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Composite, Inter-, and Intra-Individual Torque and Neuromuscular Responses During Fatiguing Forearm Flexion Tasks are Dependent on Anchor Scheme in Men

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Abstract The purpose of this study was to examine the effects of anchor scheme (RPE vs. torque) on the composite, inter- and intra-individual torque and neuromuscular patterns of responses (PoR) during fatiguing forearm flexion tasks. Twelve men (mean±SD: age=20.9±2.2 yrs.; height=179.8±5.3 cm; body mass=80.2±9.9 kg) performed maximal voluntary isometric contractions (MVIC) before and after sustained, isometric forearm flexion tasks to failure anchored to RPE=4 (RPEFT) and the torque (TRQFT) that corresponded to RPE=4. The amplitude (AMP) and mean power frequency (MPF) of the electromyographic and mechanomyographic (MMG) signals were recorded from the biceps brachii. Polynomial regression analyses were used to define the individual and composite relationships for normalized torque and neuromuscular parameters versus normalized time. Dependent t-tests were used to determine mean differences for time to task failure (TTF) and performance fatigability (PF=% decline in MVIC). The RPEFT had a greater TTF (p=0.006), but lower PF (p<0.001) than the TRQFT. During the RPEFT, the composite PoR indicated significant (p≤0.05) linear decreases for torque, EMG MPF, MMG MPF, and NME, a linear increase for MMG AMP, and no relationship for EMG AMP. During the TRQFT, the composite PoR indicated significant (p≤0.05) linear decreases for EMG MPF, MMG MPF, and NME, linear increases in EMG AMP and MMG AMP, and no relationship for torque. The individual PoR indicated substantial variability within and between anchor schemes. These findings indicated that TTF and PF as well as the composite, inter-, and intra-individual PoR were dependent on the anchor scheme of the fatiguing task.

Keywords: *ratings of perceived exertion, upper body, electromyography, mechanomyography*

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1. Introduction

Enoka and Stuart [1] previously described fatigue as a transient impairment in performance that is associated with an increase in perceived exertion as well as an eventual inability to produce force or power. Unified taxonomies proposed by Kluger et al. [2] and Enoka and Duchateau [3] define fatigue as an interaction between two interdependent attributes, performance fatigability and perceived fatigability. Performance fatigability, characterized as a decline in an objective measure of performance (e.g., maximal voluntary isometric contraction [MVIC]) over time, is affected by peripheral (i.e., impairments in excitation-contraction coupling, cross-bridge formation, and calcium kinetics) and central (i.e., voluntary activation, action potential propagation, and afferent feedback) factors [2,3]. Perceived fatigability, which is described as changes in the sensations and perceptions associated with performance, however, is affected by homeostatic (i.e., internal temperature, blood glucose and muscle glycogen levels, and hydration) and psychological (i.e., perception of effort, motivation, performance feedback, and mood) factors [2,3]. Recent studies [4,5,6,7,8,9,10,11] have examined the interaction between the two interdependent attributes of fatigue by comparing the performance fatigability and neuromuscular responses when tasks are anchored to torque versus ratings of perceived exertion (RPE) using the RPE-Clamp Model of Tucker [12].

Ratings of perceived exertion have been used to subjectively describe the sensations (i.e., strain, effort, discomfort, and/or fatigue) experienced during exercise [13,14,15] as well as to quantify and regulate exercise intensity [5,6,7,11,16]. Recently, a number of studies

[4,5,6,10,11] have used electromyographic (EMG) and mechanomyographic (MMG) signals as indirect measures of neuromuscular fatigue to make inferences about the motor unit activation strategies modulating torque production during tasks anchored to a constant RPE. Specifically, the amplitude (AMP) and mean power frequency (MPF) of the EMG signal reflect muscle excitation [17] and motor unit action potential conduction velocity (MUAP CV) [18], respectively. Although there are differences of opinion regarding its applicability [19], neuromuscular efficiency, which provides an indirect estimation of the response of the contractile elements of muscle to neural excitation [20], is calculated by dividing normalized torque by normalized EMG AMP [21]. Furthermore, under some conditions, MMG AMP reflects motor unit recruitment, while MMG MPF qualitatively tracks changes in the global firing rate of the activated, unfused motor units [22,23].

Typically, during submaximal fatiguing tasks anchored to torque, EMG AMP and MMG AMP increase, while EMG MPF and MMG MPF decrease [19,22,24,25]. During submaximal fatiguing tasks anchored to RPE, however, the neuromuscular patterns of responses are typically different than those observed during fatiguing tasks anchored to torque [5]. For example, recent studies that examined the composite relationships for torque and neuromuscular parameters versus time during sustained, isometric forearm flexion tasks anchored to RPE [4,7] reported decreases for torque, decreases for EMG AMP, a decrease or no relationship for EMG MPF, an increase or no relationship for MMG AMP, and a decrease or no relationship for MMG MPF. During sustained, isometric leg extension tasks anchored to RPE, Keller et al. [5,6] reported decreases in torque, a decrease or no relationship for EMG AMP, no relationships for EMG MPF, an increase or no relationship for MMG AMP, and no relationships for MMG MPF. In addition, substantial inter-individual (i.e., between subjects) variability was reported for the torque and neuromuscular patterns of responses [4,5,6,7]. Arnett et al. [4] also reported substantial intra-individual (i.e., comparison of within subject responses following fatiguing tasks performed at different joint angles or using different anchor schemes) variability in the torque and neuromuscular responses during fatiguing forearm flexion tasks anchored to RPE = 8 performed at elbow joint angles of 75° and 125°. No study, however, has examined the effects of anchor scheme (anchored to torque vs. RPE) on the composite, inter-, and intra-individual patterns of responses during fatiguing forearm flexion tasks. Therefore, the purpose of this study was to examine the effects of anchor scheme on the composite, inter-, and intra-individual torque and neuromuscular patterns of responses during sustained, isometric forearm flexion tasks anchored to RPE = 4 (RPEFT) and the torque (TRQFT) that corresponded to the RPE value. Based on the findings of previous studies [4,5,6,7], it was hypothesized that: (1) The composite patterns of responses for torque and the neuromuscular parameters would be different between the anchor schemes; (2) there would be substantial inter-individual variability in the individual patterns of responses for the neuromuscular parameters, but not the individual patterns of responses for torque; and (3) there would be substantial intra-individual variability in the individual patterns of responses for torque and the neuromuscular parameters.

2. Methods

Subjects

Twelve recreationally active [26] men (mean ± SD: age = 20.9 ± 2.2 yrs.; height = 179.8 ± 5.3 cm; body mass = 80.2 ± 9.9 kg) volunteered to participate in this study. The subjects were right hand dominant based on throwing preference [27] and free of upper body pathologies that would affect performance. Furthermore, the subjects were instructed to avoid upper body exercise at least 24 h prior to testing and avoid consumption of caffeine for at least 6 h prior to testing. The subjects in this study were part of a larger, multiple independent and dependent variable investigation, but none of the data in the current study have been previously published [8]. The study was approved by the Institutional Review Board for Human Subjects (IRB Approval #: 20220521909FB). Before any testing, all subjects signed a written Informed Consent form and completed a Health History Questionnaire.

