Wavelet-Based Analysis of Electromyographic and Mechanomysographic Signals Following Fatiguing Tasks Anchored to Perceptual Intensity Versus Torque

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Abstract

PURPOSE: This study used wavelet analyses, signal processing procedures that provide information about the time, frequency, and intensity components of electromyographic (EMG) and mechanomyographic (MMG) signals, to examine the effects of anchoring sustained, isometric forearm flexion tasks to a rating of perceived exertion (RPE) versus torque on the EMG and MMG intensity responses. **METHODS:** Twelve men (mean ± SD: age = 20.9 ± 2.2 yrs.; height = 179.8 ± 5.3 cm; body mass = 80.2 ± 9.9 kg) performed forearm flexion maximal voluntary isometric contractions (MVICs) before and after sustained, isometric forearm flexion tasks anchored to an RPE of 4 (RPEFT) and the torque (TRQFT) that corresponded to an RPE of 4. The EMG and MMG signals were recorded from the biceps brachii and processed using wavelet analyses that decomposed the signals onto sets of 11 nonlinearly scaled Cauchy wavelets that span the entire frequency range (EMG: approximately 7-395 Hz; MMG: approximately 2-120 Hz). Total intensity and intensity spectra were obtained from the wavelet analyses. Separate three-way [anchor (RPE vs torque) x time (pre-test MVIC vs post-test MVIC) x wavelet band (1-11)] repeated measures ANOVAs were used to analyze the EMG (% total volts squared) and MMG (% total squared meters per second squared) intensity data. **RESULTS:** For EMG intensity, there was a significant three-way interaction ($p < 0.001$) that was decomposed with two-way [anchor x time] repeated measures ANOVAs for each wavelet band. The pairwise comparisons for the significant ($p = 0.002$-0.042) interactions and main effects from the follow-up two-way ANOVAs indicated that EMG intensity from pre-test to post-test MVIC: (a) Increased at wavelet bands 2 and 3, decreased at wavelet bands 7-8 and 11, and remained unchanged at wavelet bands 1, 4-6, and 9-10 for the TRQFT; and (b) increased at wavelet band 6, decreased at wavelet bands 8 and 11, and remained unchanged at wavelet bands 1-5, 7, and 9-10 for the RPEFT. For MMG intensity, there were no significant ($p = 0.220$-0.999) interactions or main effects for anchor and time, but there was a significant ($p < 0.001$) main effect for wavelet band. The Bonferroni-corrected pairwise comparisons for the significant ($p < 0.001$) follow-up one-way ANOVA indicated that MMG intensity (collapsed across anchor and time) at: (a) Wavelet band 3 was greater than wavelet bands 1-2, and 4-11; (b) wavelet band 4 was greater than wavelet bands 1-2, and 5-11; (c) wavelet band 5 was greater than wavelet bands 1, and 10-11; and (d) wavelet band 6 was greater than wavelet bands 1, and 10-11. **CONCLUSIONS:** These findings suggested that EMG intensity decreased at high frequencies and increased at intermediate and low frequencies, respectively, following the RPEFT and TRQFT. The EMG intensity decreases at higher frequencies and increases at lower frequencies following both fatiguing tasks were likely related to peripheral fatigue mechanisms that affected motor unit action potential conduction velocity. Furthermore, the lack of change in MMG intensity following both fatiguing tasks suggested that, under some conditions, the signal reflects mechanical factors rather than motor unit activation strategies. **PRACTICAL APPLICATIONS:** Practitioners may use wavelet analyses to obtain information about the effects of fatigue on the time and frequency components of EMG and MMG signals that are not available using individual parameters, such as amplitude and mean power frequency.

