Clinical Neurophysiology 129 (2018) 1634–1641

Contents lists available at ScienceDirect

Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

Excitability tests using high-density surface-EMG: A novel approach to studying single motor units

Boudewijn T.H.M. Sleutjes [a,*], Judith Drenthen [c], Ernest Boskovic [b], Leonard J. van Schelven [b], Maria O. Kovalchuk [a], Paul G.E. Lumens [a], Leonard H. van den Berg [a], Hessel Franssen [a]

[a] Department of Neurology and Neurosurgery, Brain Center Rudolf Magnus, The Netherlands
[b] Department of Medical Technology and Clinical Physics, University Medical Center Utrecht, The Netherlands
[c] Department of Clinical Neurophysiology, Erasmus MC, University Medical Center Rotterdam, The Netherlands

ARTICLE INFO

Article history:
Accepted 29 April 2018
Available online 1 June 2018

Keywords:
Single motor unit action potentials
High-density surface-EMG
Excitability testing
Single human motor axons

HIGHLIGHTS

- We present a novel approach to studying excitability in single motor units using high-density surface-EMG.
- High-density surface-EMG helps to identify single motor units improving excitability tests in single axons.
- Single motor unit variables of the axonal and muscular part can be assessed with this novel approach.

ABSTRACT

Objective: To study excitability of single motor units (MUs) using high-density surface-EMG.
Methods: Motor unit action potentials (MUAPs) were evoked by submaximal stimulation of the median nerve at the wrist and recorded with a 9 × 14 electrode grid on the skin overlying the thenar muscles. For excitability tests of single MUs, the most optimal specific single-channel surface-EMG signal was selected based on the spatiotemporal profile of single MUs.
Results: Axonal excitability measures were successfully obtained from 14 single MUs derived from ten healthy subjects. Selecting the optimal single-channel surface-EMG signals minimized interference from other single MUs and improved signal-to-noise ratio. The muscle fiber conduction velocity (MFCV) could also be derived from the unique spatiotemporal profile of single MUs.
Conclusion: High-density surface-EMG helps to isolate single MUAP responses, making it a suitable technique for assessing excitability in multiple single motor axons per nerve.
Significance: Our method enables the reliable study of ion-channel dysfunction in single motor axons of nerves without any requirement for specific conditions, such as prominent MU loss or enlarged MUAPs due to collateral sprouting.

1. Introduction

Excitability in single human motor axons was studied extensively by Joseph Bergmans in the 1970s (Bergmans, 1970). In his early pioneering work, single motor unit action potential (MUAP) responses were recorded using surface electromyography (EMG). His approach involved major challenges: isolating electrically recruited single MUAP responses and monitoring the threshold manually by careful investigation of the motor units' all-or-none activity. The introduction of automated threshold tracking techniques (Bostock et al., 1983; Raymond, 1979; Weigl et al., 1989) facilitated studies on excitability in single human motor axons, including their activity after applying polarizing currents (Baker and Bostock, 1989; Bostock and Baker, 1988), after ischemia (Bostock et al., 1991a,b), and after tetanic stimulation (Bostock and Bergmans, 1994), their strength-duration properties (Mogyoros et al., 1996), their threshold behavior (Bostock et al., 2005; Burke et al., 2009; Hales et al., 2004), and low-threshold properties (Trevillion et al., 2010). These studies in single motor axons provided insight into the biophysical basis underlying their

* Corresponding author at: Department of Neurology and Neurosurgery, University Medical Center Utrecht, P.O. Box 855000, 3508 GA Utrecht, The Netherlands.
E-mail address: b.sleutjes@umcutrecht.nl (B.T.H.M. Sleutjes).

https://doi.org/10.1016/j.clinph.2018.04.754
1388-2457/

excitability properties. In parallel, excitability tests with single-channel surface-EMG were further refined and standardized by Bostock et al. (1998), Kiernan et al. (2000) for application in a clinical setting.

The majority of the excitability studies using a standard protocol (Kiernan et al., 2000) assess properties of a group of motor axons by tracking a fixed compound muscle action potential (CMAP) amplitude. Although this may be sufficient in many cases, excitability tests in single MUAPs have the potential to assess, more directly, pathophysiological events that are masked in excitability tests using CMAP recordings (Franssen and Straver, 2014; Maathuis et al., 2008). Despite this advantage, the fact that the number of studies on single MUAPs is relatively limited may partly be due to the difficulty in identifying isolated single MUAP responses reliably, especially in the presence of other MUAPs whose thresholds often overlap. Furthermore, prior to the recordings, the unique location and size of single MUs within the muscle is not known. Hence, excitability tests with single-channel surface-EMG also become susceptible to suboptimal electrode positioning and they are time-consuming due to the repositioning required.

With a view to overcoming the challenges associated with identifying single MUAPs, high-density surface-EMG has been introduced (Blok et al., 2002; Holobar et al., 2009; Lapatki et al., 2004; Stegeman et al., 2012). In high-density surface-EMG, multiple electrodes are positioned over the entire muscle, adding spatial information to single MUAPs. Their spatiotemporal profile helps their identification significantly compared to single-channel surface-EMG (Blok et al., 2005; Farina et al., 2008; van Dijk et al., 2008). This has led to various potentially clinically relevant applications at single MU level (Maathuis et al., 2012; Sleutjes et al., 2016a,b; Stegeman et al., 2012; Zhou et al., 2012).

