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EMGLAB: An interactive EMG decomposition program

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Abstract

This paper describes an interactive computer program for decomposing EMG signals into their component motor-unit potential (MUP) trains and for averaging MUP waveforms. The program is able to handle single- or multi-channel signals recorded by needle or fine-wire electrodes during low and moderate levels of muscular contraction. It includes advanced algorithms for template matching, resolving superimpositions, and waveform averaging, as well as a convenient user interface for manually editing and verifying the results. The program also provides the ability to inspect the discharges of individual motor units more closely by subtracting out interfering activity from other MUP trains. Decomposition accuracy was assessed by cross-checking pairs of signals recorded by nearby electrodes during the same contraction. The results show that 100% accuracy can be achieved for MUPs with peak-to-peak amplitudes greater than 2.5 times the rms signal amplitude. Examples are presented to show how decomposition can be used to investigate motor-unit recruitment and discharge behavior, to study motor-unit architecture, and to detect action potential blocking in doubly innervated muscle fibers.

Keywords: EMG; Decomposition; Motor-unit potential; Spike train; Muscle architecture; Double innervation; Common drive

1. Introduction

The electromyographic (EMG) signal recorded by a needle or fine-wire electrode is made up of trains of motor-unit potentials (MUPs), and thus provides a potentially rich source of information about motoneuron discharge behavior and motor-unit (MU) organization (Basmajian and De Luca, 1985). To obtain this information, it is necessary to sort out the activity of multiple simultaneously active MUs, a process known as decomposition. Before the advent of computers, simple EMG signals were sometimes decomposed manually by identifying distinctively shaped MUPs on traces photographed at high-sweep speed (Desmedt, 1983). Computer methods have now been developed to mechanize various aspects of this process (Lefever and De Luca, 1982; McGill et al., 1985; Haas and Meyer, 1989; De Luca, 1993; Stashuk, 2001; Zennaro et al., 2003). However, some degree of human oversight is still necessary to decompose moderately complex EMG signals completely and with consistent reliability.

The goal of full decomposition is to detect all the MUs that are active in a signal and to identify every one of their discharges. In reality, most EMG signals contain a continuum of activity, ranging from large MUPs that can be clearly distinguished to small ones that blend into and help constitute the background noise. Thus, the number of MUP trains that can be fully identified depends to some extent on the amount of effort one is willing to expend. Most EMG signals also contain frequent superimpositions. These occur when two or more MUs discharge at nearly the same time and their MUPs overlap. Full decomposition requires the ability to resolve such superimpositions.

Full decomposition is important in the study of MU discharge behavior. While it is possible to obtain complete discharge patterns for one or two MUs using single-unit recording techniques (Bigland and Lippold, 1954; Datta and Stephens, 1990), and to estimate certain global discharge

Abbreviations: EMG, electromyogram; IDI, inter-discharge interval; IFR, instantaneous firing rate; MN, motoneuron; MU, motor unit; MUP, motor-unit potential; MVC, maximum voluntary contraction

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parameters, such as mean firing rate, from incomplete discharge patterns (Stashuk and Qu, 1996), full decomposition of multi-unit signals provides a way to obtain complete discharge patterns of multiple, simultaneously active MUs. This information in essential in studies of MU coordination (Andreassen and Rosenfalck, 1980; De Luca and Erim, 1994; Adam and De Luca, 2003) and short-term synchronization (Datta and Stephens, 1990; Nordstrom et al., 1992).

Another application in which full decomposition is important is the study of muscle architecture (Lateva and McGill, 2001). The location of a MU's motor endplate and muscle/tendon junction can be estimated from the latencies of the onset and terminal wave of the MUP waveform. These features tend to be quite small, and signal averaging is needed to detect them reliably. Full decomposition makes it possible to average the MUP waveforms of multiple MUs from a single signal. Full decomposition is also useful for studying discharge irregularities such as those associated with doubly innervated muscle fibers (Lateva et al., 2002). Full decomposition makes it possible to detect such irregularities even in busy signals by subtracting out the activity of the other MUPs that are not of interest.

This paper describes an interactive decomposition program called EMGLAB that we developed and have used successfully to decompose hundreds of EMG signals from various muscles of the hand, arm, leg, and back. The program provides the capability to inspect, fully decompose, and obtain high-signal-to-noise-ratio MUP waveforms from moderately complex single- and multi-channel EMG signals recorded using conventional needle or fine-wire electrodes. The program also facilitates the identification and analysis of variable MUP components, such as potentials from doubly innervated muscle fibers. The program includes a convenient graphical interface in addition to advanced template-matching algorithms. It is written in Matlab (The Mathworks, Natick, MA), which facilitates the exportation of MUP waveforms and discharge patterns for further analysis. The use of the program is illustrated by examples from studies of MU behavior and architecture.

2. Methods

The section describes the main features of EMGLAB. The signals shown in the figures were recorded from normal subjects. The recordings were approved by the Stanford University Committee on the Use of Human Subjects in Research, and each subject gave informed consent.

2.1. EMG recordings

Although EMGLAB can be used to analyze signals recorded by various types of electrodes, all the signals reported here were recorded using monopolar needle or fine-wire electrodes. Monopolar electrodes are useful in both behavioral and architectural studies because they sample a broad muscle cross-section and because they are able to record MUP components with low-spatial gradients, including the onset, and terminal wave. The signals were referred to a surface electrode placed over the muscle or one of its tendons. A wide amplifier bandwidth (5 Hz–5 kHz) was used to capture low-frequency MUP components. The signals were sampled at a rate of 10 kHz. Contractions were kept below 30–40% of maximum voluntary contraction (MVC) to ensure signal decomposability. Signal quality and complexity were monitored at recording time by listening for a crisp sound and by looking for an appropriate balance between sharp spikes and flat baseline after 1 kHz high-pass filtering.

The fine-wire signals were recorded using 50 μm-diameter stainless steel wires insulated except for 1 mm at the tip. To increase the likelihood of obtaining signals of acceptable quality, the wires were inserted in pairs with their recording surfaces offset by 2 mm. Recordings were made either from both wires individually or from the single wire that gave the better signal quality. Although fine-wire electrodes cannot be repositioned as needle electrodes can, they have the advantage that—after a few initial contractions during which they "work themselves in," and as long as the joint configuration remains relatively unchanged—they tend to maintain the same position within the muscle, thus making it possible to record from the same set of MUs throughout the course of a long experiment involving multiple contractions.

2.2. Decomposition overview

EMGLAB provides a convenient graphical interface as well as a number of automatic procedures for decomposing and inspecting EMG signals. The computer screen is divided into four panels (see Fig. 1) that show a segment of the EMG signal, the templates of the identified MU spikes, the discharge patterns of the identified MUP trains, and a close-up of the signal for resolving superimpositions. Manual decomposition functions can be performed using the graphical interface. For example, new templates can be formed by dragging spikes from the signal panel to the template panel, and spikes in the signal panel can be identified either by dragging specific templates over them or by shift-clicking on them to have the program determine the best-fitting template. Graphical commands are also available for undoing identifications; deleting, reordering, and merging templates; deleting points from the discharge panel; and selecting and adjusting the template configuration in the close-up panel.

The decomposition process typically proceeds in the following way. First, the program reads in the initial 2 s of the EMG signal and automatically creates templates for all the spikes that occur at least three times with a high-degree of similarity. Then, the program tries to automatically classify the remaining spikes in this 2-s interval using template matching. Depending on the complexity of the signal, these automatic procedures may or may not achieve a full decomposition. The signal is then inspected manually to complete the decomposition and verify the results. This may require sev-