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Effects of monopolar and bipolar electrode configurations on surface EMG spike analysis

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ABSTRACT

This study compared the effects of monopolar and bipolar electrode configurations on interference pattern analysis of the surface electromyographic (sEMG). Twenty-four college-aged male participants performed isometric actions of the elbow flexors at 40, 60, 80, and 100 percent of maximal voluntary contraction (MVC). Separate (Ag/AgCl) electrodes were used for both configurations. There were five measures associated with "spike shape" analysis: mean spike amplitude (MSA), mean spike frequency (MSF), mean spike slope (MSS), mean spike duration (MSD) and mean number of peaks per spike (MNPPS). A load-cell and wrist-cuff assembly was used to record isometric elbow flexion forces. Both electrode configurations resulted in the same trends force changes in spike shape measures across force levels: there was a linear increase in MSA, MSS, and a quadratic decrease in MSF and the MNPPS (p's < 0.05). The MSD underwent a quadratic increase ($p < 0.05$). The spike shape measures had greater mean magnitudes and exhibited greater rates of changes across force levels for the monopolar electrode configuration (p's < 0.05). The monopolar electrode configuration was therefore more sensitive to changes in muscle activity with increases in isometric force. This is an important consideration because the rate at which muscle electrical activity develops into a full interference pattern is an important qualitative and quantitative diagnostic measure.

1. Introduction

Alterations in the recruitment and firing rate of motor units (MU) can change the amplitude and frequency content of the surface electromyographic (sEMG) signal in similar ways, so it is difficult to distinguish between the two [1]. Increased firing rates and synchronization also have a similar impact on the amplitude and frequency content of the sEMG signal [1,2]. Spike analysis was developed to detect changes in the sEMG signal associated with the different patterns of muscle activation [3]. Spike analysis is based on the observation that the superposition between motor unit action potentials (MUAPs) results in an interference pattern that is quantitatively different for each type of MU activity pattern. This has been observed for both indwelling [4,5,9] and surface [6–8,10] recordings.

Five measures that describe the average shape of individual spikes within the interference pattern were synthesized from the literature [4–8]. These five measures are: mean spike amplitude (MSA), mean spike frequency (MSF), mean spike slope (MSS), mean spike duration (MSD) and mean number of peaks per spike (MSPPS). Graphically, a spike is composed of a single upward and downward deflection that is greater than the 95 percent confidence interval for baseline activity (Fig. 1). A peak is defined as a pair of upward and downward deflections within a spike that do not together constitute a discrete spike. A pattern classification table was then constructed based on observations in the literature for how each measure changes according to alterations in MU activity patterns [4–8]. Note, that the pattern of change in the five measures is distinctly different for each MU activity pattern (Table 1). It is also important to emphasize that Table 1 does not imply that the three motor unit activity patterns occur in isolation of each other. Table 1 takes advantage of the observation that different motor unit activity patterns "dominate" the force gradation process over different intervals of percent MVC when contracting the muscle from 0 to 100% MVC.

The type of motor unit activity pattern that dominates the force gradation process over a particular interval depends on the recruitment range of the muscle. For example, the first dorsal interosseus (FDI) recruits MUs up to approximately 50% MVC while the biceps brachii (BB) recruits MUs up to approximately 80% MVC. In both cases, the lower threshold MUs start rate-coding while higher threshold MUs are progressively recruited but MU recruitment still dominates the force gradation process until the end of the recruitment range: 50% MVC for the FDI and 80% MVC for the BB. At higher

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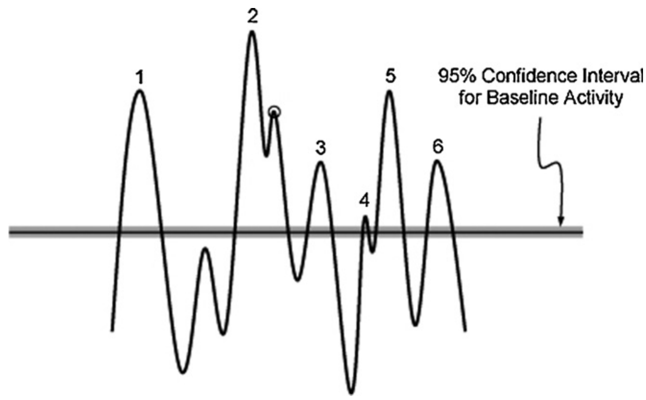

Fig. 1. Surface electromyographic (sEMG) interference pattern to illustrate the difference between a spike and a peak. A spike is composed of a single upward and downward deflection that are greater than the 95 percent confidence interval for baseline activity (shaded area). There are six spikes and spike number two has one peak (circled).

levels of force where MU recruitment is diminished, rate coding then begins to play a greater role [11–13]. The same holds true for synchronization. Synchronization is greater at higher levels of force where recruitment is greatly reduced [14].

