Journal of Electromyography and Kinesiology 27 (2016) 95–101

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

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

The effects of upper limb posture and a sub-maximal gripping task on corticospinal excitability to muscles of the forearm

Davis A. Forman [1], Julianne Baarbé [1], Julian Daligadu [1], Bernadette Murphy [1], Michael W.R. Holmes *

Faculty of Health Sciences, University of Ontario Institute of Technology, Oshawa, ON, Canada

ARTICLE INFO

Article history:
Received 28 August 2015
Received in revised form 19 January 2016
Accepted 16 February 2016

Keywords:
Upper extremity
Forearm
Posture
Transcranial magnetic stimulation
Motor evoked potential

ABSTRACT

Variations in handgrip force influences shoulder muscle activity, and this effect is dependent upon upper limb position. Previous work suggests that neural coupling between proximal and distal muscles with changes in joint position is a possible mechanism but these studies tend to use artificially constrained postures that do not reflect activities of daily living. The purpose of this study was to examine the effects of upper limb posture on corticospinal excitability to the forearm muscles during workplace relevant arm positions. Motor evoked potentials (MEPs) were elicited in four forearm muscles via transcranial magnetic stimulation at six arm positions (45°, 90° and 120° of humeral elevation in both the flexion and abduction planes). MEPs were delivered as stimulus–response curves (SRCs) at rest and at constant intensity during two gripping tasks. Boltzmann plateau levels were smaller for the flexor carpi radialis in flexion at 45° versus 90° ($p = 0.0008$). Extensor carpi radialis had a greater plateau during flexion than abduction ($p = 0.0042$). Corticospinal excitability to the forearm muscles were influenced by upper limb posture during both the resting and gripping conditions. This provides further evidence that upper limb movements are controlled as a whole rather than segmentally and is relevant for workplace design considerations.

1. Introduction

The sensorimotor system has to integrate information from multiple sources in order to allow for accurate upper limb motor control and force production. For example, the integration of proprioceptive feedback from the neck and upper limb is critical to accurately replicate upper limb joint angles (Knox et al., 2006). Changing sensory input, for example with fatigue, has both peripheral effects on muscle and central effects on sensorimotor processing, leading to decreased awareness of joint position sense (JPS) (Allen and Proske, 2006; Rudroff et al., 2008). Decreased upper limb JPS is even apparent following neck fatigue (Zabihhosseinian et al., 2015). Peripheral factors such as joint angle and the position of a limb in three-dimensional space influences muscle length, contributes to a muscle's force generating capacity and likely JPS awareness. Changes in muscle length due to postural demands are important determinants of muscle force production (Doheny et al., 2008; Leedham and Dowling, 1995) and joint mechanics are primarily controlled by the muscles that cross a joint. However, several studies have demonstrated complex relationships for muscles that are both proximal and/or distal to the joint being manipulated. Altered forearm muscle activity via changes in handgrip force can influence shoulder muscle activity, and this effect is dependent upon arm posture (Sporrong et al., 1995, 1996). Furthermore, an individual's preferred grip force changes depending on the position of the arm (Smets et al., 2009). It is possible that several mechanisms are responsible for these interactions and neuromechanical aspects must be considered to understand the links between neural activity and limb mechanics during workplace related tasks.

One explanation for the interaction between grip force and shoulder muscle activity may be that alterations in the central control of distal muscles occurs in response to variations in joint position (Ginanneschi et al., 2005; Mogk et al., 2014). Ginanneschi et al. (2005) used motor evoked potentials (MEPs) elicited via transcranial magnetic stimulation (TMS) to assess changes in corticospinal excitability to the abductor digiti minimi (ADM) following changes in limb posture. With the right arm abducted to 90° in the coronal plane and elbow flexed to 90°, motor responses were elicited from three shoulder positions in the horizontal plane (30° abduction/adduction and neutral). MEP amplitudes and

* Corresponding author at: Kinesiology, Faculty of Health Sciences, University of Ontario Institute of Technology, 2000 Simcoe St. North, Office: UAB 347, Oshawa, ON L1H 7K4, Canada. Tel.: +1 905 721 8668x6584; fax: +1 905 721 3179.

E-mail address: Michael.Holmes@uoit.ca (M.W.R. Holmes).

[1] Address: University of Ontario Institute of Technology, 2000 Simcoe St. North, Oshawa, ON L1H 7K4, Canada.

http://dx.doi.org/10.1016/j.jelekin.2016.02.005
1050-6411/

F-waves at 30° adduction were significantly larger than at neutral and 30° abduction. Not only was corticospinal excitability to the ADM susceptible to changes in upper limb posture, the changes also appeared to be driven at both supraspinal and spinal levels. Ginanneschi et al. (2005) demonstrated that a neural component is involved in the muscle-joint relationship for the control of distal muscles not directly being manipulated and changes occur at multiple sites within the central nervous system.

Few studies have examined the effect of proximal joint angles on the contributions of central control to distal muscles. However, it has been demonstrated that cortical output is mediated by static changes in limb position (Dominici et al., 2005; Ginanneschi et al., 2006). This has also been demonstrated in primates. Park et al. (2001) established a systematic mapping of the forelimb area of the primary motor cortex (M1) in rhesus macaques. While certain regions containing distal or proximal muscle representations were mostly separate, a relatively large zone existed that was a combination of the two. It was suggested that this zone within the M1 is responsible for controlling functional synergies of distal and proximal muscles of the forelimb (Park et al., 2001). Furthermore, it was found (in monkeys) that electrical stimulation of the motor cortex resulted in coordinated, complex movements that spanned multiple joints and muscles (Graziano et al., 2002). These findings, in addition to those involving humans, provide strong evidence that the motor cortex controls movement based on task or functional goal. This may explain why variations in upper limb position affects muscle properties of the entire limb.

