-RES scale, the following standardized anchoring instructions were read to each subject during the familiarization visit and prior to the sustained, isometric task anchored to RPE=8: "You will be asked to set an anchor point for both the lowest and highest values on the perceived exertion scale. To set the lowest anchor, you will be asked to lay quietly without contracting your forearm flexor muscles to familiarize yourself with a RPE of zero. Following this, you will be asked to perform a MVIC to familiarize yourself with an RPE of 10. When instructed to match a perceptual value corresponding to the OMNI-RES scale, perceived exertion should be relative to these defined anchors."

Orientation Session

During the orientation session, the subjects' age, height, and body mass values were recorded. In addition, the subjects were oriented to the testing position on the isokinetic dynamometer (Cybex II, Cybex International Inc. Medway, MA, USA) in accordance with the Cybex II user's manual on an upper body exercise table (UBXT) with the lateral epicondyle of the humerus of the dominant arm aligned with the lever arm of the dynamometer. The subjects were familiarized with the 0–10 OMNI-RES scale[33] and read the standardized OMNI-RES instructions that were also used during the testing visits[33,34]. The OMNI-RES (0–10) RPE scale has been shown to be valid and reliable for the quantification of perception of exertion during resistance exercise[33]. The subjects then completed the standardized warm-up as well as 2, 3 s forearm flexion MVICs at JA75, JA100, and JA125 to set a perceptual anchor corresponding to RPE=10. The subjects were then asked to lay quietly and relaxed on the table to set a perceptual anchor corresponding to RPE=0. Lastly, the subjects performed a brief (approximately 1 min), sustained, isometric task anchored to RPE=8 at JA100 to become familiarized with the testing and anchoring procedures.

Testing Visit

During the RPE=8 testing visit, the subjects were positioned in accordance with the Cybex II (Cybex II, Cybex International Inc. Medway, MA) user's manual. Once positioned, the subjects performed the standardized warm-up, followed by 1 min of rest. The investigators then read the OMNI-RES instructions relating to the anchoring procedures to the subjects. The subjects then performed 2, 3 s forearm flexion pre-test MVICs on a calibrated dynamometer at JA75, JA100, and JA125 in a randomized order. Strong verbal encouragement was provided during each MVIC trial. The MVICs at JA100 also served to remind the subjects of the perceptual anchor corresponding to RPE=10. The elbow joint angles of 75°, 100°, and 125° for the MVIC measurements were selected to reflect a range of isometric torque production[25]. Following the pre-test MVIC trials, the sustained, isometric forearm flexion task anchored to RPE=8 (OMNI-RES scale) was performed at JA100. During the sustained isometric task at RPE=8, the subjects were unaware of torque and elapsed time to avoid pacing strategies[5,35]. The RPE=8 trial was sustained until task failure, which was defined as torque being reduced to zero. During the RPE=8 trial, the subjects were free to adjust torque production to maintain the required RPE=8. In addition, during the sustained isometric task, the subjects were reminded to be attentive to sensations such as strain, intensity, discomfort, and fatigue felt during the contraction to maintain appropriate levels of exertion[34,36]. Furthermore, the subjects were continuously advised that there were no incorrect contractions or perceptions and were reminded to relate levels of exertion to the previously set anchors. Throughout the sustained isometric task, the subjects were asked for their RPE every 30 s to assure compliance with RPE=8. At failure, the time to task failure (TTF) was recorded. Immediately after task failure, the post-test MVIC trials were performed at JA75, JA100, and JA125 in a manner identical to the pre-test MVIC trials.

Electromyographic, Mechanomyographic, and Torque Acquisition

During the testing visit, bipolar (30-mm center-to-center) EMG electrodes (pre-gelled Ag/AgCl, AccuSensor; Lynn Medical, Wixom, MI, USA) were attached to the BB of the dominant arm based on the recommendations of the Surface Electromyography for the Non-Invasive Assessment of Muscles[37]. Prior to electrode placement, the skin was shaved, carefully abraded, and cleaned with alcohol. The active electrodes were placed over the BB at one-third of the distance between the medial acromion process and the antecubital fossa. A reference electrode was also placed on the styloid process of the radius of the forearm. Using double-sided adhesive tape, a miniature accelerometer (Entras EGAS FT 10, bandwidth 0-200 Hz, dimensions 1.0 x 1.0 x 0.5 cm, mass 1.0 g, sensitivity 550.4 $mV \cdot g^{-1}$) was placed between the bipolar EMG electrodes to detect the MMG signals for the BB muscle.