However, the situation for neuromuscular patients is very different. Disruptions to the neuromuscular system result in distinct adaptations in motor unit activity patterns to compensate for motor unit (neuropathic) versus muscle fiber (myopathic) loss. Muscle fiber loss decreases the twitch force for each MU so myopathic patients must rely to a greater degree on enhanced recruitment earlier in the force gradation process. In contrast, neuropathic patients relay more heavily upon synchronizations to coordinate the remaining MUs in the force gradation process [15–19].

The spike shape measures have been demonstrated to correlate highly with traditional time and frequency analyses [20], and exhibit deterministic changes with increases in force [3]. Spike shape analysis has recently shown promise in the clinical domain. Calder et al. [10] demonstrated that spike shape analysis was able to discriminate between normal controls, individuals with non-specific arm pain, and those at risk for non-specific arm pain. The three groups differed with respect to the rates of change in specific sEMG spike shape measures with increases in contraction force from 20 to 80% of maximum. Further, the changes in the sEMG interference pattern were consistent with the predictions for myopathic disorders. These findings were supported by an earlier quantitative indwelling EMG study on the same participants [9].

There are a number of technical factors related to recording the sEMG signal that can affect the sensitivity and specificity to the different motor unit behaviors, and spike shape analysis is not immune from these considerations. The most obvious and relevant of these is the electrode configuration. Action potential shape is altered as it propagates along the muscle fibers towards the electrode, and then it is spatially filtered by the bipolar detection system [21–23]. The differential recording process decreases both the amplitude and rate of change in the signal, as well as introduces additional phases into the recorded potentials. The magnitude of these effects also depends on the interelectrode distance [24]. However, a bipolar electrode configuration has the advantage of reducing volume conducted potentials because the differential amplifier suppresses common signal components from far away bioelectric sources, e.g. deep MUs. This is not the case for a monopolar electrode configuration which is more susceptible to common mode signals which decrease the signal-to-noise ratio and make it more difficult to detect changes in muscle activity [25–29].

The purpose of this paper is therefore to determine the impact of monopolar versus bipolar recordings on the sensitivity to change in sEMG spike shape measures across force levels. This question is important because clinicians use "absolute" EMG amplitude and rates of change in EMG measures to categorize neuromuscular patients. It is hypothesized the measures obtained by monopolar recording will exhibit greater rates of change across force levels. This was assessed using an analysis of variance with an orthogonal polynomial breakdown for means across force levels. If for example, MSA exhibits a significant linear increase for both monopolar and bipolar electrode configurations, the interaction term can test if linear trend component is significantly different for the two electrode configurations.

Table 1
Predicted changes in the surface electromyographic (sEMG) spike parameters: mean spike amplitude (MSA), mean spike frequency (MSF), mean spike duration (MSD), mean spike slope (MSS), and mean number of peaks per spike (MNPPS) for alterations in MU recruitment.

Motor unit firing pattern	Five sEMG spike measures				
	MSA	MSF	MSS	MSD	MNPPS
Increased firing frequency	-	↑	-	↓	-
Increased recruitment	↑	↑	↑	↓	↑
Increased synchronization	↑	↓	↑	↑	↓

Table 2
The means (M) and standard deviations (SD) for subject's (N = 24) physical characteristics.

Measures	$M \pm$ SD
Age (years)	24 ± 3.4
Height (cm)	174 ± 10
Mass (kg)	89 ± 12
Skin-fold (mm)	7 ± 4
Forearm length (mm)	29 ± 3

2. Methods

2.1. Participants

Twenty-four male participants reported twice to the laboratory. The first session was to familiarize participants with the experimental set-up and the demands of the task. Each participant then read and signed the informed consent document accordance with the university research ethics guidelines. All subjects were free of upper body disabilities and were all right-handed. Their physical characteristics are presented in Table 2.

2.2. Experimental design

Height, weight, and skin-fold thickness of the biceps brachii (BB) at the location of the surface electrode were obtained at the beginning of the second session. Participants performed step isometric contractions because they allow for a longer data analysis window and therefore less variability in the calculated sEMG measures [30]. The selected percentages of maximal voluntary contraction (40, 60, 80, and 100 percent MVC) have already been demonstrated to result in significant changes in the time and frequency measures of sEMG activity consistent with numerous other studies [3].

Maximal isometric strength of the elbow flexors was first obtained by the following procedures. There were three 5-s contractions with a 3-min rest interval. A target was presented as a horizontal line on an oscilloscope (Hitachi, VC-6525) that was placed in front of the subject. The target was a load cell (JR3 Inc., Woodland, CA) voltage that represented 110 percent of the mean peak value of the previous three contractions. If participants were able to reach the target line during the fourth trial, the MVC value was updated. The mean of the 3 trials was used to identify the mean