To date, excitability studies in single MUs have relied solely on information from single-channel surface-EMG (Bostock et al., 2005; Burke et al., 2009; Mogyoros et al., 1996; Trevillion et al., 2010). In this study, we assess the excitability in single MUs where the novelty lies in the integration of high-density surface-EMG with excitability testing. We hypothesize that improved identification of single MUs by using high-density surface-EMG will facilitate excitability testing. To evaluate this hypothesis, we applied our novel approach in healthy subjects.

2. Materials and methods

2.1. Subjects

Ten healthy subjects (mean age, 30.1 years; range 18–43 years; 6 men) participated in this study. None of them had a history of any condition that could affect motor axon function. All subjects gave informed consent for the experiments. The investigation was in accordance with the principles of the Declaration of Helsinki and approved by the local ethical committee.

2.2. Single MUAP registration using high-density surface-EMG

Single MUAPs were recorded by applying a 9 x 14 array of densely spaced electrodes attached to the skin over the thenar muscle group (Maathuis et al., 2008, 2012) of the left (n = 4), or right (n = 6) hand. The electrodes had an inter-electrode distance of 4 mm overlaying an skin area of 32 × 52 mm. The long axis was positioned transversally over the thenar muscles (Fig. 1). This enables identification of single MUAPs by their spatiotemporal profile (Figs. 2, 3A and 3B). The reference electrode was positioned on the dorsal side of the metacarpophalangeal joint of the second finger. The ground electrode was attached to the dorsum of the hand. The high-density surface-EMG signals were recorded using an

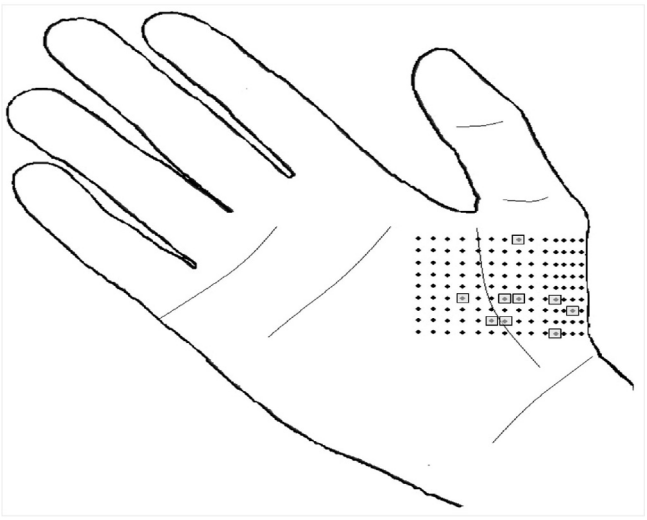

Fig. 1. A schematic drawing of the right hand is shown including the 9 × 14 electrode array (dots) overlaying the thenar muscle group. In six of the ten subjects, 9 single MUAPs were recorded from the right hand. The 9 gray boxes represent the 9 selected positions in the 9 × 14 electrode array, which provided the single-channel surface-EMG signals for excitability testing.

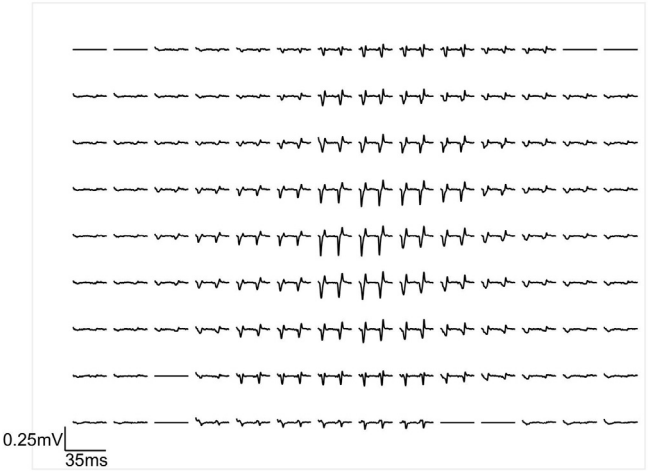

Fig. 2. The spatiotemporal profile of a single MUAP together with its F-wave, which was recorded during excitability testing in one of the subjects. The characteristic spatiotemporal profile of the single MUAP and its F-wave further confirmed that the threshold of a 'true' single MUAP was tracked.

ActiveTwo amplifier system (BioSemi, Amsterdam, The Netherlands), band pass filtered (2.5–500 Hz) and sampled at 4096 Hz.

To visualize the monopolar 126-channel surface-EMG signals and properly integrate the ActiveTwo system with the excitability software, the freely online available LabView based acquisition software for this system (ActiView, BioSemi, Amsterdam, The Netherlands) was modified. The modified acquisition program allowed each single-channel surface-EMG signal from the 126-channel surface-EMG signals to be selected by the operator for excitability testing, since the excitability testing setup is based on a single-channel surface-EMG technique. This single-channel surface-EMG signal was DA-converted (PCI-6251, National instruments) giving a 1000× amplification of the electrode signal. This analog output signal was connected to the AD-converter (PCI-6221, National instruments) of the excitability setup, and subsequently fed into the excitability software (Qtrac-S, TRONDNF, version 19/06/2015, Institute of Neurology, Queen Square, London,