Time Course of Procedures

Each subject visited the laboratory on three separate occasions (orientation session and two test visits), and each visit was separated by 3 days to 3 weeks. The initial visit was an orientation session where demographic information was recorded, and the subjects were familiarized with the standardized warm-up, the testing protocol, and the standardized OMNI-RES [28] anchoring instructions (Table 1). Test visit 1 included the standardized warm-up, pre-test MVIC trials to set a perceptual anchor to RPE = 10, a sustained, isometric forearm flexion task to failure anchored to RPE =4 (RPEFT), and post-test MVIC trials. Test visit 2 included the standardized warm-up, pre-test MVIC trials, a sustained, isometric forearm flexion task anchored to the torque (TRQFT) that corresponded to the torque produced during the first 1 s of the RPEFT, and post-test MVIC trials. All forearm flexion muscle actions were performed with the dominant (right) arm at an elbow joint angle of 100° to reflect the approximate point in the range of motion where maximal isometric torque production occurs [29]. During both fatiguing tasks, the EMG and MMG signals were recorded from the biceps brachii (BB) of the dominant arm. The time course of procedures is presented in Table 1.

OMNI-RES Scale Standardized Anchoring Instructions

The anchoring instructions used in the current study were originally developed by Gearhart Jr. et al. [30] as a standardized method to gauge training intensity during lower body exercise and adapted by Smith et al. [7] for use during isometric forearm flexion tasks anchored to RPE. During the orientation session and prior to the sustained task anchored to RPE = 4, the following standardized anchoring instructions were read to each subject: “You will be asked to set an anchor point for both the lowest and highest values on the perceived exertion scale. In order to set the lowest anchor, you will be asked to lay quietly without contracting your forearm flexor muscles to familiarize yourself with an RPE of zero. Following this, you will be asked to perform a maximal voluntary isometric contraction 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 related to these defined anchors."

Table 1. Time course of procedures

Orientation Session	Test Visit 1	Test Visit 2
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% max effort) isometric forearm flexion muscle actions. 7. 2, 3 s isometric forearm flexion MVICs to set a perceptual anchor of RPE = 10. Brief (~ 1 min) sustained, isometric forearm flexion task anchored to RPE = 4 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 an elbow joint angle of 100°. 4. Sustained, isometric forearm flexion task anchored to RPE = 4 (OMNI-RES scale) performed at an elbow joint angle of 100° to task failure. 5. Post-test: 2, 3 s MVICs at an elbow joint angle of 100°.	1. Standardized warm-up. 2. Pre-test: 2, 3 s MVICs at an elbow joint angle of 100°. 3. Sustained, isometric forearm flexion task anchored to the torque value that corresponded to the torque produced during the first 1 s of the RPE = 4 (OMNI-RES scale) task, performed at an elbow joint angle of 100° to task failure. 4. Post-test: 2, 3 s MVICs at an elbow joint angle of 100°.

MVIC = maximal voluntary isometric contraction; RPE = rating of perceived exertion

Orientation Session

During the orientation session, each subject's dominant arm (based on throwing preference), age, height, and body mass were recorded. The subjects were then oriented to the testing position 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 calibrated isokinetic dynamometer in accordance with the Cybex II (Cybex II International Inc. Medway, MA, USA) user's manual. While positioned on the UBXT, the subjects were familiarized with the OMNI-RES (0 – 10) RPE scale, which has been shown to be valid and reliable for quantifying perception during resistance exercise [28], and read the standardized OMNI-RES instructions [7,28] used during test visit 1. In addition, to become familiarized with the testing and anchoring procedures, the subjects then completed the standardized warm-up (Table 1), 2, 3 s forearm flexion MVICs to set a perceptual anchor corresponding to RPE = 10, and a brief (approximately 1 min) sustained, isometric forearm flexion task anchored to RPE = 4.

Test Visits

During test visit 1, the subjects were positioned on the UBXT in accordance with the Cybex II user's manual with the lateral epicondyle of the humerus of the dominant arm aligned with the lever arm of the dynamometer at an elbow joint angle of 100°. Once positioned, the subjects performed the standardized warm-up, followed by 1 min of rest. After the warm-up, the subjects were read the OMNI-RES anchoring instructions and performed 2, 3 s forearm flexion MVICs on the calibrated isokinetic dynamometer at an elbow joint angle of 100° to set a perceptual anchor to RPE = 10. During each MVIC repetition, the subjects were given strong verbal encouragement. After the pre-test MVIC trials, the subjects performed a sustained, isometric forearm flexion task anchored to RPE = 4 (OMNI-RES scale) at an elbow joint angle of 100° (RPEFT). The subjects were asked their RPE every 30 s to ensure compliance with the prescribed anchor during the RPEFT. Furthermore, during the RPEFT, the subjects were continuously advised to be attentive to sensations of strain, intensity, discomfort, and fatigue [5,28] to maintain the appropriate level of exertion. In addition, the subjects were reminded that there were no incorrect contractions or perceptions and to relate the level of exertion to the previously set anchors of RPE = 0 and RPE = 10. Thus, the subjects were able adjust their torque to maintain RPE = 4 as fatigue developed. The RPEFT was sustained to task failure, which was defined as torque reduced to zero. At task failure, the RPEFT was terminated, TTF was recorded, and 2, 3 s post-test MVICs were performed.

During test visit 2, the subjects were positioned on the UBXT and their arm was aligned in a manner identical to test visit 1. Once positioned, the subjects performed the standardized warm-up (followed by 1 min of rest) and 2, 3 s forearm flexion MVICs on the calibrated isokinetic dynamometer at an elbow joint angle of 100°. Following the warm-up and pre-test MVIC trials, the subjects performed a sustained, isometric forearm flexion task anchored to the torque (TRQFT) that corresponded to the torque produced during the first 1 s of the RPEFT (35.9 ± 11.5% MVIC). This was conducted so that both fatiguing tasks began at the same initial torque value. During the TRQFT, a torque line was displayed on a computer screen to allow the subjects to track their torque output. The TRQFT was sustained to task failure, which was defined as the time point at which the subjects could no longer maintain the prescribed torque despite strong verbal encouragement. At task failure, the TRQFT was terminated, TTF was recorded, and 2, 3 s post-test MVICs were performed.

Electromyographic, Mechanomyographic, and Torque Acquisition

During each test visit, pre-gelled surface EMG electrodes (Ag/AgCl, Accusensor; Lynn Medical, Wixom, MI, USA) were placed in a bipolar arrangement (30-mm center-to-center) on the BB of the dominant arm according to the recommendations of the Surface Electromyography for the Non-Invasive Assessment of Muscles [31]. To prepare the electrode sites, the skin was carefully shaved, abraded, and cleaned with alcohol. The electrodes were placed over the BB between the medial acromion and the antecubital fossa, at one-third the distance from the antecubital fossa. The reference electrode was placed on the radial styloid process 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·g^{-1}) was placed between the bipolar EMG electrodes.

A 12-bit-analog-to-digital converter (Model MP150; Biopac Systems, Inc., Goleta, CA, USA) was used to digitize the raw EMG and MMG signals at 2000 samples per second. The EMG signals were amplified (gain: x 1000) using differential amplifiers (EMG2-R Bionomadix, Biopac Systems, Inc. Goleta, CA, USA; bandwidth: 10-500 Hz). Furthermore, the EMG and MMG signals were digitally band-pass filtered (fourth-order Butterworth) at 10-500 Hz and 5-100 Hz, respectively, and stored on a personal computer (Dell Inspiron Dell Inc., Round Rock, TX, USA) for signal processing using custom written LabVIEW (version 22.3f0, National Instruments, Austin, TX, USA) programs. The TTF (0-100%) was divided into 10% increments and a 1 s epoch from the center of each 10% increment (i.e., 500 ms before and 500 ms after) was used to calculate the AMP (root mean square) for the EMG (µVrms) and MMG ($m \cdot s^{-2}$) signals, as well as the MPF (in Hz). The MPF was selected to represent the power density spectrum and was calculated as described by Kwatny et al. [32]. The torque signals were sampled from the digital torque of the calibrated Cybex II isokinetic dynamometer and stored on a personal computer (Dell Inspiron Dell Inc., Round Rock, TX, USA) for analysis.