Background

Simultaneously recorded electromyographic (EMG) and mechanomyographic (MMG) signals provide complementary information about the electrical and mechanical activity of muscles during various types of exercise tasks (Madeleine et al., 2001; Malek & Coburn, 2012). Typically, the responses of single parameters (e.g., amplitude and mean power frequency) obtained from the EMG and MMG signals are analyzed to make inferences about motor unit activation strategies (Beck et al., 2004; Farina et al., 2004), however, they do not provide information about the timing of muscular events (von Tscharner, 2000; Beck et al., 2008). Therefore, von Tscharner (2000) and Beck et al. (2008) developed wavelet analyses that use filter banks of 11 nonlinearly scaled Cauchy wavelets that maintain the time, frequency, and intensity resolution across the frequency range of EMG (10-500 Hz) and MMG (5-100 Hz) signals, respectively. A recent study (Benitez et al., 2024) used the MMG wavelet analysis (Beck et al.,2008) to examine sex-related differences in MMG intensity responses during a sustained, isometric leg extension task anchored to the torque at MVIC. No study, however, has examined the wavelet-based EMG and MMG intensity responses following sustained tasks anchored to a rating of perceived exertion (RPE) versus torque.

Thus, this study used wavelet analyses to examine the effects of anchoring sustained, isometric forearm flexion tasks to RPE versus torque on the EMG and MMG intensity responses.

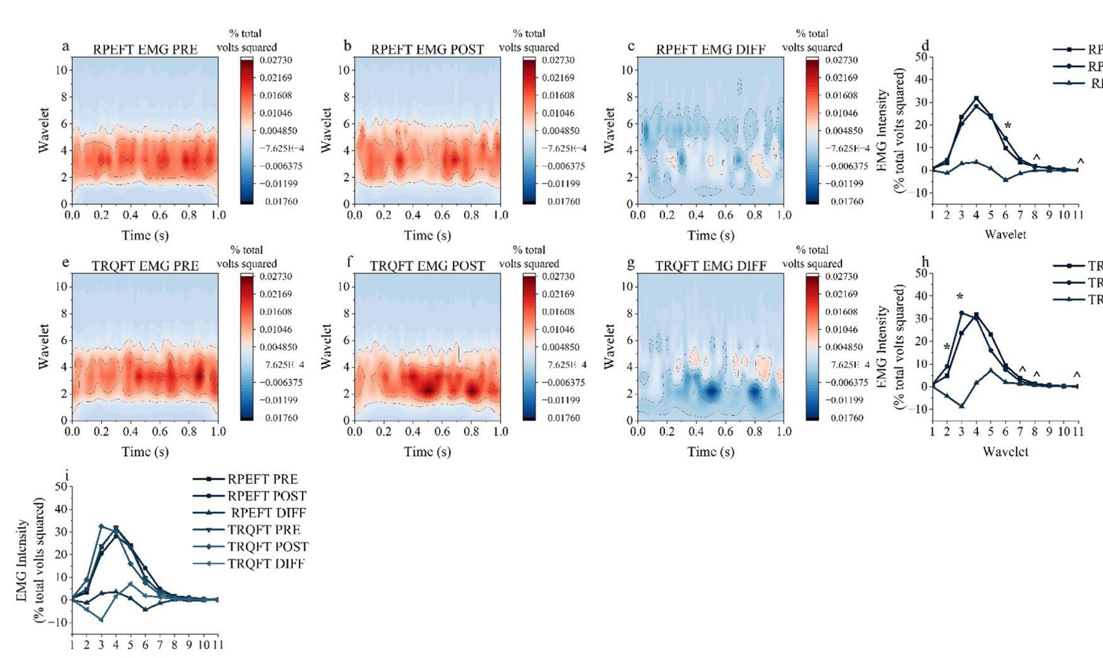

Fig 1 Electromyographic (EMG) intensity patterns for the normalized (% total intensity) composite pre-test (a, e) and post-test (b, f) maximal voluntary isometric contractions (MVICs) before and after sustained, isometric forearm flexion tasks anchored to a rating of perceived exertion of 4 (RPEFT) and the torque (TRQFT) that corresponded to a rating of perceived exertion of 4. EMG difference (pre-test MVIC – post-test MVIC) intensity patterns for the RPEFT (c) and TRQFT (g). EMG intensity spectra for the pre-test MVIC, post-test MVIC, and difference (pre-test MVIC – post-test MVIC) for the RPEFT (d), TRQFT (h), and the RPEFT and TRQFT combined (i)
PRE = pre-test MVIC, POST = post-test MVIC, DIFF = difference
*POST > PRE ($p \leq 0.0125$ to 0.025)
^PRE > POST ($p \leq 0.0125$ to 0.025)