The raw EMG and MMG signals were digitized at 2000 samples/second with a 12-bit analog-to-digital converter (Model MP150; Biopac Systems, Inc.) and stored on a personal computer (HP Laptop Model 14-dk1013dx HP

Table 2. Time to Task Failure (TTF) for the fatiguing task anchored to RPE = 8 at an elbow joint angle of 100°.

Subjects	TTF (seconds)
1	178.2
2	234.0
3	180.6
4	369.6
5	179.4
6	250.2
7	252.0
8	378.0
9	288.0
Mean ± SD	256.7 ± 17.6

Inc., Palo Alto, CA, USA) for analyses. The EMG signals were amplified (gain: ×1000) using differential amplifiers (EMG2-R Bionomadix, Biopac Systems, Inc. Goleta, CA, USA; bandwidth—10-500 Hz). The EMG and MMG signals were digitally bandpass filtered (fourth-order Butterworth) at 10-500 Hz and 5-100 Hz, respectively. Signal processing was performed using custom programs written with LabVIEW programming software (version 20.0f1, National Instruments, Austin, TX, USA). A 1 s epoch from the center of the 3 s forearm flexion MVICs with the greatest torque production was used to calculate the AMP (root mean square) for EMG (μVrms) and MMG ($m \cdot s^{-2}$) signals, as well as the mean power frequency (MPF in Hz) for both signals. The MPF was selected to represent the power density spectrum and was calculated as described by Kwatny et al.[38]. The neuromuscular efficiency (NME) was calculated by dividing the normalized MVIC torque by the normalized EMG AMP[14,39]. The torque signals were sampled from the digital torque of the Cybex II dynamometer and stored on a personal computer (HP Laptop Model 14-dk1013dx HP Inc., Palo Alto, CA, USA) for analyses.

Statistical Analysis

The mean differences for pre-test versus post-test MVIC and neuromuscular parameters (EMG AMP, EMG MPF, MMG AMP, and MMG MPF, and NME values) were determined using six, separate 2 (Time: Pre-test and Post-test) x 3 (Joint Angle: 75°, 100°, and 125°) repeated measures ANOVAs. An alpha value of $p \leq 0.05$ was used for all ANOVAs. Significant interactions were decomposed with follow-up ANOVAs and post-hoc, Bonferroni corrected, paired t-tests[40,41]. Effect sizes were reported as partial eta squared (η_p^2) and Cohen's *d* for the ANOVAs and pairwise comparisons, respectively. All statistical analyses were completed in IBM SPSS v. 28 (Armonk, NY, USA).

Results

The TTF values for the fatiguing task at JA100 are presented in Table 2.

Maximal Voluntary Isometric Contraction

The results of the repeated measures ANOVA for MVIC indicated no significant 2-way ($p=0.313$, $\eta_p^2=0.135$) interaction. There were, however, significant main effects for Time ($p<0.001$, $\eta_p^2=0.918$) and Joint Angle ($p<0.001$, $\eta_p^2=0.829$). The main effect for Time (collapsed across Joint Angle) indicated that the pre-test MVIC value (27.9±6.1 Nm) was significantly greater ($p<0.001$, $d=1.059$) than the post-test MVIC value (21.8±5.4 Nm) (Figure 1). The follow-up pairwise comparisons for the main effect for Joint Angle (collapsed across Time) indicated that JA100 (27.8±5.3 Nm) was significantly greater ($p=0.003$, $d=0.454$; Bonferroni corrected alpha=0.0167) than JA75 (25.4±4.9 Nm) and JA125 (21.4±5.0 Nm; $p<0.001$, $d=1.236$), and JA75 was significantly greater ($p=0.002$, $d=0.825$) than JA125 (Figure 2).

Electromyographic Amplitude

The results of the repeated measures ANOVA for EMG AMP indicated no significant 2-way ($p=0.147$, $\eta_p^2=0.213$) interaction and no significant ($p=0.990$, $\eta_p^2=0.001$) main effect for Joint Angle. There was, however, a significant main effect for Time ($p<0.001$, $\eta_p^2=0.768$). The main effect for Time (collapsed across Joint Angle) indicated that the pre-test EMG AMP value (754.9±304.9 μVrms) was significantly greater ($p<0.001$, $d=0.261$) than the post-test EMG AMP value (675.5±303.4 μVrms) (Figure 1).