Statistical Analysis

The test-retest for the pre-test MVIC, EMG AMP, EMG MPF, MMG AMP, and MMG MPF values of test visit 1 and test visit 2 were assessed with repeated measures ANOVAs to evaluate systematic error and a 2,1 model was used to determine intraclass correlation coefficients (ICC) [33]. The corresponding pre-test forearm flexion MVIC with the greatest torque production was used to normalize the torque and neuromuscular parameters (EMG AMP, EMG MPF, MMG AMP, MMG MPF, and NME) for each 10% of the TTF for the RPEFT and TRQFT. Separate polynomial regression analyses (linear and quadratic) were used to define the individual and composite relationships for the normalized torque and neuromuscular parameter values versus normalized time (every 10%) during the RPEFT and TRQFT. Dependent t-tests were used to determine mean differences for TTF and performance fatigability (% decline in MVIC = [((pre-test MVIC – post-test MVIC) / pre-test MVIC) x 100]) between anchor schemes, and effect sizes were reported as Cohen's *d*. A *p*-value ≤ 0.05 was considered statistically significant for the analyses. All the statistical analyses were completed in IBM SPSS v. 29 (Armonk, NY, USA).

3. Results

Reliability

Table 2 includes the test-retest reliability parameters (P-value (systematic error), ICC, $ICC_{95\%}$, SEM, and CV) for MVIC, EMG AMP, EMG MPF, MMG AMP, and MMG MPF. There were no mean differences ($p > 0.05$) for test versus retest for MVIC and the neuromuscular parameters. The ICC values ranged from 0.578 (MMG AMP) to 0.878 (EMG AMP).

Time to Task Failure and Performance Fatigability

The results of the dependent t-test for TTF indicated a significant mean difference between the RPEFT and TRQFT (503.1 ± 401.1 vs. 144.3 ± 90.9 s, $p = 0.006$, $d = 0.974$) (Figure 1A). The results of the dependent t-test for performance fatigability indicated a significant mean difference between the RPEFT and TRQFT (12.4 ± 12.4 vs. 29.3 ± 13.2%, $p < 0.001$, $d = 1.545$) (Figure 1B).

Torque Responses

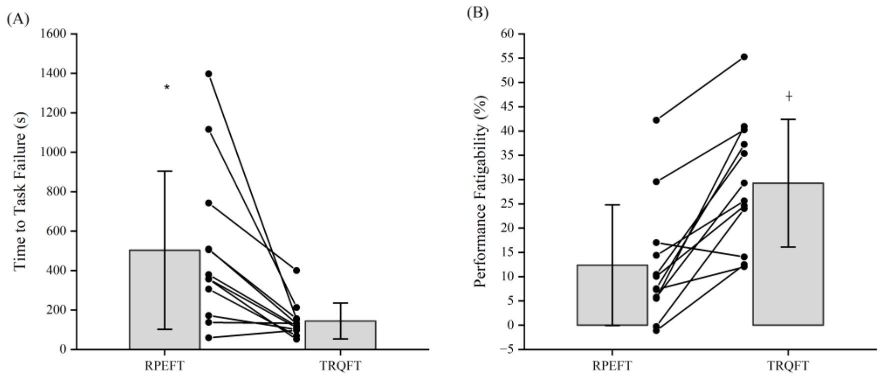
During the RPEFT, the normalized individual and composite torque responses indicated significant negative linear relationships for torque vs. time (r = -0.713 to -0.985) for all 12 subjects, and a negative linear relationship (r = -0.955) for the composite data (Figure 2 and Table 3).

During the TRQFT, the normalized individual and composite torque responses indicated a significant positive linear relationship for torque vs. time (r = 0.716) for 1 of the 12 subjects, a negative linear relationship (r = -0.724) for 1 subject, no significant relationships for 10 subjects, and no significant relationship for the composite data (Figure 3 and Table 4).

Table 2. Reliability data for maximal voluntary isometric contraction (MVIC) torque and neuromuscular parameters (EMG AMP, EMG MPF, MMG AMP, and MMG MPF) during the pre-test forearm flexion MVICs prior to the sustained, isometric forearm flexion task anchored to RPE = 4 (RPEFT) and the sustained, isometric forearm flexion task anchored to the torque (TRQFT) value that corresponded to the torque produced during the first 1 s of the RPEFT

Variables (mean ± SD)	Visit 1	Visit 2	P	ICC	$ICC_{95\%}$	SEM	CV Visit 1	CV Visit 2
MVIC (Nm)	81.0 ± 19.3	81.4 ± 16.6	0.905	0.827	0.496 – 0.947	7.8	23.8%	20.3%
EMG AMP (µVrms)	1447.3 ± 719.7	1456.1 ± 740.6	0.937	0.878	0.627 – 0.963	265.2	49.7%	50.9%
EMG MPF (Hz)	79.6 ± 15.2	76.4 ± 8.3	0.262	0.700	0.266 – 0.902	6.6	19.1%	10.8%
MMG AMP ($m \cdot s^{-2}$)	0.49 ± 0.26	0.52 ± 0.17	0.707	0.578	0.016 – 0.859	0.1	49.8%	32.8%
MMG MPF (Hz)	22.3 ± 5.4	22.7 ± 6.9	0.838	0.626	0.089 – 0.877	3.9	24.3%	30.6%

P = Alpha from the ANOVA for systematic error; ICC = intraclass correlation coefficient; $ICC_{95\%}$ = ICC 95% confidence interval; SEM = standard error of the measurement; CV = coefficient of variation; MVIC = maximal voluntary isometric contraction; EMG = electromyography; MMG = mechanomyography; AMP = amplitude; MPF = mean power frequency.



* RPEFT > TRQFT (p = 0.006, d = 0.974)

┼ TRQFT > RPEFT (p < 0.001, d = 1.545)

Figure 1. (A) Mean (± SD) time to task failure (TTF) values for the sustained, isometric forearm flexion task anchored to RPE = 4 (RPEFT) and the sustained, isometric forearm flexion task anchored to the torque (TRQFT) value that corresponded to the torque produced during the first 1 s of the RPEFT. (B) Mean (± SD) performance fatigability (% decline in MVIC = [((pre-test MVIC – post-test MVIC) / pre-test MVIC) x 100]) values for the sustained, isometric forearm flexion task anchored to RPE = 4 (RPEFT) and the sustained, isometric forearm flexion task anchored to the torque (TRQFT) value that corresponded to the torque produced during the first 1 s of the RPEFT

Electromyographic Amplitude Responses

During the RPEFT, the normalized individual and composite EMG AMP responses indicated significant positive linear relationships for EMG AMP vs. time (r = 0.725 and r = 0.730) for 2 of the 12 subjects, negative linear relationships (r = -0.799 to -0.947) for 4 subjects, no relationships for 6 subjects, and no significant relationship for the composite data (Figure 2 and Table 3).

During the TRQFT, the normalized individual and composite EMG AMP responses indicated a significant positive quadratic relationship for EMG AMP vs. time (R = 0.890) for 1 of the 12 subjects, positive linear relationships (r = 0.670 to 0.958) for 6 subjects, no significant relationships for 5 subjects, and a positive linear relationship (r = 0.961) for the composite data (Figure 3 and Table 4).