Methods

Subjects: Twelve recreationally active men (mean ± SD: age = 20.9 ± 2.2 yrs.; height = 179.8 ± 5.3 cm; body mass = 80.2 ± 9.9 kg) free of any upper body pathologies participated in this study. The subjects visited the laboratory on two occasions for testing. **Procedures:** The subjects performed a standardized warm-up (4, 3 s submaximal [50-75% maximal effort] isometric forearm flexion muscle actions), 2, 3 s forearm flexion pre-test maximal voluntary isometric contractions (MVICs) before and after the sustained, isometric forearm flexion tasks anchored to a RPE of 4 (RPEFT) and the torque (TRQFT) that corresponded to a RPE of 4, and 2, 3 s post-test MVICs. **Signal Processing:** The EMG and MMG signals were recorded from the biceps brachii and processed using wavelet analyses that decomposed the signals onto sets of 11 nonlinearly scaled Cauchy wavelets that span the entire frequency range (EMG: approximately 7-395 Hz; MMG: approximately 2-120 Hz) of the signals. Total intensity and intensity spectra were obtained from the wavelet analyses. **Analyses:** Separate three-way [anchor (RPE vs torque) x time (pre-test MVIC vs post-test MVIC) x wavelet band (1-11)] repeated measures ANOVAs were used to analyze the EMG (% total volts squared) and MMG (% total squared meters per second squared) intensity data. A p-value ≤ 0.05 was considered statistically significant.

Results

For EMG intensity, there was a significant three-way interaction ($p < 0.001$) that was decomposed with two-way [anchor x time] repeated measures ANOVAs for each wavelet band. The pairwise comparisons for the significant ($p = 0.002$-0.042) interactions and main effects from the follow-up two-way ANOVAs indicated that EMG intensity from pre-test to post-test MVIC: (a) Increased at wavelet bands 2 and 3, decreased at wavelet bands 7-8 and 11, and remained unchanged at wavelet bands 1, 4-6, and 9-10 for the TRQFT; and (b) increased at wavelet band 6, decreased at wavelet bands 8 and 11, and remained unchanged at wavelet bands 1-5, 7, and 9-10 for the RPEFT.

For MMG intensity, there were no significant ($p = 0.220$-0.999) interactions or main effects for anchor and time, but there was a significant ($p < 0.001$) main effect for wavelet band. The Bonferroni-corrected pairwise comparisons for the significant ($p < 0.001$) follow-up one-way ANOVA indicated that MMG intensity (collapsed across anchor and time) at: (a) Wavelet band 3 was greater than wavelet bands 1-2, and 4-11; (b) wavelet band 4 was greater than wavelet bands 1-2, and 5-11; (c) wavelet band 5 was greater than wavelet bands 1, and 10-11; and (d) wavelet band 6 was greater than wavelet bands 1, and 10-11.

Conclusions

These findings suggested that EMG intensity decreased at high frequencies and increased at intermediate and low frequencies, respectively, following the RPEFT and TRQFT. The EMG intensity decreases at higher frequencies and increases at lower frequencies following both fatiguing tasks were likely related to peripheral fatigue mechanisms that affected motor unit action potential conduction velocity. Furthermore, the lack of change in MMG intensity following both fatiguing tasks suggested that, under some conditions, the signal reflects mechanical factors rather than motor unit activation strategies.