Electromyographic Mean Power Frequency

The results of the repeated measures ANOVA for EMG MPF indicated no significant 2-way ($p=0.313$, $\eta_p^2=0.135$)

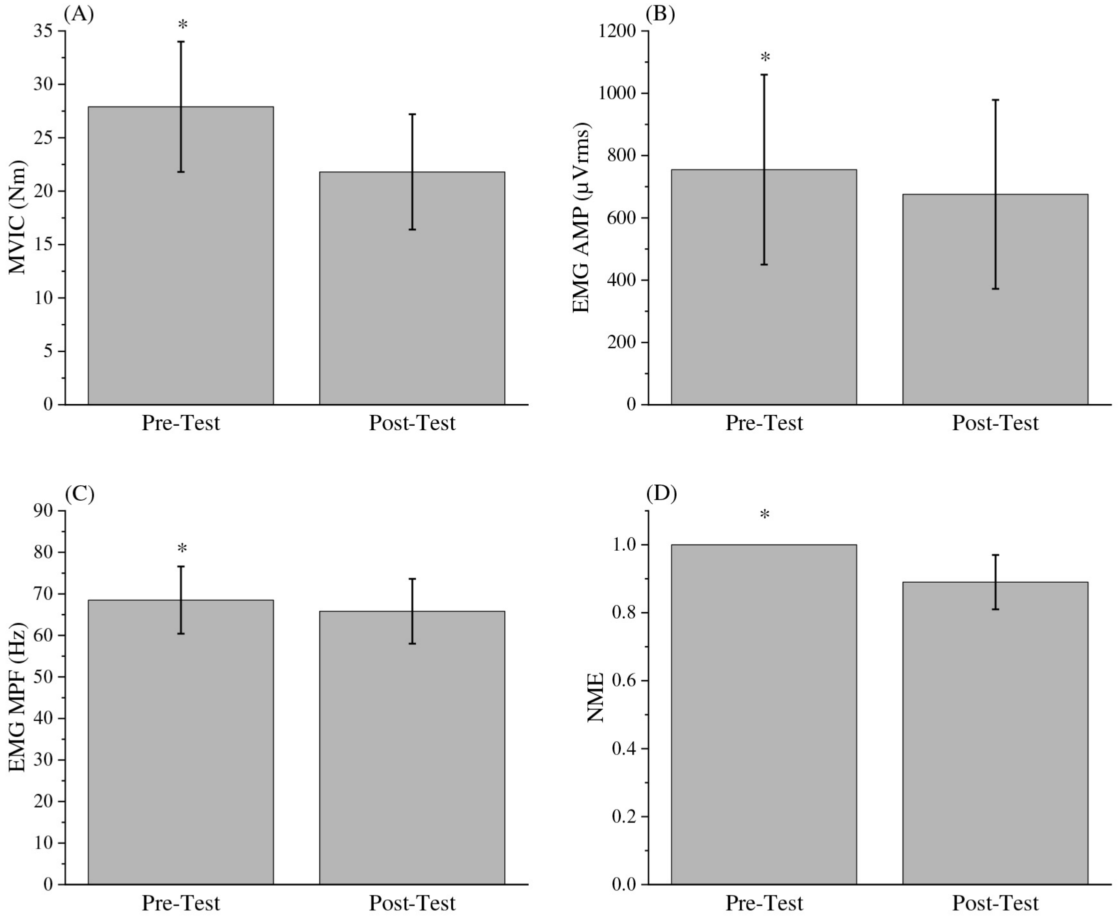

Figure 1. Mean ± SD Pre-test and Post-test values (collapsed across Joint Angles (JA): 75°, 100°, and 125°) for (A) MVIC, (B) EMG AMP, (C) EMG MPF, and (D) NME. *(A), (B), (C), (D) Pre-test value significantly ($p \leq 0.05$) greater than post-test value.

interaction. There were, however, significant main effects for Time ($p<0.001$, $\eta_p^2=0.918$) and Joint Angle ($p<0.001$, $\eta_p^2=0.829$). The main effect for Time (collapsed across Joint Angle) indicated that the pre-test EMG MPF value (68.5±8.1 Hz) was significantly greater ($p=0.004$, $d=0.340$) than the post-test EMG MPF value (65.8±7.8 Hz) (Figure 1). The follow-up pairwise comparisons for the main effect for Joint Angle (collapsed across Time) indicated that there were no significant ($p=0.037$ to $p=0.143$; Bonferroni corrected alpha= 0.0167) differences between joint angles (Figure 2).