Electromyographic Mean Power Frequency Responses

During the RPEFT, the normalized individual and composite EMG MPF responses indicated a significant positive linear relationship for EMG MPF vs. time (r = 0.646) for 1 of the 12 subjects, negative linear relationships (r = -0.788 to -0.796) for 3 subjects, no significant relationships for 8 subjects, and a negative linear relationship (r = -0.751) for the composite data (Figure 2 and Table 3).

During the TRQFT, the normalized individual and composite EMG MPF responses indicated significant negative quadratic relationships for EMG MPF vs. time (R = -0.960 and -0.971) for 2 of the 12 subjects, negative linear relationships (r = -0.748 to 0.963) for 5 subjects, no significant relationships for 5 subjects, and a negative linear relationship (r = -0.951) for the composite data (Figure 3 and Table 4).

Mechanomyographic Amplitude Responses

During the RPEFT, the normalized individual and composite MMG AMP responses indicated a significant positive quadratic relationship for MMG AMP vs. time (R = 0.953) for 1 of the 12 subjects, a positive linear relationship (r = 0.655) for 1 subject, a negative linear relationship (r = 0.786) for 1 subject, no significant relationships for 9 subjects, and a positive linear relationship (r = 0.689) for the composite data (Figure 2 and Table 3).

During the TRQFT, the normalized individual and composite MMG AMP responses indicated significant positive quadratic relationships for MMG AMP vs. time (R = 0.464 and 0.649) for 2 of the 12 subjects, a negative quadratic relationship (R = -0.153) for 1 subject, positive linear relationships (r = 0.632 to 0.825) for 3 subjects, a negative linear relationship (r = -0.848) for 1 subject, no significant relationships for 5 subjects, and a positive linear relationship (r = 0.840) for the composite data (Figure 3 and Table 4).

Mechanomyographic Mean Power Frequency Responses

During the RPEFT, the normalized individual and composite MMG MPF responses indicated a significant positive quadratic relationship for MMG MPF vs. time (R = 0.036) for 1 of the 12 subjects, negative linear relationships (r = -0.665 to -0.819) for 5 subjects, no significant relationships for 6 subjects, and a negative linear relationship (r = -0.879) for the composite data (Figure 2 and Table 3).

During the TRQFT, the normalized individual and composite MMG MPF responses indicated a significant positive linear relationship for MMG MPF vs. time (r = 0.820) for 1 of the 12 subjects, negative linear relationships (r = -0.640 to -0.898) for 4 subjects, no significant relationships for 7 subjects, and a negative linear relationship (r = -0.806) for the composite data (Figure 3 and Table 4).

Neuromuscular Efficiency Responses

During the RPEFT, the normalized individual and composite torque responses indicated significant negative linear relationships for NME vs. time (r = -0.661 to -0.969) for all 12 subjects, and a negative linear relationship (r = -0.974) for the composite data (Figure 2 and Table 3).

During the TRQFT, the normalized individual and composite NME responses indicated significant negative linear relationships for NME vs. time (r = -0.657 to -0.972) for 10 of the 12 subjects, no significant relationship for 2 subjects, and a negative linear relationship (r = -0.963) for the composite data (Figure 3 and Table 4).

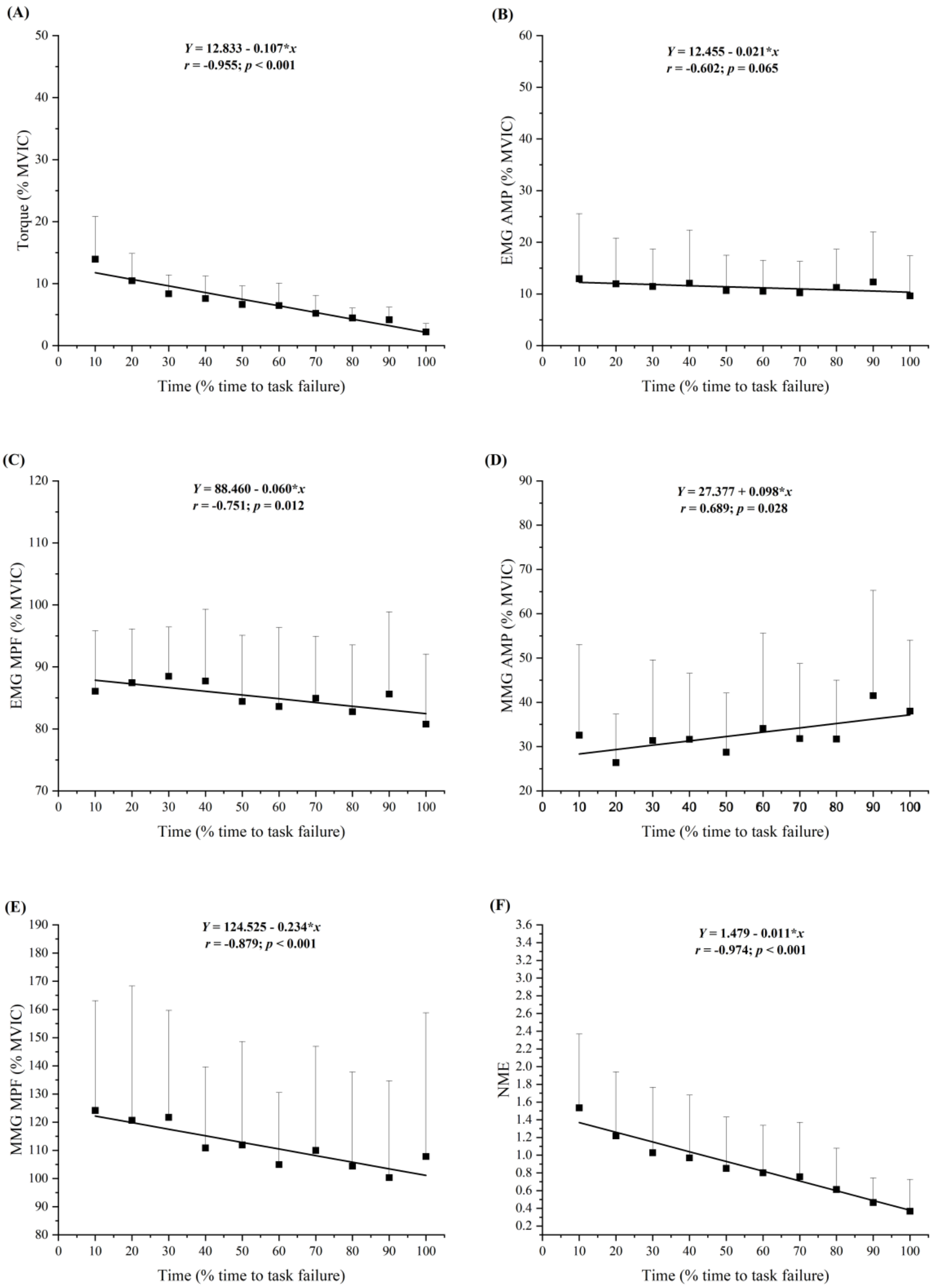


Figure 2. Time course of changes (mean ± SD) for the normalized (% of pre-test MVIC) torque and neuromuscular values for the sustained, isometric forearm flexion task anchored to RPE = 4 (RPEFT) at an elbow joint angle of 100°. Regression analyses represent torque and neuromuscular values from 10-100% time to task failure. (A) Torque, (B) Electromyographic amplitude (EMG AMP), (C) Electromyographic mean power frequency (EMG MPF), (D) Mechanomyographic amplitude (MMG AMP), (E) Mechanomyographic mean power frequency (MMG MPF), (F) Neuromuscular efficiency (NME)

