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High-density surface electromyography provides reliable estimates of motor unit behavior

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HIGHLIGHTS

- The reliability of high-density surface electromyography (HDEMG) for the measurement and estimation of motor unit properties was assessed for the first time.
- HDEMG-derived measures of motor unit behavior provide reliable results across and within sessions.
- Motor unit decomposition is accurate enough to detect changes in motor unit behavior over a wide range of force levels (from 10% to 70% of maximum force).

ABSTRACT

Objective: To assess the intra- and inter-session reliability of estimates of motor unit behavior and muscle fiber properties derived from high-density surface electromyography (HDEMG).
Methods: Ten healthy subjects performed submaximal isometric knee extensions during three recording sessions (separate days) at 10%, 30%, 50% and 70% of their maximum voluntary effort. The discharge timings of motor units of the vastus lateralis and medialis muscles were automatically identified from HDEMG by a decomposition algorithm. We characterized the number of detected motor units, their discharge rates, the coefficient of variation of their inter-spike intervals (CoV_{isi}), the action potential conduction velocity and peak-to-peak amplitude. Reliability was assessed for each motor unit characteristics by intra-class correlation coefficient (ICC). Additionally, a pulse-to-noise ratio (PNR) was calculated, to verify the accuracy of the decomposition.
Results: Good to excellent reliability within and between sessions was found for all motor unit characteristics at all force levels (ICCs > 0.8), with the exception of CoV_{isi} that presented poor reliability (ICC < 0.6). PNR was high and similar for both muscles with values ranging between 45.1 and 47.6 dB (accuracy > 95%).
Conclusion: Motor unit features can be assessed non-invasively and reliably within and across sessions over a wide range of force levels.
Significance: These results suggest that it is possible to characterize motor units in longitudinal intervention studies.

1. Introduction

Motor neurons are the common final pathway to muscle (Sherrington, 1925) and analysis of their behavior provides a direct indication of changes occurring within the central nervous system (CNS). The assessment of the firing patterns of motor units (MUs) provides the opportunity to evaluate the mechanisms of muscle

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control utilized by the CNS (De Luca and Erim, 1994). Classically, MU activities have been recorded from human muscles in vivo via intramuscular electromyography (EMG) (e.g., concentric needle or fine wire electrodes). However, this is an invasive procedure and, because of the high selectivity, it allows the concurrent detection of only a few MUs (Merletti et al., 2008), usually during low force isometric contractions. As an alternative, high-density surface EMG (HDEMG) techniques have been developed to study MU behavior non-invasively. Using these techniques, the number of detectable MUs has increased (Holobar et al., 2009) with respect to invasive methods, a wider range of force levels can be analyzed, and peripheral properties of the MUs, such as muscle fiber conduction velocity, can be assessed together with the MU behavior (Merletti et al., 2008; Holobar et al., 2009).

The application of HDEMG to evaluate MU properties may be especially relevant for monitoring changes in muscle properties and neuromuscular control following an intervention, such as training. Indeed, the relatively large MU sample identified may be representative enough to provide reliable information on the properties of the MU pool under multiple measurement sessions. For this purpose, there is the need to test whether MU decomposition methods are accurate (e.g., correct detection of MU action potentials and quantification of errors) and reliable (e.g., provide comparable results in different measurement sessions). Despite the fact that several efforts have been made to enhance the accuracy of HDEMG in detecting MU activity (Kleine et al., 2007; Farina et al., 2008; Holobar et al., 2009, 2014; De Luca and Hostage, 2010), the reliability of the information extracted from these methods remains largely unknown. Relatively few studies have attempted to monitor changes in MU behavior over long time periods, as would be necessary for characterizing neuromuscular adaptations to training. While some authors have reported training-related changes in MUs characteristics such as recruitment thresholds (Duchateau et al., 2006), discharge rate (Vila-Cha et al., 2010), conduction velocity (Hedayatpour et al., 2009) and MUs synchronization (Semmler, 2002), the relevance of these changes is difficult to fully assess because of the unknown measurement variability.

In this study we assessed the intra and inter-session reliability of MU properties estimated from the decomposition of HDEMG. Specifically, we investigated features of MU behavior (number of detected MUs, discharge rate, discharge rate variability) and muscle fiber properties (conduction velocity, amplitude of motor unit action potentials). Additionally, the accuracy of the decomposed set of MU discharge timings was determined.