Mechanomyographic Amplitude

The results of the repeated measures ANOVA for MMG AMP indicated no significant 2-way ($p=0.430$, $\eta_p^2=0.100$) interaction and no significant ($p=0.326$, $\eta_p^2=0.120$) main effect for Time. There was, however, a significant main effect for Joint Angle ($p=0.018$, $\eta_p^2=0.393$). The follow-up pairwise comparisons for the main effect for Joint Angle (collapsed across Time) indicated that there were no significant ($p=0.017$ to $p=0.188$; Bonferroni corrected alpha= 0.0167) differences between joint angles (Figure 2).

Mechanomyographic Mean Power Frequency

The results of the repeated measures ANOVA for MMG MPF indicated no significant 2-way ($p=0.102$, $\eta_p^2=0.248$) interaction and no significant ($p=0.095$, $\eta_p^2=0.309$) main effect for Time. There was, however, a significant main effect for Joint Angle ($p=0.047$, $\eta_p^2=0.317$). The follow-up pairwise comparisons for the main effect for Joint Angle (collapsed across Time) indicated that there were no significant ($p=0.028$ to $p=0.406$; Bonferroni corrected alpha= 0.0167) differences between joint angles (Figure 2).

Neuromuscular Efficiency

The results of the repeated measures ANOVA for NME indicated no significant 2-way ($p=0.300$, $\eta_p^2=0.140$) interaction and no significant ($p=0.300$, $\eta_p^2=0.140$) main effect for Joint Angle. There was, however, a significant