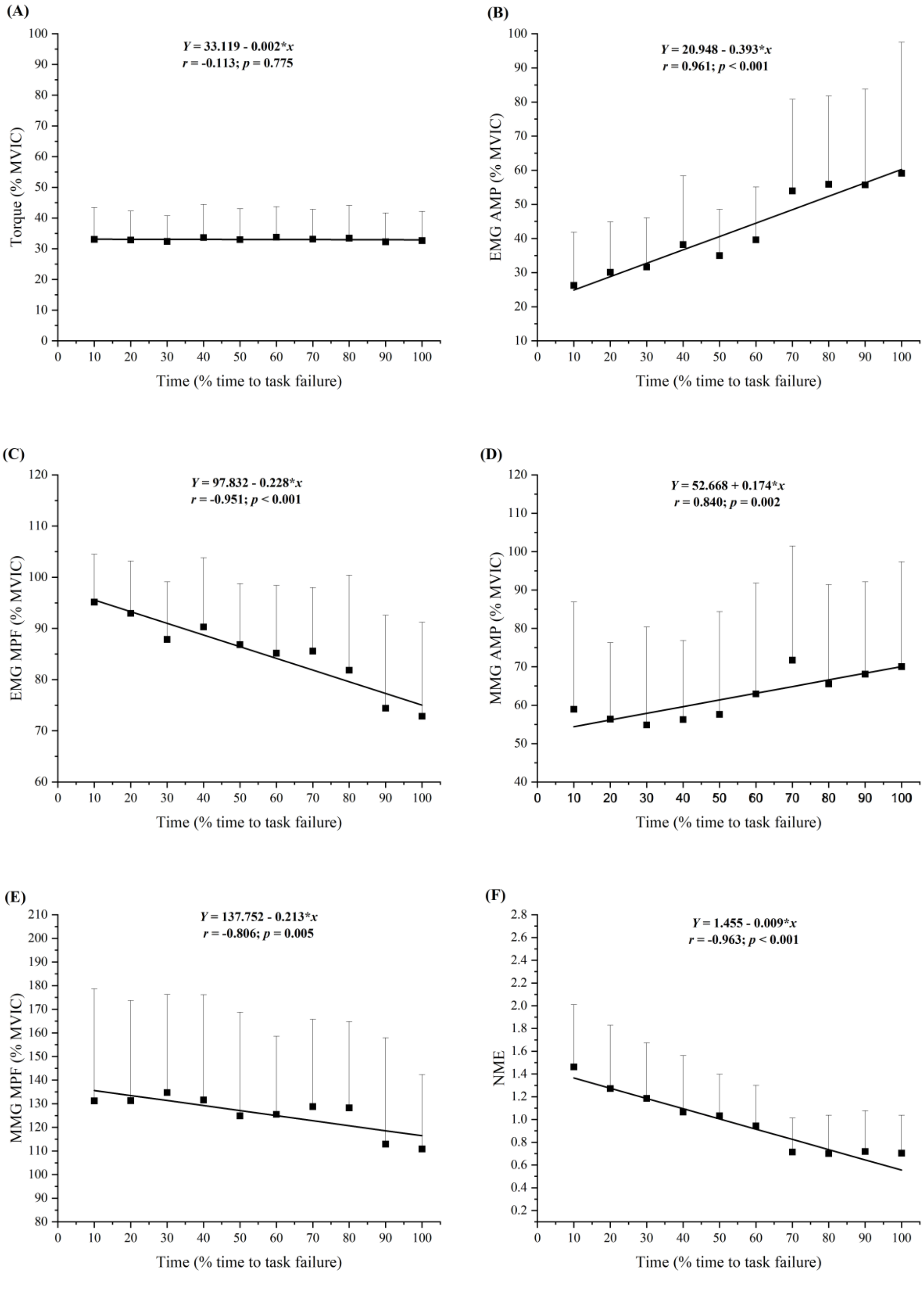


Figure 3. Time course of changes (mean ± SD) for the normalized (% of pre-test MVIC) torque and neuromuscular values for the sustained, isometric forearm flexion task anchored to the torque (TRQFT) that corresponded to the torque produced during the first 1 s of the RPEFT at an elbow joint angle of 100°. Regression analyses represent torque and neuromuscular values from 10-100% time to task failure. (A) Torque, (B) Electromyographic amplitude (EMG AMP), (C) Electromyographic mean power frequency (EMG MPF), (D) Mechanomyographic amplitude (MMG AMP), (E) Mechanomyographic mean power frequency (MMG MPF), (F) Neuromuscular efficiency (NME).

Table 3. Polynomial regression models, correlations (Cor), and *p* - values for normalized Torque, EMG AMP, EMG MPF, MMG AMP, MMG MPF, and NME vs. Time relationships during the sustained, isometric forearm flexion task anchored to RPE = 4 at an elbow joint angle of 100°

Subjects	Torque			EMG AMP			EMG MPF			MMG AMP			MMG MPF			NME		
	Model	Corr.	p - value	Model	Corr.	p - value	Model	Corr.	p - value	Model	Corr.	p - value	Model	Corr.	p - value	Model	Corr.	p - value
1	Linear	-0.786	0.007	-	-	NS	-	-	NS	Linear	0.655	0.04	-	-	NS	Linear	-0.823	0.003
2	Linear	-0.916	< 0.001	Linear	0.725	0.018	Linear	-0.788	0.007	Quadratic	0.953	0.011	-	-	NS	Linear	-0.916	< 0.001
3	Linear	-0.935	< 0.001	-	-	NS	Linear	-0.796	0.006	-	-	NS	Linear	-0.698	0.025	Linear	-0.869	0.001
4	Linear	-0.985	< 0.001	-	-	NS	Linear	-0.796	0.006	-	-	NS	Linear	-0.747	0.013	Linear	-0.969	< 0.001
5	Linear	-0.897	< 0.001	Linear	-0.802	0.005	Linear	0.646	0.044	-	-	NS	-	-	NS	Linear	-0.824	0.003
6	Linear	-0.859	0.001	Linear	-0.836	0.003	-	-	NS	-	-	NS	Linear	-0.665	0.036	Linear	-0.661	0.037
7	Linear	-0.744	0.014	-	-	NS	-	-	NS	-	-	NS	Quadratic	0.036	0.011	Linear	-0.748	0.013
8	Linear	-0.713	0.021	-	-	NS	-	-	NS	-	-	NS	-	-	NS	Linear	-0.917	< 0.001
9	Linear	-0.935	< 0.001	Linear	-0.799	0.006	-	-	NS	-	-	NS	Linear	-0.78	0.008	Linear	-0.694	0.026
10	Linear	-0.926	< 0.001	-	-	NS	-	-	NS	-	-	NS	-	-	NS	Linear	-0.949	< 0.001
11	Linear	-0.967	< 0.001	Linear	0.73	0.016	-	-	NS	-	-	NS	Linear	-0.819	0.004	Linear	-0.785	0.007
12	Linear	-0.985	< 0.001	Linear	-0.947	< 0.001	-	-	NS	Linear	-0.786	0.007	-	-	NS	Linear	-0.918	< 0.001

Table 4. Polynomial regression models, correlations (Corr), and *p* - values for normalized Torque, EMG AMP, EMG MPF, MMG AMP, MMG MPF, and NME vs. Time relationships during the sustained, isometric forearm flexion task anchored to the torque that corresponded to RPE = 4 at an elbow joint angle of 100°

