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Short communication

# Does the fast Fourier transformation window length affect the slope of an electromyogram's median frequency plot during a fatiguing isometric contraction?

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ABSTRACT

Reduced median frequencies (MDFs) are the hallmark of muscle fatigue in an electromyogram (EMG), the magnitude of which may be influenced by window lengths in fast Fourier transformation (FFT) algorithms used to compute power spectra. This study examined whether MDF reductions in fatigued muscles differed across varying FFT windows. EMG data were acquired from the gluteus maximus and semitendinosus muscles during a modified Biering–Sørensen test. Data were processed through varying FFT windows (0.1-, 0.5-, 1.0-, 2.0- and 5.0-s) and MDF slopes were compared with repeated measures analyses of variance. While FFT windows influenced variability in MDFs, the slopes did not differ across window lengths in either muscle group. When muscle fatigue is assessed via MDF slopes during submaximal isometric contractions, the FFT windows through which spectral characteristics are processed may have little bearing on results.



## 1. Introduction

Localized muscle fatigue affects postural stability, recovery from postural perturbations and slip propensity [1–3] and is marked by characteristic changes in the surface electromyogram (EMG). The EMG amplitude during isometric contractions typically increases whereas the frequency decreases [4]. A decrease in median frequencies (MDFs) from power spectral densities is the electrical hallmark of localized muscle fatigue.

Data processing procedures may influence analysis and interpretation of EMG spectral characteristics, however, and warrant attention. While the fast Fourier transformation (FFT) is the most common procedure for tracking time-dependent changes in frequencies [5], it has limitations. Specifically, power spectra are computed over user-defined epochs that affect time- and frequency resolutions of the signal [6]. Shorter epochs have better time resolution but poor frequency resolution, whereas longer epochs have better frequency resolution but poor time resolution. Studies investigating spinal and hip extensor muscle fatigue, for example, have used FFT windows ranging from approximately 0.25- to 2-s [7,8]. It is uncertain whether differences in the MDF slopes may have occurred because of their FFT window lengths. This study examined whether MDF slopes from fatiguing muscles differed across varying FFT windows.

## 2. Methods

### 2.1. Participants

Twenty volunteers (age = 22.9 ± 1.8 years, body mass index = 23.0 ± 2.9 kg/m$^2$) participated. All were healthy, active women without prior histories of disabling back pain or lower extremity injuries. Using a repeated measures design, 20 participants provided 80% statistical power ($1-\beta$) at $\alpha = 0.05$ to detect small effect sizes ($f = 0.10$) representing minimum meaningful differences between MDF slopes. All participants provided written informed consent. The Mayo Foundation Institutional Review Board approved the study.

### 2.2. Instrumentation

EMG data were acquired with Bagnoli™ DE-3.1 double-differential bipolar surface electrodes and a Bagnoli™-16 amplifier (Delsys® Inc., Boston, MA, USA) having a common mode rejection ratio of 92 dB at 60 Hz, input impedance > $10^{15}$ Ohms, estimated noise ≤ 1.2 μV and overall amplification of 100–10,000 (v/v). Electrodes were constructed of 10-mm × 1-mm silver bars, 1-cm apart, within preamplifiers having a gain of 10 (v/v). Data were acquired at 1000 Hz through a 16-bit NI-DAQ PCI-6220 analog-to-digital card (National Instruments Corporation, Austin, TX, USA). Signals were processed with EMGworks® 3.7.2.0 software.

### 2.3. Procedures

EMG data were acquired from the right gluteus maximus and semitendinosus muscles during a single, isometric modified Biering–Sørensen test [9]. The participant's skin was cleansed and electrodes were placed over the gluteus maximus at one-half the distance between the sacrum and greater trochanter and over the semitendinosus at one-half the distance between the gluteal fold and popliteal fossa, parallel with the muscles' respective lines of action. The reference