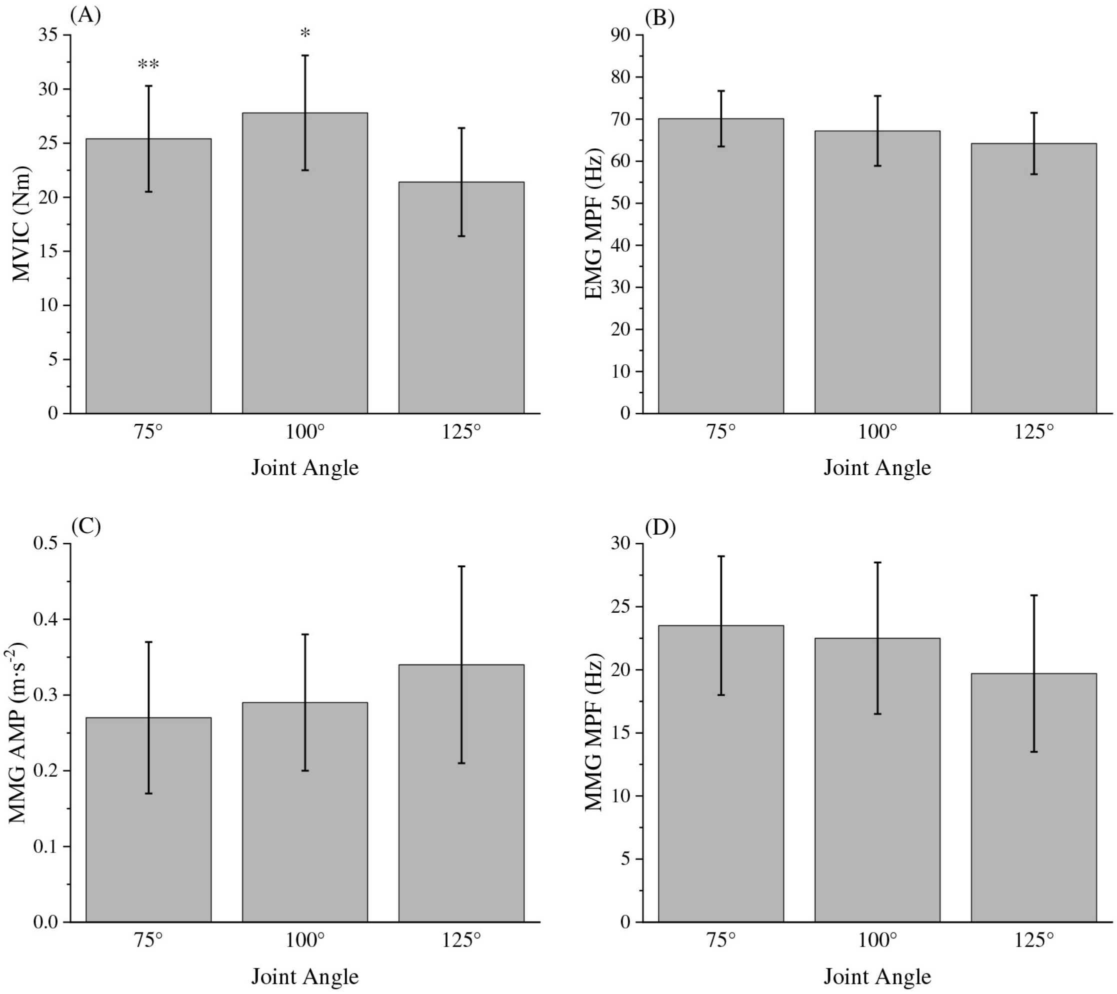

Figure 2. (A) MVIC, (B) EMG MPF, (C) MMG AMP, and (D) MMG MPF values (Mean±SD) at elbow joint angles (JA) of 75°, 100°, and 125° (collapsed across Time: Pre-test and post-test). *(A) JA100 significantly greater than JA75 (p=0.003; Bonferroni corrected alpha=0.0167) and JA125 (p<0.001). **(A) JA75 significantly greater (p=0.002) than JA125.

main effect for Time (p=0.005, η_p^2=0.647). The main effect for Time (collapsed across Joint Angle) indicated that the pre-test NME value (1.0±0.0) was significantly greater (p=0.005, d=1.804) than the post-test NME value (0.89±0.08) (Figure 1).

Discussion

The results of the present study were consistent with a previous study[9], and indicated that MVIC was greater at JA100 (27.8±5.3 Nm) than JA75 (25.4±4.9 Nm) and JA125 (21.4±5.0 Nm) (Figure 2). During maximal, isometric forearm flexion tasks, the greatest MVIC values typically occur between elbow joint angles of 90° and 120° due to an optimal degree of actin-myosin overlap and cross-bridge formation. The lower MVIC values at both ends of the range of motion are due to disadvantageous actin-myosin overlap that interferes with cross-bridge formation[21,23,25,26]. Specifically, at smaller joint angles force production is limited by excessive actin-myosin overlap, while at larger joint angles, force production is diminished by reduced actin-myosin overlap[21,23,26].

The current findings suggested that while anchoring to a constant RPE, there was an interaction between perceived fatigability and performance fatigability that was evident by decreases in the MVIC torque production from pre- to post-test. Specifically, the results of the present study indicated there were parallel fatigue-induced decreases in the MVIC values at JA75 (24.7%), JA100 (17.2%), and JA125 (24.0%) as a result of the sustained, isometric forearm flexion task anchored to RPE=8 at JA100 (Figure 1). Previous studies have reported decreases in MVIC from pre-test to post-test following sustained, isometric unilateral and bilateral leg extension[5,12,13] and forearm flexion[8,9] fatiguing tasks, anchored to RPE=5 and RPE=8 for women and men. Specifically, when anchored to RPE=5, Keller et al.[5,13] reported 29.0% (unilateral) and 13.1% (bilateral) decreases in leg extension MVIC values for women and men, respectively. Keller et al.[5,12] also reported 12.1% and 15.4% (unilateral) decreases in leg extension MVIC values for women and men, respectively, as well as a 13.1% (bilateral) decrease in MVIC for men when anchored to RPE=8. For forearm flexion tasks anchored to RPE=8 at elbow joint angles of 75° and 125°, Arnett et al.[9] reported decreases in MVIC for women that ranged from 9.65% to 27.12%. In addition, for men following a fatiguing task anchored to RPE=8 at an elbow joint angle of 100°, the decreases in MVIC ranged from 9.9% to 20.7%[8]. Thus, the fatigue-induced decreases in MVIC from the present study were consistent with previous studies[5,8,9,12,13] and suggested that following a sustained, isometric fatiguing task, similar decreases in MVIC occur regardless of joint angle, muscle action, level of perceptual intensity, and/or sex.

