Brain Research 1676 (2017) 91–99

Contents lists available at ScienceDirect

Brain Research

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

Research report

Differentiation of motor evoked potentials elicited from multiple forearm muscles: An investigation with high-density surface electromyography

J.L. Neva [a,*], A. Gallina [b], S. Peters [b], S.J. Garland [a,c], L.A. Boyd [a]

[a] Department of Physical Therapy, Faculty of Medicine, University of British Columbia, Vancouver, BC, Canada
[b] Graduate Program in Rehabilitation Sciences, Faculty of Medicine, University of British Columbia, Vancouver, Canada
[c] Faculty of Health Sciences, University of Western Ontario, London, Ontario, Canada N6A 5B9

ARTICLE INFO

Article history:
Received 25 May 2017
Received in revised form 7 September 2017
Accepted 13 September 2017
Available online 18 September 2017

Keywords:
Transcranial magnetic stimulation
Primary motor cortex
Motor evoked potential
High-density electromyography
Forearm muscles
EMG

ABSTRACT

Transcranial magnetic stimulation (TMS) is a non-invasive method to measure corticospinal excitability of the primary motor cortex. However, motor evoked potentials (MEPs) elicited by TMS in a target muscle are variable; inconsistent MEPs may be due to overlapping cortical muscle representations and/or volume conduction from neighbouring muscles. The source of variable muscle responses may not be apparent using conventional bipolar electromyography (EMG), particularly over areas with several distinct neighbouring muscles (e.g. the forearm). High-density surface EMG (HDsEMG) may provide a useful means to investigate the underlying variability in amplitude and spatial distribution of MEPs. Here, we investigated the spatial distribution of MEPs in the forearm extensors using HDsEMG. HDsEMG consisted of a 16 × 5 grid of surface electrodes placed on the right (dominant) dorsal forearm over the extensor carpi radialis (ECR), ulnaris (ECU) and extensor digitorum communis finger extensors (EDC). MEP amplitude and distribution were recorded from 100 to 170% of resting (RMT) and active motor threshold (AMT). The distribution of MEPs was correlated to the activity recorded during selective, isometric contractions of the ECR, ECU, middle (EDC-D3) and ring (EDC-D4) finger extensors to determine the spatial distribution of MEPs in the forearm extensors. Although ECR was the hotspot, resting MEP spatial distribution was primarily correlated to that of EDC-D4 and ECU. With background ECR activation, the spatial distribution of MEPs correlated strongly with ECR. Further, while holding a background ECR contraction, EDC-D4 and ECU MEPs increased with greater stimulation intensity. Our results suggest that HDsEMG provides a useful way to differentiate which wrist extensor muscles are activated by TMS.

1. Introduction

Transcranial magnetic stimulation (TMS) is a powerful method to non-invasively measure the excitability of the corticospinal system. When a TMS coil is triggered over the primary motor cortex (M1), *trans*-synaptic activation of the corticospinal output neurons occurs which can generate a muscle twitch and a well-defined waveform known as the motor evoked potential (MEP). MEPs elicited over the hand muscle representations of M1 can generate reasonably consistent amplitude responses in the contralateral hand, partly due to the large and well-defined M1 hand representation often referred to as the 'hand knob' (Yousry et al., 1997). However, it is known that MEPs elicited in the hand, and in slightly more proximal muscle representations like the forearm, are inconsistent and variable within and between subjects (Christie et al., 2007; Goldsworthy et al., 2016; Koski et al., 2005; Malcolm et al., 2006; Terao and Ugawa, 2002). Variability in MEP response in more proximal muscles, such as the forearm, could be due to 1) overlapping cortical muscle representations centrally (Lotze et al., 2003; Wassermann et al., 1992), 2) lack of focality of TMS stimulation which activates surrounding non-target cortical regions (Rothwell et al., 1991; Thielscher and Kammer, 2004) or 3) peripheral volume conduction ("crosstalk") from neighbouring muscles.

The nature of variable MEP responses may not be apparent using conventional bipolar electromyography (EMG), particularly over areas with several distinct neighbouring muscles with distinct motor functions, such as the forearm. High-density surface EMG (HDsEMG) is a technique that consists of the application of a large

* Corresponding author at: Department of Physical Therapy, Faculty of Medicine, University of British Columbia, 212-2177 Westbrook Mall, Vancouver, British Columbia V6T 1Z3, Canada.
E-mail address: jason.neva@ubc.ca (J.L. Neva).