Practical Applications

Practitioners may use wavelet analyses to obtain information about the effects of fatigue on the time and frequency components of EMG and MMG signals that are not available using individual parameters, such as amplitude and mean power frequency.

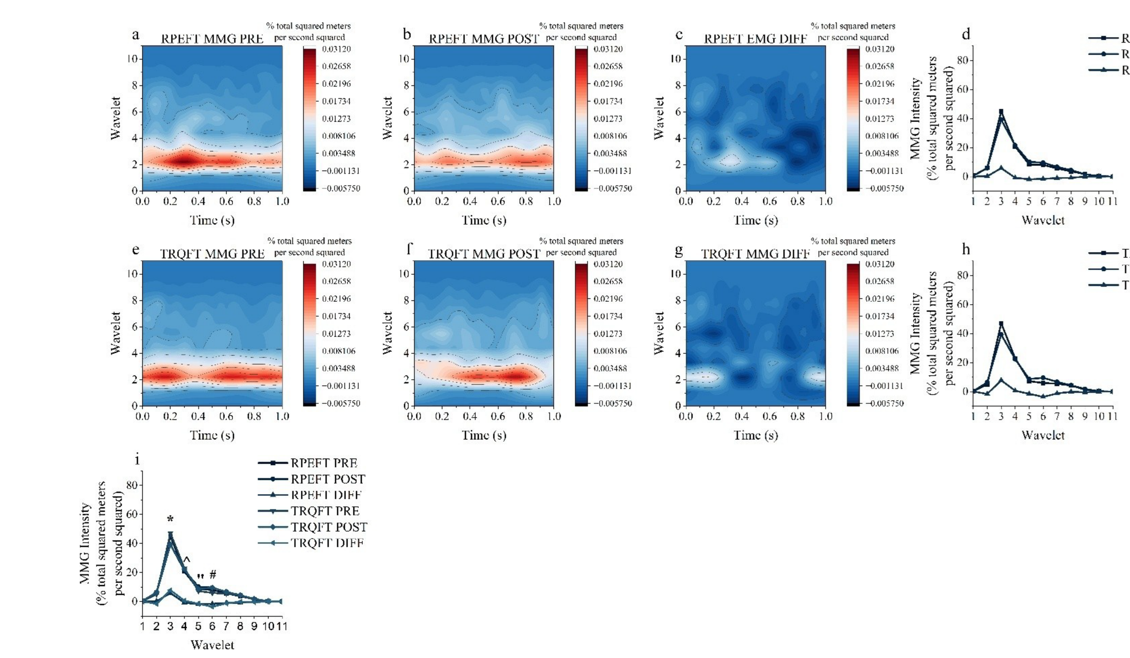

Fig 2 Mechanomyographic (MMG) intensity patterns for the normalized (% total intensity) composite pre-test (a, e) and post-test (b, f) maximal voluntary isometric contractions (MVICs) before and after sustained, isometric forearm flexion tasks anchored to a rating of perceived exertion of 4 (RPEFT) and the torque (TRQFT) that corresponded to a rating of perceived exertion of 4. MMG difference (pre-test MVIC – post-test MVIC) intensity patterns for the RPEFT (c) and TRQFT (g). MMG intensity spectra for the pre-test MVIC, post-test MVIC, and difference (pre-test MVIC – post-test MVIC) for the RPEFT (d), TRQFT (h), and the RPEFT and TRQFT combined (i)
PRE = pre-test MVIC, POST = post-test MVIC, DIFF = difference
*wavelet 3 > wavelets 1, 2, 4, 5, 6, 7, 8, 9, 10, and 11 ($p \leq 0.05$)
^wavelet 4 > wavelets 1, 2, 5, 6, 7, 8, 9, 10, and 11 ($p \leq 0.05$)
"wavelet 5 > wavelet 1, 10, and 11 ($p \leq 0.05$)
#wavelet 6 > wavelet 1, 10, and 11 ($p \leq 0.05$)

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