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# Spike shape analysis for the surface and needle electromyographic interference pattern

Lara A. Green[a,*], Anita Christie[b], David A. Gabriel[a]

[a] Faculty of Applied Health Sciences, Brock University, St. Catharines, ON L2S 3A1 Canada
[b] Department of Human Physiology, University of Oregon, Eugene, OR 97403, United States

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ABSTRACT

*Introduction:* The ability of surface and needle electromyographic (EMG) spike shape measures to match changes in motor unit recruitment, firing rate, and synchronization during force gradation, were compared. The purpose of the study was to determine the force level at which the surface EMG spike shape measures no longer parallel their indwelling analogues. Secondarily, the impact of the noise rejection criterion on the sensitivity of the spike shape measures was examined.
*Methods:* Maximal isometric elbow flexion ramp contractions were performed while recording surface and needle EMG from the biceps brachii. Spike shape measures were calculated in 500 ms epochs over the duration of the ramp contraction. The spike threshold for needle EMG spike detection was varied to examine the effect of the algorithm's selectivity. The pattern of change across force levels between surface and needle EMG measures was compared.
*Results:* Spike detection resulted in the same pattern of change for both surface and needle amplitude measures over the gradation of force. Frequency measures and mean number of peaks per spike (MNPPS) were affected by electrode-source distance and spike threshold. Surface and needle frequency measures changed in parallel to 50% MVC while the MNPPS plateaued at 50–55% MVC.
*Discussion:* Spike shape analysis of surface EMG can track changes in the interference pattern produced by recruitment and rate-coding up to 50% MVC.

## 1. Introduction

Surface electromyography (sEMG) is a non-invasive way to assess global muscle activity, but is insufficient for recording motor unit activity patterns. Cancellation and alteration of the signal as it is recorded from the muscle through fascia, fat, and skin are some of the main factors that limit the physiological interpretation of the sEMG signal [1,2]. Indwelling EMG, recorded through wires or needles inserted directly into the muscle, allows for the identification of individual motor units. However, indwelling recordings are more invasive, technically demanding, and have a limited pick-up volume [3,4]. As a result, the needle must be re-inserted in different locations of the muscle to obtain a sufficient number of motor units to collect a representative sample [5,6].

Spike shape analysis of the sEMG signal has the advantage of identifying motor unit activity patterns from the non-invasive sEMG signal which comprises a larger pick-up volume compared to the analysis of indwelling recordings [7]. The analysis technique detects changes in recruitment, firing rate, and synchronization through pattern classification of alterations in five discrete measures extracted from the sEMG interference pattern [8]. The five measures are mean spike amplitude (MSA), mean spike slope (MSS), mean spike frequency (MSF), mean spike duration (MSD), and the mean number of peaks per spike (MNPPS). Experimental and modelling studies have shown that these five measures change in a systematic way that is unique for each of the three different motor unit activity patterns (recruitment, firing rate, and synchronization) [9–11]. It is important to emphasise that spike shape analysis does not identify individual motor units, or calculate their discharge rate and recruitment. Rather, changes in the shape of individual spikes of the interference pattern have been used to successfully identify changes in motor unit activity *patterns*

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*Abbreviations:* ANOVA, analysis of variance; EMG, electromyography; MDF, median power frequency; MNPPS, mean number of peaks per spike; MPF, mean power frequency; MSA, mean spike amplitude; MSD, mean spike duration; MSF, mean spike frequency; MSS, mean spike slope; MVC, maximal voluntary contraction; RMS, root mean square; sEMG, surface electromyography.

* Corresponding author at: Faculty of Applied Health Sciences, Brock University, 1812 Sir Isaac Brock Way, St. Catharines, ON L2S 3A1, Canada.
*E-mail addresses:* lara.green@brocku.ca (L.A. Green), adc1@uoregon.edu (A. Christie), dgabriel@brocku.ca (D.A. Gabriel).

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with the gradation in force [9,12] and have previously been used to discriminate between healthy controls versus a patient population [10,13]. In this respect, spike shape analysis is consistent with the call for a non-invasive approach to the detection of neuromuscular disorders [14], however, further experimental validation is necessary to define the limitations of surface EMG spike shape measures.

Our previous modelling and simulation work has demonstrated that the ability of spike shape measures to detect changes in the sEMG interference pattern (sensitivity) during the gradation of force, is affected by both inter-electrode distance and electrode-source distance [11]. With larger inter-electrode and electrode-source distances, the spike shape measures plateau earlier in the force gradation process (i.e., at lower percentages of maximal voluntary contraction, % MVC). Experimentally, electrode-source distance effects may be evaluated by comparing indwelling and surface EMG recordings, which also incorporates differences in inter-electrode distance. Since indwelling needle electrodes have the smallest electrode-source and inter-electrode distances and presumably the greatest sensitivity to changes in muscle activity [15], the primary purpose of this paper was to experimentally determine the force level (%MVC) at which the surface EMG spike shape measures no longer parallel their indwelling analogues (i.e., become insensitive).