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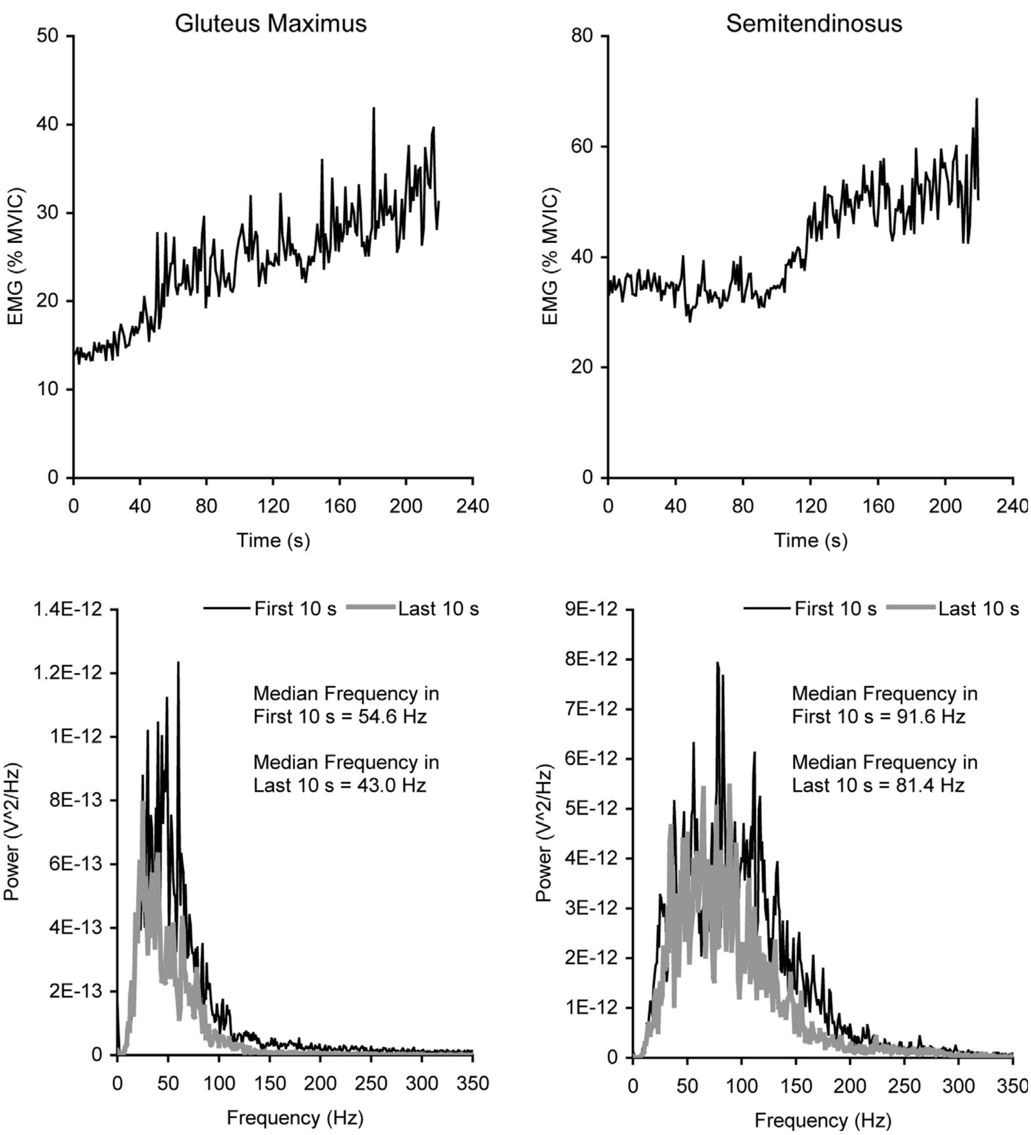


**Fig. 1.** Representative example of the EMG amplitudes (top row) and power spectra (bottom row) during the modified Biering–Sørensen test. The EMG amplitude increased in the gluteus maximus (left column) and semitendinosus (right column) as fatigue occurred throughout the test. Median frequencies decreased in both muscles. Window lengths for the fast Fourier transformations in this example were 1.0-s.

electrode was placed at the ipsilateral medial malleolus. During testing, participants laid prone with their trunk positioned off the head of an examination table. Their lower extremities were secured with straps. At initiation they folded their arms across their chests and held a neutral trunk position for as long as possible.

Prior to completing the test, EMG data were acquired during maximum voluntary isometric contractions (MVICs) to establish the amplitude to which subsequent data were normalized. MVICs were conducted in standardized positions. For the gluteus maximus the participant lay prone, flexed the knee to 90° and extended the hip. For the semitendinosus the participant lay prone and flexed the knee to 45°. Participants contracted maximally for five seconds against external resistance provided by a fixation strap.

### 2.4. Data processing

Recruitment amplitude was assessed by processing EMG signals with a root mean square algorithm using 500 ms windows and 50% overlap between windows, normalized to the MVIC (Fig. 1). MDFs were examined after processing raw data through five different window lengths: 0.1-, 0.5-, 1.0-, 2.0- and 5.0-s, respectively. Spectral analyses were conducted with FFT algorithms using Hanning windows without zero padding. Fatigue was quantified by the slope of a linear regression through the MDFs as a function of time from initiation to termination of the test (Fig. 2), which is a standard method for evaluating fatigue-related EMG changes [10].

**Table 1**
Descriptive statistics. Data represent calculated slopes from linear regressions of the median frequency time series obtained when power spectra were processed via fast Fourier transformation (FFT) algorithms with varying window lengths.

| FFT window length | Mean slope (Hz/s) | SD |
|---|---|---|
| Gluteus maximus | | |
| 0.1-s window | −0.079 | 0.072 |
| 0.5-s window | −0.077 | 0.072 |
| 1.0-s window | −0.077 | 0.072 |
| 2.0-s window | −0.076 | 0.070 |
| 5.0-s window | −0.075 | 0.067 |
| Semitendinosus | | |
| 0.1-s window | −0.171 | 0.135 |
| 0.5-s window | −0.174 | 0.137 |
| 1.0-s window | −0.172 | 0.134 |
| 2.0-s window | −0.168 | 0.128 |
| 5.0-s window | −0.166 | 0.127 |

*Note*: Based on repeated measures analyses of variance, differences in the mean slopes between the five conditions were not statistically significant ($F_{4,76} = 0.831$, $p = 0.423$ and $F_{4,76} = 2.066$, $p = 0.158$ in the gluteus maximus and semitendinosus, respectively).