Subjects	Torque			EMG AMP			EMG MPF			MMG AMP			MMG MPF			NME		
	Model	Corr.	p - value	Model	Corr.	p - value	Model	Corr.	p - value	Model	Corr.	p - value	Model	Corr.	p - value	Model	Corr.	p - value
1	Linear	0.716	0.02	-	-	NS	Quadratic	-0.971	< 0.001	Quadratic	0.649	0.012	Linear	-0.826	0.003	Linear	-0.733	0.016
2	-	-	NS	Linear	0.670	0.034	Linear	-0.748	0.013	Linear	0.632	0.05	Linear	-0.769	0.009	Linear	-0.754	0.012
3	-	-	NS	Linear	0.958	< 0.001	-	-	NS	Linear	0.639	0.047	Linear	0.82	0.004	Linear	-0.972	< 0.001
4	-	-	NS	-	-	NS	Linear	-0.912	< 0.001	Linear	-0.848	0.002	Linear	-0.640	0.046	Linear	-0.657	0.039
5	-	-	NS	Linear	0.855	0.002	Linear	-0.944	< 0.001	Quadratic	-0.153	0.027	-	-	NS	Linear	-0.844	0.002
6	Linear	-0.724	0.018	-	-	NS	-	-	NS	Quadratic	0.464	0.045	-	-	NS	-	-	NS
7	-	-	NS	-	-	NS	Linear	-0.954	< 0.001	-	-	NS	Linear	-0.898	< 0.001	-	-	NS
8	-	-	NS	Linear	0.819	0.004	-	-	NS	Linear	0.825	0.003	-	-	NS	Linear	-0.918	< 0.001
9	-	-	NS	Linear	0.765	0.01	-	-	NS	-	-	NS	-	-	NS	Linear	-0.843	0.002
10	-	-	NS	-	-	NS	-	-	NS	-	-	NS	-	-	NS	Linear	-0.713	0.021
11	-	-	NS	Linear	0.88	< 0.001	Quadratic	-0.960	0.021	-	-	NS	-	-	NS	Linear	-0.806	0.005
12	-	-	NS	Quadratic	0.89	0.050	Linear	-0.963	< 0.001	-	-	NS	-	-	NS	Linear	-0.902	< 0.001

4. Discussion

The test-retest reliability analyses for the MVIC and neuromuscular parameters (EMG AMP, EMG MPF, MMG AMP, and MMG MPF) in the current study are presented in Table 2. There was no significant mean difference for the test versus retest reliability for forearm flexion MVIC and the ICC (R = 0.827) reflected excellent reliability [34]. The ICC reported for MVIC in the current study was lower than that reported by Smith et al. [11] for forearm flexion MVIC at an elbow joint angle of 100° in men. For the neuromuscular parameters, there were also no significant mean differences between the test versus retest reliability. The ICCs for the neuromuscular parameters ranged from R = 0.578 (MMG AMP) to 0.878 (EMG AMP), and reflected fair to excellent reliability [34]. The ICCs for the neuromuscular parameters in the current study were higher than those reported by Smith et al. [11] for forearm flexion MVIC at an elbow joint angle of 100° in men. Koo and Li [35] have stated that ICCs can be affected by the degree of variability of the sample. Furthermore, variations in the absolute values of the neuromuscular parameters used in the test-retest reliability analyses can be due to slight day-to-day changes in the location of the electrodes and accelerometer used to record the EMG and MMG signals [36].

The results of the current study indicated that TTF for the RPEFT was 3.5 times greater than that of the TRQFT (Figure 1A). These results were in agreement with previous studies that reported TTF values following fatiguing forearm flexion tasks anchored to RPE that were 2.7 [10] and 3.0 [11] times greater than those following fatiguing forearm flexion tasks anchored to the torque that corresponded to RPE = 8 and RPE = 7, respectively. Smith et al. [10,11] suggested that the difference in TTF between fatiguing tasks anchored to RPE versus torque was due to the unique strategies associated with each anchor scheme to maintain the prescribed intensity. For example, during tasks anchored to RPE, the perceptual intensity is maintained by consciously reducing torque. Theoretically, the decrease in torque results in decreased muscle excitation and derecruitment of some of the activated motor units [7,37] as well as decreased risk of disruption to direct and indirect systems involved in the fatiguing tasks [38]. In contrast, during tasks anchored to torque, the intensity (torque) must remain constant, which, in theory, is accomplished by recruiting additional motor units to compensate for fatigued motor units [39,40]. Thus, the ability to decrease torque during fatiguing tasks anchored to RPE allows individuals to withstand the adverse effects of fatigue for a longer period of time [3] and result in a longer TTF than fatiguing tasks anchored to torque.

In the current study, the TRQFT resulted in greater performance fatigability than the RPEFT, despite the RPEFT having a longer TTF (Figure 2). The current results were in disagreement with those of previous studies that reported anchor scheme-specific differences for TTF but not performance fatigability following sustained, isometric forearm flexion tasks anchored to RPE = 7 and the torque that corresponded to RPE = 7 in a combined sample of men and women [11], as well as RPE = 8 and the torque that corresponded to RPE = 8 in women [10]. Smith et al. [10,11] suggested that the lack of difference in performance fatigability between the anchor schemes (RPE vs. torque), despite the greater TTF following the fatiguing task anchored to RPE, was due to the same Sensory Tolerance Limit (STL) being reached. According to the STL, exercise tolerance is limited by global sensory feedback from primary and remote muscles and feedforward corollary discharges associated with central motor command [40]. Specifically, the intensity of the task is informed by the sum of feedback and feedforward sources and task termination occurs once a finite level of stimulation from those sources is reached [40,41]. Theoretically, when a task is anchored to torque, motor unit recruitment increases to maintain exercise intensity [39,40]. Furthermore, as the TRQFT progresses toward the STL, there are increases in central drive, corollary discharges, and sensory afferent feedback [39,40]. When a fatiguing task is anchored to RPE, however, the perceptual intensity is maintained by consciously decreasing torque [37,41,42], which allows for the tolerable continuation of the task and avoidance of the STL [40]. Thus, the fatiguing task anchored to RPE is able to continue for a longer period of time (i.e., greater TTF) [10,11] before the task is deemed unattractive to continue, the STL is attained, and volition task termination occurs [40]. The results of Smith et al. [10,11], therefore, indicated that the fatiguing tasks (RPE vs. torque) were discontinued once the same STL was reached (as reflected by the similar performance fatigability), which occurred later during the fatiguing tasks anchored to RPE due to the ability to decrease torque. The greater performance fatigability following the TRQFT than the RPEFT in the current study, however, may have suggested that the fatiguing tasks did not reach the same STL, likely due to the distinct characteristics associated with anchoring a fatiguing task to a lower (RPE = 4) perceptual intensity. In particular, Smith et al. [10,11] reported that the initial torque for the fatiguing task anchored to RPE = 8 was about 60% MVIC and 58.5% MVIC for the fatiguing task anchored to RPE = 7, respectively. In contrast, in the current study, the torque produced during the initial 1 s of the RPEFT was about 35.9 ± 11.5% MVIC, therefore, since the fatiguing task started at a low percentage of MVIC, the changes in torque had to be fine-tuned to avoid reaching zero before the STL was attained. Thus, the lower performance fatigability following the RPEFT than the TRQFT was possibly due to the torque reaching zero before the STL was attained.