Joint posture and muscle length modulate excitability (Lewis et al., 2001; Ginanneschi et al., 2005), however, muscle function in relation to upper extremity posture should also be considered (Mogk et al., 2014). Previous work has been conducted with the upper limb positioned in postures that are not representative of workplace tasks or during activities of daily living (Dominici et al., 2005; Ginanneschi et al., 2006) so it is unknown whether previous findings generalize to these activities. The investigation of more universally adopted postures is import to provide a robust and practical understanding of the relationship between arm position and corticospinal excitability to forearm muscles.

Understanding motor pathways is beneficial to surgical procedures in the upper extremity that aim to restore limb function and this work also has implications for workplace design considerations, particularly in situations where proximal limb positioning is constrained while distal muscles perform a task. The central nervous system may be primed for motor outputs at certain limb positions while depressed at others. Therefore, the purpose of this study was to assess corticospinal drive to the forearm muscles in limb orientations commonly used in the workplace during both active and resting muscle states.

2. Methods

2.1. Participants

Ten volunteers (8 males, 2 females; 22.4 ± 2.5 years, 1.74 ± 0.04 m, 79.8 ± 7.9 kg) participated in this study. All participants provided informed, written consent. Participants had no neurological conditions or upper extremity injuries and were screened for contraindications to magnetic stimulation prior to the experiment (Rossi et al., 2009). This study was approved by the University of Ontario Institute of Technology research ethics board.

2.2. Experimental set-up

Participants were seated with their right arm placed on a custom built apparatus that could be adjusted to accommodate changes in limb position. Limb position was altered by adjusting the humeral elevation angle from 45° to 120° of shoulder flexion or abduction. The right arm was supported by the apparatus with the elbow fully extended and the wrist in a neutral position that was in-line with the forearm. Elbow and wrist angles were not restrained, but initial joint angles were visually assessed and monitored by the researchers throughout the session. Participants were seated, with both feet flat on the floor during all measurements. By manipulating the apparatus and orientation of the participant, the right arm was placed at 45°, 90° and 120° degrees of humeral elevation in both the flexion and abduction planes.

2.3. Electromyography

Muscle activity was measured using surface electromyography (EMG) from four muscles on the right forearm, including: (1) Flexor carpi radialis (FCR), (2) Extensor carpi radialis (ECR), (3) Flexor carpi ulnaris (FCU), and (4) Extensor carpi ulnaris (ECU). Placement was confirmed following previous guidelines (Holmes and Keir, 2015; Mogk and Keir, 2003; Perotto, 2005). Disposable bipolar Ag–AgCl surface electrodes (Meditrace 130, Kendall, Mansfield, MA, USA) were placed over each muscle-belly and in-line with muscle fiber orientation (inter-electrode distance 2.5 cm), following mild abrasion and sanitization with alcohol. EMG was band-pass filtered (10–1000 Hz), differentially amplified (CMRR > 100 dB at 60 Hz; input impedance ~10 GΩ) and sampled at 5 kHz (CED 1902 and CED 1401, Cambridge Electronic Design Ltd., Cambridge, UK).

2.4. Transcranial magnetic stimulation (TMS)

Corticospinal excitability was assessed by eliciting MEPs via single pulse TMS of the motor cortex. TMS was delivered through a circular coil (13.5 cm outside diameter) using a Magstim 200^2 (Magstim, Dyfed, UK) with the coil placed directly over the vertex of each participant (marked on the participant's scalp with a marker). The coil was placed tangentially to the participant's skull and firmly held over vertex by the investigator. In order to assess corticospinal excitability to four muscles simultaneously, a circular coil was chosen. This type of coil is less focal, allowing for activation of a larger portion of the motor cortex, thus eliciting responses in multiple muscles (Copithorne et al., 2014; Forman et al., 2014). Only one researcher held the coil during a session to limit variations in coil placement. The current of the TMS coil flowed in the direction that would optimally activate the left motor cortex.

2.5. Experimental protocol

Four maximal voluntary contractions (MVC's) were performed to elicit muscle-specific maximal voluntary excitations (MVE), used to normalize EMG as a percentage of maximum (%MVE). MVC's consisted of combinations of a power grip, while maximally flexing, extending and/or deviating the wrist using manual resistance (Holmes and Keir, 2014, 2015). With the right arm by their side, participants also performed two maximal grip trials using a hand dynamometer (1 kHz; MLT004/ST, Lab Chart 7, AD Instruments, Australia), with two minutes of rest between trials. The largest force between the two trials was considered the maximum voluntary grip force (MVG).

Following maximal trials, participants were instructed to sit upright and relax with both arms resting in their lap. TMS was delivered at vertex to determine the resting MEP threshold of ECR. Resting MEP threshold was defined as the percent of maximum stimulator output (%MSO) that resulted in an ECR MEP (peak-to-peak amplitude) of 50 μV for at least 50% of trials (4 out of 8). Next, active MEP threshold was determined. In the same position, participants were shown a horizontal line on a computer screen that represented 5.0 ± 1.0% MVE for ECR (root mean square