2. Methods

2.1. Participants

Ten healthy and physically active men (mean (SD) age: 27 (4) years, height: 180 (8) cm, mass: 78 (10) kg) participated in the study. All subjects were right leg dominant (determined by asking which leg they would use to naturally kick a ball). Exclusion criteria included any neuromuscular disorders, current or previous history of knee pain and age < 18 or >35 years. Participants were asked to avoid any strenuous activity 24 h prior to the measurements. The ethics committee of the Universitaetsmedizin Goettingen approved the study (approval number 24/1/14), according to the declaration of Helsinki. All participants gave written, informed consent.

2.2. Experimental protocol

Participants attended the laboratory on three occasions. The three sessions were 7 days apart and were conducted at the same time of the day for each subject. In each experimental session, subjects were seated comfortably on an isokinetic dynamometer (Biodex System 3, Biodex Medical Systems Inc., Shirley, NY, USA) in an adjustable chair with their trunk reclined to 15° and their hip and distal thigh firmly strapped to the chair. The rotational axis of the dynamometer was aligned with the right lateral femoral epicondyle while the lower leg was secured to the dynamometer lever arm above the lateral malleolus. Maximal and submaximal isometric knee extensions were exerted with the knee flexed by 90°. Subjects performed two maximum voluntary contractions (MVC) of knee extension each over a period of 5 s. These trials were separated by 2 min of rest. The highest MVC value was used as a reference for the definition of the submaximal force levels. In each of the three experimental sessions, the submaximal forces were expressed as a percent of the MVC measured during the same session. Five minutes of rest were provided after the MVC measurement. Then, following a few familiarization trials at low force levels, subjects performed submaximal isometric knee extension contractions at 10%, 30%, 50% and 70% MVC in a randomized order. The contractions at 10–30% were sustained for 20 s, while the contractions at 50% and 70% MVC lasted 15 and 10 s respectively. In each trial, the subjects received visual feedback of their knee extension force, which was displayed as a trapezoid (5 s ramps with hold-phase durations as specified above). Each contraction level was performed 3 times per session and 2, 3, 4 and 5 min of rest were allowed after the 10%, 30%, 50% and 70% MVC contractions respectively. To evaluate whether the protocol induced fatigue, one MVC was performed at the end of each testing session.

2.3. Data acquisition

Surface EMG was recorded in monopolar derivation with two-dimensional (2D) adhesive grids (SPES Medica, Salerno, Italy) of 13 × 5 equally spaced electrodes (each of 1 mm diameter, with an inter-electrode distance of 8 mm) (Fig. 1). First, the skin of the participants was marked according to the Atlas of muscle

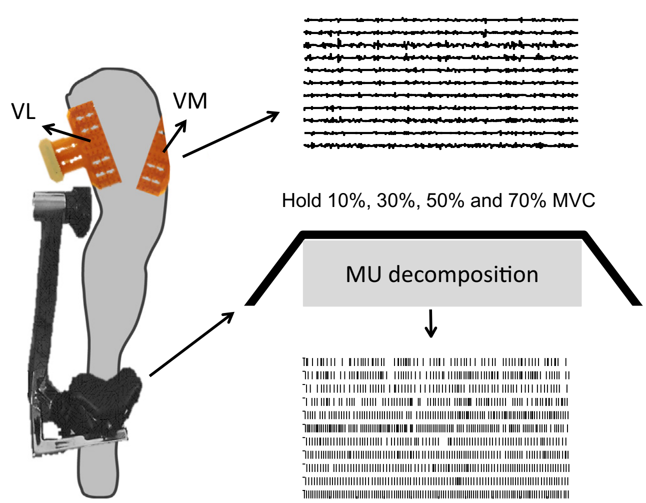

Fig. 1. High-density surface EMG (HDEMG) signals (64 channels) were recorded from the vastus medialis (VM) and vastus lateralis (VL) muscles of healthy participants during the production of isometric knee extension force. A schematic representation of one participant's leg attached to the isokinetic dynamometer lever arm with the HDEMG electrodes mounted over the vasti muscles is presented on the left side of the figure. Surface EMG signals from one column of the HDEMG electrode grid (11 channels) over the VM are shown on the upper right half of the figure. Visual force feedback was displayed as a trapezoid at 10%, 30%, 50% and 70% of the maximum voluntary contraction (MVC). Only the hold-phase of the contractions (grey area under the trapezoid) was used to decompose the vasti motor units (lower right half of the figure).