https://doi.org/10.1016/j.brainres.2017.09.017
0006-8993/

number of surface electrodes over the muscle(s) of interest and may provide a useful means to investigate the underlying variability in the amplitude and spatial distribution of MEPs. Using HDsEMG, EMG amplitude distributions associated with activation of individual dorsal forearm muscles such as the extensor carpi radialis (ECR), extensor carpi ulnaris (ECU), and the particular finger extensors of the extensor digitorum communis (EDC) muscle compartments can be differentiated, such as EDC-Digit 3 (middle finger – EDC-D3) and EDC-Digit 4 (ring finger – EDC-D4) (Gallina and Botter, 2013). Our previous work has shown that although MEPs could be observed over the ECR using conventional bipolar EMG whether at rest or while holding a slight contraction, simultaneous HDsEMG recordings revealed that the spatial amplitude distribution of MEPs, elicited at a single suprathreshold intensity, was localized far from the ECR, especially at rest compared to holding a wrist extension (Gallina et al., 2017). This work suggested that MEPs recorded by conventional EMG may contain crosstalk from non-target muscles, particularly when the stimulation is at rest within the forearm musculature. Previous work has also suggested similar findings using HDsEMG, which showed that MEPs elicited at rest compared to during voluntary muscle activity largely originated from a neighbouring muscle. Further, with higher stimulus intensity non-target muscles increasingly contributed to the elicited MEPs while holding a wrist extension (van Elswijk et al., 2008). However, previous work has not identified the contribution of each of the distinguishable muscles that may be identified by HDsEMG (ECR, ECU, EDC-D3,4,5) which contribute to MEPs elicited by single pulse TMS. Further, we do not understand the systematic relationship between increasing stimulator intensity while at rest and while holding background ECR activation. Identifying the contribution of individual forearm muscles to elicited MEPs may be useful for understanding the variability in response to single pulse TMS. Consideration of individual forearm muscle contribution to MEPs may be important to consider targeted corticospinal excitability modulation within a single session and multiple sessions before and after interventions. Additionally, differentiation of forearm muscle activity (wrist extensors, finger extensors, etc.) may be important to understand the corticospinal excitability changes in elbow pain (Schabrun et al., 2015) and following chronic stroke (Borich et al., 2015; Garland et al., 2009; Kline et al., 2007) since muscle activation in these conditions is known to be abnormal.

Therefore, this study aimed to determine the contribution of: 1) multiple identifiable forearm muscles from MEPs elicited by TMS while at rest and holding background ECR activation; and 2) the contribution of forearm muscles to the elicited MEP at higher and lower stimulation intensities under both conditions. We hypothesized that HDsEMG would: 1) identify multiple forearm muscles with unique contribution to TMS-elicited MEPs, 2) demonstrate that active wrist extension, but not rest, would result in preferential ECR activation via TMS across stimulator intensities, and 3) reveal that increasing stimulator intensity would increase contribution of both target (ECR) and non-target (ECU, EDC, etc) forearm muscles to the observed MEPs.

2. Results

2.1. Differentiation of muscle and muscle compartment activity with HDsEMG

Fig. 2A displays colour maps of the spatial distribution and amplitude of HDsEMG activity during light selective isometric contraction of the ECR, ECU, EDC-D3 and EDC-D4. Fig. 2b displays the mean correlation coefficients across participants between 5% isometric contractions of each muscle. Low correlations indicate that the spatial distributions of HDsEMG activity do not overlap, and therefore can be differentiated. All muscles and muscle compartments were found to be distinguishable from each other ($R < 0.28$) except for ECU and EDC-D5 ($R = 0.67$) and EDC-D4 and EDC-D5 ($R = 0.56$), therefore EDC-D5 was excluded from further

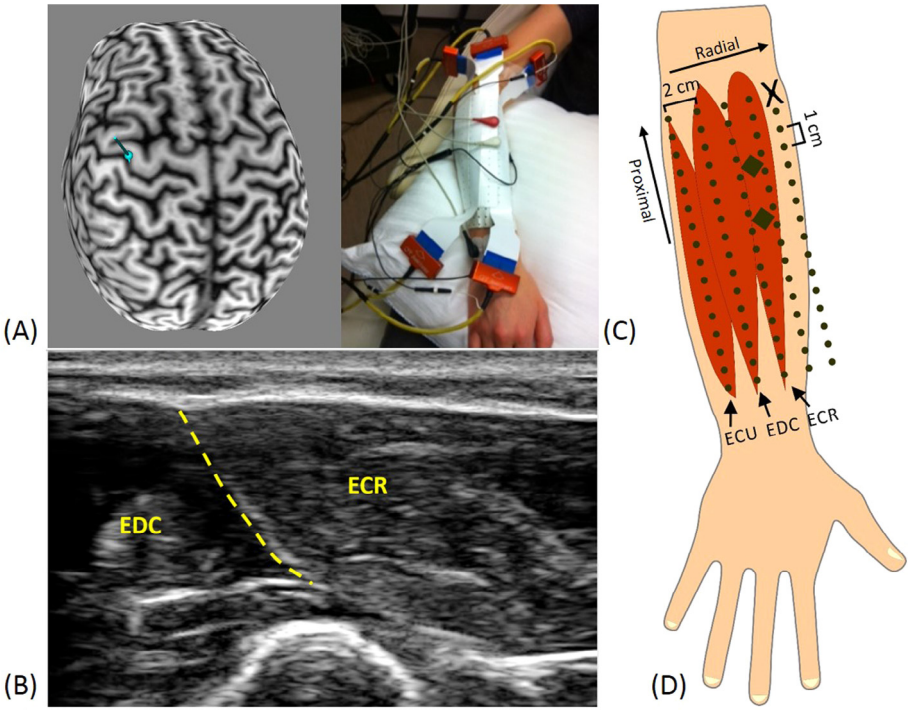

Fig. 1. Methods and procedures. (A) Stereotactic imaging: hand/forearm representation over M1 located using participants' T1-weighted MRI. (B) Ultrasound: location and borders of extensor carpi radialis (ECR) muscle was identified and marked. (C,D) High-density surface electromyography (HDsEMG): electrode grid placed over extensor forearm muscles. X indicates the most proximal and radial HD-EMG grid location for reference in Figs. 2 and 4.