The current findings indicated anchor scheme-specific composite patterns of responses for torque. Specifically, there was a linear decrease in torque for the RPEFT, while the TRQFT indicated no significant relationship. The current findings for the RPEFT were consistent with those of previous studies that reported decreases in torque during sustained, isometric forearm flexion [4,7] and leg extension [5,6] tasks anchored to RPE, however, the patterns of responses (linear vs. quadratic) were not uniform across the studies. For instance, quadratic decreases in torque were reported during sustained, isometric leg extension tasks anchored to RPE = 5 in women [5] and men [6], as well as sustained, isometric forearm flexion tasks anchored to RPE = 8 at elbow joint angles of 75° and 125° in women [4]. In contrast, a linear decrease in torque was reported during a sustained, isometric forearm flexion task anchored to RPE = 7 at an elbow joint angle of 100° in women [7]. Therefore, the current findings and those of previous studies [4,5,6,7] suggested that the direction, but not the pattern (linear vs. quadratic), of the torque responses during fatiguing tasks anchored to RPE was consistent across the tasks. It is possible that the different patterns of responses were due to differences in the RPE value used to anchor the task, the muscle group of interest, the joint angle at which the task was performed, and/or the sex of the subjects [4]. Unlike the RPEFT, where the subjects were able to decrease torque to maintain the intensity, the intensity (torque) during the TRQFT had to remain constant and the task ended at the time point at which the prescribed torque could no longer be maintained despite strong verbal encouragement. Thus, the difference in the composite patterns of responses for torque between the TRQFT (no change) and RPEFT (linear decrease) was expected and due to the distinct characteristics associated with each anchor scheme.

Typically, during fatiguing tasks anchored to torque, the neuromuscular responses are characterized by increases in EMG AMP (muscle excitation) and MMG AMP (motor unit recruitment) but decreases in EMG MPF (MUAP CV) and MMG MPF (global firing rate of the unfused, activated motor units) [19,22,24,25]. In addition, NME, which provides an indirect estimation of the response of contractile elements of muscle to neural excitation [20,21], tends to decrease as torque remains constant and EMG AMP increases [43]. Keller et al. [5] previously suggested that the neuromuscular responses during fatiguing tasks anchored to torque provide insight into the physiological mechanisms underlying torque production capabilities. The neuromuscular responses during fatiguing tasks anchored to RPE, however, do not follow the typical patterns of responses observed during fatiguing tasks anchored to torque and likely reflect the physiological mechanisms underlying perceived exertion [5]. For example, Smith et al. [7] reported quadratic decreases in EMG AMP, quadratic increases in MMG AMP, but no change in EMG MPF or MMG MPF over time during a sustained, isometric forearm flexion task anchored to RPE = 7 in women. In the current study, the composite patterns of responses for the neuromuscular parameters during the TRQFT indicated linear decreases in EMG MPF, MMG MPF, and NME, as well as linear increases in EMG AMP and MMG AMP (Figure 3 and Table 4). In contrast, the composite patterns of responses for the neuromuscular parameters during the RPEFT indicated linear decreases in EMG MPF, MMG MPF, and NME, a linear increase in MMG AMP, and no change in EMG AMP (Figure 2 and Table 3). Thus, the current results indicated that anchor scheme affected muscle excitation (EMG AMP), but not MUAP CV (EMG MPF), motor unit recruitment (MMG AMP), the global firing rate of the unfused, activated motor units (MMG MPF), or how the contractile elements of the muscle responded to neural excitation (NME).

The composite increases in the AMP and decreases in the MPF of the EMG and MMG signals during the TRQFT in the current study were consistent with the typical neuromuscular responses for fatiguing tasks anchored to torque [19,22,24,25]. Electromyographic

AMP is reflective of muscle excitation [17], which is influenced by motor unit recruitment, motor unit firing rate, and/or motor unit synchronization [44]. Normalized EMG AMP is used to calculate NME and decreases in NME may be indicative of peripheral fatigue. Peripheral fatigue occurs at or distal to the neuromuscular junction when excitation-contraction coupling is impaired [45] due to the accumulation of intramuscular metabolites, such as inorganic phosphate (P_i) and hydrogen ions (H^+) [46]. Electromyographic MPF, which reflects changes in MUAP CV [18], may also decrease due to the accumulation of intramuscular metabolites and be associated with peripheral fatigue [46]. In comparison to peripheral fatigue, central fatigue occurs proximal to the neuromuscular junction when group III/IV afferent neurons sense the interstitial accumulation of H^+ [46]. Furthermore, during submaximal fatiguing tasks, central fatigue may result in enhanced motor cortical drive to recruit additional motor units as well as increases, decreases, or no change in motor unit firing rate [47]. Changes in the global firing rate of activated, unfused motor units are qualitatively tracked by changes in MMG MPF while changes in motor unit recruitment are in some cases reflected by changes in MMG AMP [22,23]. Under some conditions, however, the MMG signal is influenced by mechanical factors (i.e., muscle stiffness and intramuscular fluid pressure) that affect the lateral oscillations of the muscle fibers rather than motor unit activation strategies [22,23,48]. During the TRQFT, the composite increase in EMG AMP likely reflected an increase in muscle excitation as a result of increased motor unit recruitment, as indicated by the increase in MMG AMP, to compensate for fatigued motor units [39,40]. According to the Onion Skin Scheme, higher threshold motor units have lower firing rates than lower threshold motor units [49], thus, as motor unit recruitment (MMG AMP) increased to maintain the target torque during the TRQFT, the global firing rate of the activated, unfused motor units (MMG MPF) decreased. In addition, the decrease in EMG MPF was likely due to the accumulation of intramuscular metabolites, which resulted in excitation-contraction coupling failure and decreases in MUAP CV. Neuromuscular efficiency also decreased during the TRQFT as torque remained constant while EMG AMP increased. In contrast, during the RPEFT, there was a composite increase in MMG AMP as well as decreases in EMG MPF, MMG MPF, and NME, but no change in EMG AMP. During the RPEFT, torque was consciously decreased to maintain the perceptual intensity, which may have led to a decrease in muscle stiffness and intramuscular fluid pressure, which allowed for greater lateral oscillation of the muscle fibers, and therefore, an increase in MMG AMP [5,22]. The decrease in MMG MPF, however, indicated a decrease in global firing rate while the lack of change in EMG AMP suggested that there was no change in muscle excitation. Furthermore, the disproportionate fatigue-induced decrease in torque relative to EMG AMP resulted in the decrease in NME during the RPEFT. Similar to the TRQFT, EMG MPF decreased, likely due to the accumulation of P_i and H^+ that resulted in excitation-contraction coupling failure. Thus, during the TRQFT, the composite increase in EMG AMP (muscle excitation) and MMG AMP (motor unit recruitment), in conjunction with the decrease in MMG MPF (global firing rate), suggested the likely presence of central fatigue while the decreases in EMG MPF (MUAP CV) and NME indicated the presence of peripheral fatigue. During the RPEFT, however, the composite patterns of responses for EMG AMP (no change in muscle excitation), MMG AMP (increase due to decreased muscle stiffness and intramuscular fluid pressure), and MMG MPF (decrease in global firing rate) did not suggest the likely presence of central fatigue, but the decreases in EMG MPF (MUAP CV) and NME suggested the presence of peripheral fatigue.