A secondary purpose was to determine the impact of the noise rejection criterion on the sensitivity of the spike shape measures to changes in indwelling EMG interference patterns during the force gradation process. To date, the detection of individual spikes in the surface EMG interference pattern is based on both upward and downward deflections of a spike exceeding the 95% confidence interval for baseline noise [9]. The threshold level used to determine the number of turns and turns amplitude for the indwelling EMG signal has been shown to impact the ability to detect differences between groups in underlying motor unit activity patterns [16], and the EMG-to-force relationship during step isometric contractions from 0 to 100% MVC [17]. It is important therefore to determine the impact of the noise rejection criterion for indwelling EMG spike shape measures.

To this end, spike shape measures from biceps brachii needle and surface EMG interference patterns were calculated over a 0–100% MVC isometric ramp contraction. The biceps brachii was selected for two reasons. First, motor unit recruitment and rate-coding during the gradation of force are well-known for this muscle [12,18,19]. Second, there are only two studies to date that have quantified the same measures from simultaneous recordings of surface and indwelling EMG: Preece et al. [20] compared surface and indwelling EMG of the tibialis anterior, but only in 100% MVC contractions, while Philipson and Larsson [17] studied step isometric contractions of the biceps brachii in 20% MVC increments up to 100% MVC. Thus, only other study available for a direct comparison is based on the biceps brachii.

## 2. Materials and methods

Eleven participants (8 males, 3 females) between the ages of 18 and 45 participated in the present study. Participants reviewed and signed the informed consent document, which detailed all procedures and included ethical approval from the Human Ethics Review Board at the University of Massachusetts, Amherst. Testing for each participant was completed within a single session.

### 2.1. Experimental set up

Participants were seated in a chair for testing and rested their right elbow on a platform directly in front of them so that the shoulder and elbow were flexed to approximately 90°. The wrist was in a neutral position with a custom-moulded fiberglass splint on the anterior side of the right wrist and forearm. Isometric elbow flexion was performed by pulling against the strain gauge force transducer (Interface Model MB-250, Scottsdale, AZ) attached to the fiberglass splint. The force signal was amplified and low-pass filtered at 10 Hz (DataQ PM-100, DataQ Instruments, Akron, OH), then sampled at 50 Hz using a 16-bit A/D converter (DT-322, Data Translation, Marlboro, MA). The force signals were also sent to a second computer to be sampled at 25,600 Hz using another 16-bit A/D converter (NI-DAQ PCI-6251, National Instruments, Austin, TX) and stored offline for analysis.

### 2.2. Electromyography

Electromyography was recorded from the short head of the biceps brachii. Surface EMG was recorded in a bipolar electrode configuration. Ag/AgCl electrodes (3-mm diameter) were placed 2-cm apart on the belly of the biceps. The sEMG signals were amplified and band-pass filtered at 10–2000 Hz using a Dantec Counterpoint Electromyograph (Dantec Electronik Medicinsk, Sklovlunde, Denmark). The sEMG signals were initially sampled at 25,600 Hz and later downsampled to 2560 Hz for analysis using MATLAB (Mathworks Inc., Natick, MA).

Needle EMG was recorded using a quadrifilar needle consisting of a 25-gauge stainless steel cannula housing 4 platinum-iridium wires 50 μm in diameter. This provided three channels of differential recordings. The needle EMG was amplified as required and bandpass filtered at 1–10 kHz using a Dantec Counterpoint Electromyograph (Dantec Electronik Medicinsk, Sklovlunde, Denmark). The needle signals were initially sampled at 25,600 Hz and later upsampled to 51,200 Hz to maximize resolution for motor unit identification in previous analyses [12] using MATLAB (Mathworks Inc., Natick, MA, USA).

### 2.3. Protocol

The testing session began with three "hard and fast" maximal voluntary contractions lasting 5-s each to determine each participant's maximal force. There were 2 min of rest between each contraction. Using the highest value of the three contractions a force trajectory was presented to the participants as a ramp to maximal force at a rate of 10% MVC/s. Participants completed 10 ramp contractions to maximum force with three minutes rest between each contraction.

### 2.4. Data reduction

A total of 10 trials were selected to be used for analysis. One ramp contraction was selected per participant with the exception of one participant for which no contraction was usable. Selection criteria for the contractions included: reaching 100% MVC force level, minimal EMG baselines, and the presence of an needle EMG interference pattern. Once the 10 trials had been selected, one needle EMG channel was selected from the three channels based on interference pattern quality. While the channel was deemed excellent for interference pattern analysis of the particular trial, it had been unusable for motor unit identification in a previous study [12].

The onset of each contraction was the point at which the sEMG activity exceeded a noise threshold, which was set at the baseline sEMG activity plus 1.96 times the standard deviation. Each trial was then visually inspected for accuracy of sEMG onset. Surface and needle EMG data were then assessed using 22 epochs, 500 ms in duration, starting from the onset of the contraction. For each 500 ms epoch traditional and spike shape measures were calculated for both surface and needle EMG. Traditional measures included