Previous studies[5,8] have utilized pre-test and post-test EMG and MMG parameters to make inferences regarding changes in motor unit activation strategies following fatiguing tasks anchored to RPE. Keller et al.[5] reported no changes in EMG AMP (muscle activation) and decreases in EMG MPF (action potential conduction velocity) following fatiguing, isometric leg extension tasks anchored to RPE= 1, 5, and 8. Arnett et al.[8], however, reported joint angle-specific decreases from pre-test to post-test for EMG AMP, but no changes in EMG MPF, MMG AMP (motor unit recruitment), or MMG MPF (global firing rate of activated, unfused motor units) following an isometric forearm flexion task anchored to RPE=8. The current findings indicated that from pre-test to post-test MVIC assessments, there were decreases in EMG AMP, EMG MPF, and NME (Figure 1), but no changes in MMG AMP and MMP MPF. Furthermore, joint angle did not affect the neuromuscular responses following the fatiguing task at JA100 (Figure 2). These findings were not consistent with Arnett et al.[8] who reported joint angle-specific neuromuscular responses following a fatiguing task at JA100 for men. Hunter[28] suggested that men and women may perceive and manifest fatigue differently due to differences in contractile mechanisms, fiber-type proportional area, and muscle perfusion. Therefore, it is possible that the differences in neuromuscular responses reported by Arnett et al.[8] versus the current findings were due to the sex of the subjects.

Previously, Arnett et al.[8] hypothesized that central fatigue, in addition to peripheral fatigue, may have influenced the pre-test to post-test decreases in EMG AMP following a fatiguing task anchored to RPE. Central fatigue can result from the accumulation of interstitial hydrogen ions that stimulate group III/IV afferent neuron feedback to motor areas of the brain, which leads to decreases in central motor drive and torque production[42]. In addition, Taylor et al.[43] suggested that during fatiguing tasks, central fatigue is also characterized by decreases in motor unit firing rates. In the present study, however, there were no fatigue-induced changes for MMG AMP or MMG MPF, which suggested that central fatigue may not have contributed to the decreases in MVIC and EMG AMP. Peripheral fatigue occurs distal to the myoneural junction and affects excitation-contraction coupling via exercise-induced metabolic perturbations. These metabolic perturbations include increases in inorganic phosphate and ammonia, and decreases in intracellular pH, calcium release and reuptake, actin-myosin binding, and troponin-calcium binding[44,45]. In the present study, the decrease in NME (Figure 1) may have suggested that metabolic perturbations and peripheral fatigue impaired excitation-contraction coupling which led to decreased MVIC torque production. Because the contributions of central and peripheral mechanisms of fatigue cannot be determined from pre-test and post-test MVICs alone, future studies should continue to examine the decreases in MVIC following fatiguing tasks anchored to RPE utilizing evoked potentiated twitch amplitude and interpolated twitch techniques at various joint angles for men and women.

In the present study, the sustained, isometric task was performed at an elbow joint angle of 100° while anchored to RPE=8. Thus, the current findings are limited to those conditions and should be replicated using various joint angles, as well as low and moderate intensities. In addition, the neuromuscular responses are limited to the BB and future studies should examine fatigue-induced neuromuscular responses from all muscles involved in forearm flexion.

In summary, the results of the present study indicated that there were decreases in MVIC, EMG AMP, EMG MPF, and NME following the isometric forearm flexion fatiguing task. For MMG AMP and MMG MPF, however, there were no fatigue-induced changes following the fatiguing task. These responses suggested that mechanisms associated with peripheral fatigue led to excitation-contraction coupling failure, which resulted in decreased MVIC torque production and EMG AMP. It is still unknown, however, if mechanisms associated with central fatigue also contributed to the fatigue-induced MVIC and neuromuscular responses. In addition, the MVIC and neuromuscular responses were not affected by the joint angle at which the MVICs were performed. Thus, the current findings indicated that following a sustained, isometric forearm flexion task anchored to RPE = 8 at an elbow joint angle of 100°, joint angle did not affect the fatigue-induced MVIC and neuromuscular responses and that peripheral fatiguing mechanisms likely contributed to these responses.

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Author contributions

JEA was primarily responsible for data collection, analyses, manuscript writing, and accepts responsibility for the integrity of the data analysis. JPVA, TJN, DGO, and RWS assisted with data collection and data analyses. TJH, RWS, RJS, and GOJ conceived and designed the study. RJS and GOJ provided administrative oversight of the study. All authors contributed to the final drafting and approved the final submission of this manuscript. *There was no external funding for this project.*

Ethics approval

The study was approved by the University Institutional Review Board for Human Subjects (IRB Approval #: 20201220785FB).

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