In the current study, 100% of the individual patterns of responses for torque during the RPEFT and 83.3% during the TRQFT matched the composite patterns (Table 3 and Table 4). These percentages (83.3 - 100%) were similar to those reported (90.9%) for sustained, isometric forearm flexion tasks anchored to RPE = 7 at an elbow joint angle of 100° in women [7] as well as those reported (100%) for sustained, isometric leg extension tasks anchored to RPE = 5 in women and men [5,6], but higher than those reported (55.6 - 77.8%) for sustained, isometric forearm flexion tasks anchored to RPE = 8 at elbow joint angles of 75° and 125° in women [4]. The differences in the inter-individual responses among the current study and previous studies [4,5,6,7] may be due to the definitions used to determine task failure, the muscle group of interest, and RPE value used to anchor the fatiguing tasks. For example, during sustained, isometric leg extension tasks, Keller et al. [5,6] defined task failure as the timepoint in which RPE = 5 could not be maintained or reaching a time limit of 5 minutes. In contrast, during sustained, isometric forearm flexion tasks, Smith et al. [7] defined task failure "… as a torque that would require RPE > 7 or torque was reduced to zero" (p. 5) while Arnett et al. [4] defined it as "…torque being reduced to zero" (p. 9). In the current study, task failure for the RPEFT was defined as the timepoint in which torque was reduced to zero. For the TRQFT, task failure was defined as the timepoint in which the target torque could no longer be maintained despite strong verbal encouragement. Despite the differences in the definitions of task failure, muscle groups, and anchoring schemes, the current findings and those of previous studies [4,5,6,7] indicated that, in most cases, during fatiguing tasks anchored to RPE and the torque that corresponded to the RPE value, the individual torque responses matched the composite responses. In regard to the intra-individual responses, the current results indicated that 1 out of the 12 (8.3%) subjects demonstrated the same pattern of response for torque during the RPEFT and TRQFT. In contrast, Arnett et al. [4] reported that 77.8% of the individual responses for torque were similar between sustained, isometric forearm flexion tasks anchored to RPE = 8 at elbow joint angles of 75° and 125° in women. Thus, while the results of Arnett et al. [4] suggested that in most cases, but not all, individual torque responses during fatiguing forearm flexion tasks anchored to RPE were not dependent on the joint angle at which the fatiguing tasks were performed, the intra-individual variability in the current study suggested that the individual torque responses were dependent on the anchor scheme of the fatiguing task.

For the TRQFT in the current study, 50.0%, 41.7%, 25.0%, 33.3%, and 83.3% of the individual patterns of responses for EMG AMP, EMG MPF, MMG AMP, MMG MPF, and NME, respectively, matched the composite responses (Table 4, Figure 3). For the RPEFT, 50% of the individual patterns of responses for EMG AMP, 25% for EMG MPF, 8.3% for MMG AMP, 41.7% for MMG MPF, and 100% for NME were the same as the composite responses (Table 3, Figure 2). The results of the current study were consistent with those of previous studies that anchored fatiguing forearm flexion tasks [4,7] and fatiguing leg extension tasks anchored [5,6] to RPE. Specifically, for sustained, isometric forearm flexion tasks anchored to RPE, Arnett et al. [4] and Smith et al. [7] reported that 11.1 – 77.8% and 18.2 – 54.5% of the individuals demonstrated the same neuromuscular responses (EMG AMP, EMG MPF, MMG AMP, and MMG MPF) as the composite responses, respectively. For NME, Arnett et al. [4] reported that 66.7% of the individuals exhibited a similar response as the composite response. For sustained, isometric leg extension tasks anchored to RPE, Keller et al. [5,6] reported that 50 - 100% of the individuals demonstrated neuromuscular responses (EMG AMP, EMG MPF, MMG AMP, and MMG MPF) that matched the composite responses. It is possible that the percent of consistency between the individual neuromuscular responses and the composite responses in the current study and those of previous studies [4,5,6,7] were dependent on the muscle group that was assessed as well as the anchor scheme. In the current study, as well as in Arnett et al. [4] and Smith et al. [7], neuromuscular responses were examined during sustained, isometric forearm flexion tasks. In contrast, Keller et al. [5,6] assessed the neuromuscular responses during sustained, isometric leg extension tasks. Previously, Neyroud et al. [50] suggested that elbow flexor muscles may be more susceptible to mechanisms of peripheral fatigue than leg extensor muscles as indicated by greater decreases in electrically evoked force following sustained, isometric tasks anchored to 50% of MVIC. Thus, the mechanisms of fatigue during fatiguing forearm flexion tasks may differ from those observed during fatiguing leg extension tasks and necessitate different motor unit activation strategies to sustain the tasks. The anchor schemes in the current study (RPE = 4 vs. the torque that corresponded to RPE = 4) also differed from those of Arnett et al. [4] (RPE = 8), Smith et al. [7] (RPE = 7), and Keller et al. [5,6] (RPE = 5), which may explain the need for different neuromuscular responses on a subject-by-subject basis. In the current study, intra-individual responses for the neuromuscular parameters were also assessed. For EMG AMP and EMG MPF, 6 subjects (50.0%) exhibited the same patterns of responses during the RPEFT and the TRQFT (Table 3 and Table 4). For MMG AMP, MMG MPF, and NME, 4 (33.3%), 5 (41.7%), and 10 (83.3%) subjects demonstrated the same patterns of responses during the RPEFT and TRQFT, respectively (Table 3 and Table 4). A previous study [4] reported that 55.6%, 44.4%, 66.7%, 55.6%, and 66.7% of the individual responses for EMG AMP, EMG MPF, MMG AMP, MMG MPF, and NME, respectively, differed between sustained, isometric forearm flexion tasks anchored to RPE = 8 at elbow joint angles of 75° and 125° in women. Thus, the results of Arnett et al. [4] and those of the current study suggested that subjects may use different motor unit activation strategies to modulate torque production when a fatiguing task was performed at an elbow joint angle of 75° versus 125° and when a fatiguing task was anchored to RPE versus the torque that corresponded to that RPE value. Furthermore, the current findings supported the recommendations of previous studies [4,5,6,7] that individual responses for neuromuscular parameters (EMG AMP, EMG MPF, MMG AMP, MMG MPF, and NME) versus time relationships should be reported in addition to the composite responses due to inter- and intra-individual variability.

The current findings are limited to college aged men during sustained, isometric forearm flexion tasks anchored to RPE = 4 and the torque that corresponded to the torque produced during the first 1 s of the RPE task at an elbow joint angle of 100°. Future studies should replicate the current study in women, examine the effects of various anchor schemes (lower or higher RPE vs. torque), and perform the fatiguing tasks at a different elbow joint angle. The EMG and MMG signal were only recorded from the BB, therefore, future studies should examine the neuromuscular responses from the three forearm flexor muscles. Furthermore, future studies should utilize the interpolated twitch technique and potentiated twitch amplitude to examine the mechanisms of fatigue (central vs. peripheral) modulating torque production and influencing the neuromuscular responses during sustained, isometric forearm flexion tasks anchored to RPE versus torque.

In conclusion, the findings of the current study indicated that TTF, performance fatigability, torque, and neuromuscular responses during sustained, isometric forearm flexion tasks were dependent on anchor scheme. Specifically, the RPEFT resulted in a greater TTF but lower performance fatigability than the TRQFT, and the differences were likely due to the ability to decrease torque during the RPEFT, but not the TRQFT. Furthermore, during the TRQFT, the composite increases in EMG AMP and MMG AMP as well as the decrease in MMG MPF suggested the likely presence of central mechanisms of fatigue, whereas the decreases in EMG MPF and NME indicated the presence of peripheral mechanisms of fatigue. During the RPEFT, the composite linear decreases in EMG MPF and NME suggested the presence of peripheral mechanisms of fatigue, however, the lack of change in EMG AMP, increase in MMG AMP, and decrease in MMG MPF did not suggest the likely presence of central mechanisms of fatigue. In addition, the inter- and intra-individual variability in the individual patterns for responses for torque and neuromuscular parameters indicated that motor unit activation strategies varied on a subject-by-subject basis and were dependent on the anchor scheme. Thus, composite and individual patterns of responses should be reported for fatiguing tasks anchored to RPE as well as the torque that corresponded to the RPE value.

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